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WIP: Enhancing Critical Thinking in Engineering Students: A Pedagogical Framework for Sociotechnical Integration

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I. Introduction

Educators and employers have long recognized that critical thinking is a foundational skill, enabling individuals to evaluate information, weigh evidence, and make well-reasoned judgments in increasingly complex academic, professional, and societal environments. As Braun, Shavelson, Zlatkin-Troitschanskaia, and Borowiec [1] note, critical thinking requires learners to analyze problems, interpret data, synthesize evidence, and navigate ambiguity in situations where information may conflict or be incomplete. Systematic reviews in higher education further emphasize that the development of critical thinking depends on interacting physiological, psychological, sociocultural, technological, and educational factors, all of which shape learners' ability to think reflectively and independently [2]. Moreover, decades of scholarship show that critical thinking is consistently valued across academic disciplines and employer expectations, as it supports problem solving, informed decision-making, and the capacity to navigate information-saturated environments [3]. Collectively, these findings demonstrate that critical thinking is not only a cognitive skill but also a vital competency for personal agency, academic success, and effective participation in contemporary society.

For engineers specifically, critical thinking is central to engineering practice. Though not explicitly listed as an independent outcome, critical thinking is woven into each of the seven ABET Student Outcomes [4]. Each criterion requires some measure of analysis, evaluation, judgment, and reasoning - core components of critical thinking and the practice of engineering. Critical thinking informs how engineers engage in ethical and professional decision-making. Therefore, critical thinking skills are a necessary component of an engineer's professional formation.

Despite its importance to student success and calls to improve the teaching of critical thinking in engineering [5], very little has been published on critical thinking in prominent engineering education journals. A search for the term "critical thinking" in JEE, for instance, results in no articles with it in the title. Considering it is the most prevalent of the "[variant] thinkings" in research broadly, this lack of emphasis is notable [6]. Employers also do not explicitly call for critical thinking skills in job postings, with fewer than 4% of advertisements listing it [7]. This apparent lack of explicit emphasis on critical thinking may result from two factors: a cultural deemphasis on the need to teach critical thinking in engineering and the reframing of critical thinking to fit the ethos of engineering.

As a discipline, engineering education has a long history of resisting the intentional development of "soft" skills – or, as we prefer and Berdanier [8] argues, professional skills – within the curriculum. Although engineering faculty often value these capabilities in their students, they frequently perceive a tension between technical and professional skill development. When instructional time is limited, technical content usually takes precedence [8], [9]. As a result, students often acquire professional skills passively through self-study and rely on extracurricular and out-of-classroom learning, resulting in accidental competencies and incompetencies [10].

Another possible reason critical thinking is not ingrained in the engineering education lexicon is that, as a field, engineering education has replaced critical thinking with concepts that engineers find more consistent with their ethos. The most obvious replacement is problem solving. As Robinson notes, problem-solving is central to engineering thinking [11]. Problem solving is also the most commonly identified skill in engineering job advertisements, whereas critical thinking was among the lowest [7]. However, such a framing of critical thinking as logic, reasoning, validity, or, ultimately, as a set of skills or processes executed by an individual fails to account for the social dimensions of critical thinking [12]. As Claris and Riley argue, such a framing of critical thinking fails to leave space for the reflexivity and reflection necessary to adequately consider the people and power dynamics at play [5].

Encouragingly, other reframings of critical thinking in the engineering education literature begin to embrace a more holistic approach to critical thinking. In their ways of thinking framework, Dalal et al. still focus on how engineers make decisions and solve problems but consider four ways of thinking that includes the social – futures, values, systems, and strategic [13]. Similarly, Ge and Liu frame critical thinking as one of an assortment of complex capabilities, comprising a set of cognitive abilities (including problem solving, systems thinking, interdisciplinary integration, and critical thinking) and personal and professional competencies that are necessary to solve complex engineering problems [14]. Other researchers frame critical thinking as sociotechnical thinking, marrying considerations of technology, people, and the broader context [15]. Yet another framing is creativity in problem solving, where the emphasis is on generating ideas, digging deeper, openness to exploring ideas, and reflection [16].

Given the continued concern about students' critical thinking skills and the central role it plays in engineering practice, there is an opportunity to re-envision how critical thinking is intentionally integrated into engineering courses. This WIP paper describes early insights from ongoing curricular design efforts to develop a critical reasoning-focused course within the school of engineering at a private, four-year university. The *Critical Reasoning in Engineering* (CRE) course was developed through an iterative design approach grounded in cognitive psychology, student development theory, and critical thinking pedagogy. Insights from each of these disciplines were integrated to scaffold students' understanding of how cognitive patterns shape critical thinking, particularly during interactions with smart technologies and AI. Based on the Community of Inquiry framework, the CRE course was designed to emphasize experiential learning in the classroom, the formation of a learning community, metacognitive and critical thinking skills, scaffolded learning, and iterative learning opportunities.

In this paper, we use *critical thinking* as an umbrella term for broad cognitive processes (e.g., analyzing information, evaluating evidence, and synthesizing perspectives), whereas we use *critical reasoning* to denote the more structured, argument-centered application of logic (i.e., evaluating claims in terms of premises, inferences, and conclusions).

II. Course Design Framework

To guide the design of this course, the Content – Assessment – Pedagogy (CAP) design triangle was leveraged [17]. Therefore, the instructional team sought to align what students are learning with how they are being taught and assessed (Figure 1).

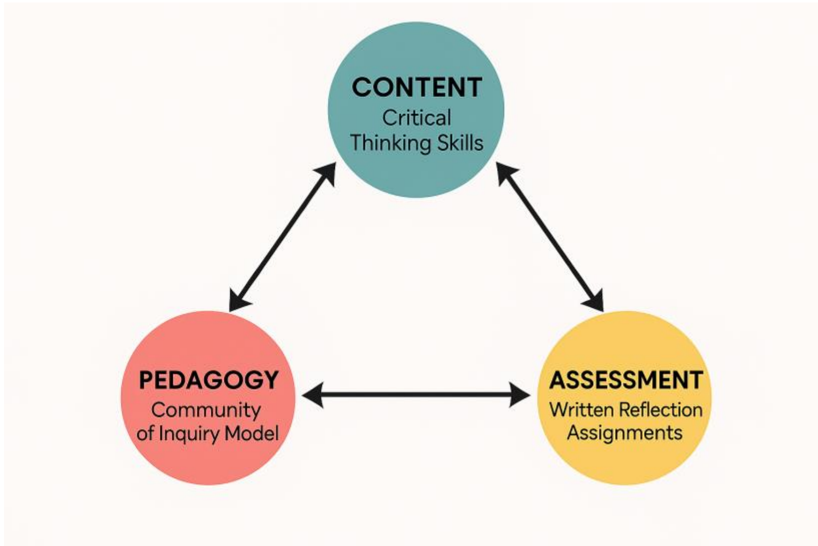

Figure 1: Alignment with CAP Design Triangle

A. *Course Design Context and Evolution*

CRE is offered at a private four-year institution in the Southwest United States. In 2025, the undergraduate body size was approximately 7,500 students, with roughly 900 undergraduates in the school of engineering. The institution requires all undergraduate students to fulfill university-wide curriculum requirements in addition to course requirements directly related to their majors. One of the shared requirements for all incoming first-year students is the completion of a two-semester sequence of academic writing courses. The first of the two courses teaches students the foundations of university-level writing, including analytical reasoning and writing skills. The second course, called *Critical Reasoning* (*CR)*, expands on the first with the introduction of critical reasoning competencies [18], argument evaluation, cognitive biases, logical fallacies, and academic research.

For several years, both first-year writing courses were housed within the university's Writing and Reasoning Program in the College of Humanities and Sciences. In 2024, however, the undergraduate curriculum was restructured so that CR courses were distributed across academic units and offered discipline-specific emphases. As a result, the school of engineering was charged with designing and implementing its own iteration of the course, *Critical Reasoning in Engineering (CRE)*. Though offered by the school of engineering, the course must be intellectually accessible to first-year students from diverse academic backgrounds. To that end, the course introduces students to critical reasoning competencies by contextualizing examples in engineering, technology, and AI, but CRE does not teach engineering-specific problem-solving methods or strategies.

B. *Content: Critical Thinking and Logical Reasoning*

The foundational design parameter that informed CRE's structure was ensuring that the course content adhered to university requirements for CR courses. Among these requirements is an emphasis on critical thinking and logical reasoning. The CRE instructional team determined that establishing the course's foundation in cognitive psychology was the most effective starting point for exploring critical thinking and reasoning concepts. The first portion of the course aims to make students' cognition 'visible' so that they better understand the cognitive principles that frame the rest of the course. Specifically, human cognition is taught through the System 1 / System 2 framework as presented in Kahneman's *Thinking, Fast and Slow* [19]. This framing of cognition allows instructors to articulate a foundation from which students' thinking can be understood and evaluated. Beginning with cognitive psychology gives students a foundation that helps them see the practical relevance of the course material and provides shared vocabulary for the topics that follow.

Kahneman describes the relationship between humans' unconscious thought processes and how they inform conscious decision-making. Drawing on a body of dual process research in cognitive psychology, he characterizes human cognition as comprising two systems: *System 1* thinking refers to quick, automatic thought that requires little effort but is prone to errors. In contrast, *System 2* thinking involves more deliberate, intentional thought that is generally more accurate but requires more effort and is difficult to sustain. While the dual process framework draws on decades of cognitive psychology research, Kahneman's *Thinking, Fast and Slow* offers a synthesis that is intellectually accessible to undergraduates and provides a theoretical lens through which students can evaluate their own reasoning processes.

The dual process model explains why humans are predisposed to avoid cognitive effort, even when it is important. This psychological barrier to critical thinking is used to transition into a second content requirement of CR courses: a concentrated focus on logical reasoning and argumentation. Through an assigned textbook, students learn introductory concepts related to arguments, premises, conclusions, assumptions, inductive and deductive reasoning, etc., so that they gain the vocabulary necessary to engage in meaningful argument evaluation in their major essays (a requirement of all CR courses). Critical thinking texts likewise address important course concepts like logical fallacies, information literacy, and identifying expertise.

To enhance students' learning and introduce an engineering-specific lens, the above reading assignments are supplemented with recent publications that contextualize course concepts within the realm of technology and AI. For example, students read opinion pieces from reputable periodicals (such as the *New York Times* or *The Atlantic*) that summarize recent research on human cognition and AI. They are then asked to evaluate arguments made within these readings using critical reasoning terminology and their new knowledge of human cognition. They are challenged with exploring cognitive processes (or lack thereof) during engagement with technology and AI, such as GPS navigation, personalized streaming recommendations, and predictive texts.

Students watch interviews and documentaries in which tech experts reveal how persuasive technology is used to exploit flaws in human cognition. Case studies are also employed to show how cognitive biases contribute to engineering and technology failures, such as Amazon's failed hiring algorithm, which illustrated how training data can reproduce human bias, and the Fukushima Daiichi Nuclear Disaster, which has been discussed in relation to overconfidence and risk perception. Students learn about how AI systems inherit human biases through training data, which is tied back to concepts presented by Kahneman, such as the *Law of Small Numbers*.

C. Assessment: Writing, Reflection, and Assessment Practices

The assessment of students' learning in the course seeks to provide both formative feedback and summative evaluation in line with our selected pedagogical approach. Though a similar model was employed during other in-class activities and assignments, e.g., during group discussions, we share here the intentional structuring of major writing assignments to provide summative and formative feedback throughout the semester.

To fulfill CR course requirements, all students are required to produce approximately 15-20 pages of written content, which is divided across three major essays. The first major essay is a critical analysis of an argument presented in one of the assigned readings (e.g., students identify and evaluate an argument related to the role of AI in education). The second essay delves deeper into the intersection of human cognition and technology. The third major essay is a research argument paper on AI's role within a topic of their choice that students spend extensive time researching and writing as they build their information literacy and research skills.

Preparation for each of these essays involves the completion of two drafts that require students to emphasize specific skills (e.g., the first draft of their research argument essay must contain, at a minimum, a working thesis statement). Students engage in formative peer feedback on each draft, allowing them to critique and learn from one another's work. The essay writing and re-writing process emphasizes revision-based learning, one of the best practices for developing critical thinking skills [20].

Summative assessment of students' essays is provided when the final draft of each major assignment is submitted. The instructor evaluates student work using a scoring rubric aligned with the assignment criteria and provides detailed written feedback through in-text comments. Feedback includes both general commentary on writing quality and mechanics, as well as targeted suggestions related to the learning outcomes of each prompt, such as the strength of argument analysis, depth of reasoning, and integration of course concepts and terminology.

In the critical analysis essay, for example, students are required to apply concepts from *Thinking, Fast and Slow* to evaluate interactions between AI use and critical thinking. Instructor feedback highlights effective use of cognition terminology (e.g., *cognitive load*, *law of least effort*, *ego depletion*) and argumentation vocabulary (e.g., *premise*, *conclusion*, *inductive reasoning*), while also identifying opportunities for deeper concept integration and clearer reasoning. The rubric reinforces these expectations by assessing writing quality, analytical depth, content integration, and proper citation practices on a five-point scale ranging from "excellent" to "absent."

Additional assessment methods include in-class quizzes to gain insights into students' comprehension of assigned readings and course content. Students also complete short, personal reflections throughout the semester to discuss how their increased awareness of course concepts impacts their thinking and behavior (e.g., students reflect on cognitive biases that influence their assumptions and how design elements of smartphone apps hook their engagement).

D. Pedagogy: Guiding Principles Used to Scaffold Learning

After content and assessment approaches were determined, the instructional team explored options for a pedagogical approach to support students' development of critical thinking skills. Unlike the domain-specific knowledge that engineering students learn in introductory coursework, critical thinking encompasses processes that can be transferred across disciplines (e.g., analysis, evaluation, and synthesis of information) in accordance with Bloom's taxonomy [21]. Best practices in critical thinking pedagogy emphasize the importance of active learning, deliberate practice, and reflection to build these higher-order cognitive skills [20]. Further, active learning is vital for students' ability to analyze, synthesize, and evaluate knowledge and evidence.

In recognition that the development of critical thinking is facilitated by structured dialogue that engages learners in moments of cognitive conflict and reflective examination [22], we opted to leverage a Community of Inquiry-inspired pedagogical framework. The *Community of Inquiry* (*CoI*) framework offers a theoretically grounded model for designing and evaluating collaborative, constructivist learning environments in higher education [23]. Originating with the work of Garrison, Anderson, and Archer, the framework posits that deep and meaningful learning arises through the dynamic interplay of teaching presence, social presence, and cognitive presence. When these three presences are intentionally cultivated, the CoI framework provides a robust structure for developing learning environments that promote critical thinking, shared knowledge construction, and purposeful engagement - outcomes that have been substantiated by extensive empirical research across diverse educational contexts [24], [25].

Teaching presence encompasses the intentional design, facilitation, and direction of learning experiences to support learner engagement and guide inquiry [23]. Further, the more valued students feel by their faculty members, the more likely they are to experience positive outcomes [26]. In CRE, instructors explicitly state their intent to create a classroom learning community by assigning in-class group projects (typically limited to four members). For example, rather than discussing the syllabus and course policies on the first day of class, students work in small groups to examine classic ethical dilemmas (e.g., the Trolley Problem [27]). Once the class debriefs on each group's reasoning, they work in new small groups to discuss hypothetical, applied challenges (e.g., "the university is considering piloting a new AI tool to detect at-risk students but only has resources to support 30% of those identified – what should they do?"). As students reason through solutions, the instructor circulates between groups to prompt students to deepen their thinking (e.g., asking "how do we determine who is 'at-risk'"?). Emphasizing small group collaboration from the first day of class allows students to learn each other's names, become comfortable working together, and experience collaborative learning as the class norm, and encourages students to engage in critical reasoning experientially before encountering the formal vocabulary in later units.

Experiential and inductive learning activities are often employed to introduce required course concepts in a nonconventional way. During the previously mentioned course unit on cognitive biases, students work in small groups to create presentations on well-known engineering disasters. They are tasked with researching details of their case study, then identifying potential cognitive biases that contributed to the project's failure. In a separate unit on logical fallacies, students are given a list of common logical fallacies with definitions, then asked to create their own humorous examples of fallacies to be voted on by their peers, with the winners receiving bonus points. This design approach allows students to exercise and apply their thinking in an engaging manner while also advancing the class community's understanding of critical thinking concepts.

Social presence enables participants to project themselves as authentic, "real" individuals within the learning community, thereby fostering trust, open communication, and a sense of belonging that supports collaborative meaning-making [24], [25]. To foster the sort of space where psychological safety can thrive, one of the first course assignments asks students to write a letter to the instructor explaining more about their personal and academic background, their preferred methods of learning (i.e., through experiential learning, group work, individually, etc.), and an optional 'creative element' asks them to include a favorite song recommendation, photograph of something meaningful to them, or the top three items on their bucket list. The instructor responds to each of these letters to affirm students' presence in the learning community. Another intentional strategy for developing community is learning each student's preferred name and addressing them accordingly within the first two weeks of class.

Further, students' social presence is reinforced through active participation in developing course policies, particularly those related to AI use. Early in the semester (while students are independently writing critical analysis essays on AI use and critical thinking skills), students work together to draft the AI policy for their class section. Original ideas are formulated in small groups, then deliberated and refined as a class until a clear course policy, including acceptable use, prohibited use, and consequences for policy violations, is written. Through this process, students develop ownership over their learning, which reinforces that their lived experiences as college students in the age of AI are valid and real. During these and other activities throughout the semester, the instructor shares openly about their own learning and uncertainty, creating space for students to do the same.

Cognitive presence reflects learners' ability to construct and confirm understanding through sustained reflection and discourse, progressing through the phases of the Practical Inquiry Model: *triggering events*, *exploration*, *integration*, and *resolution* [28]. In CRE, visual and cognitive illusions serve as triggering events by disrupting students' confidence in intuitive judgments and creating cognitive dissonance. For example, demonstrations of selective attention (e.g., the *Invisible Gorilla* video) and System 1 errors (e.g., the "Moses on the ark" question) expose the limits of human cognition and prompt students to question initial assumptions [19]. Class-wide discussion then supports exploration as students connect their experiences to concepts, such as heuristics and cognitive load. Integration occurs as students link these observations to formal terminology from course texts, such as *Thinking, Fast and Slow*. Finally, written reflections and essays represent a form of resolution, requiring students to apply these concepts to real-world sociotechnical examples involving AI and technology.

III. Positionality Statement

Before presenting initial observations from this pilot implementation, we briefly note the authors' positionalities. The first author is a clinical assistant professor in the school of engineering and the instructor of the CRE course. Although her academic training and early professional roles were in applied physiology, her teaching experience in higher education shifted her work toward undergraduate student learning, first-year student development, and educational equity. Prior to joining the school of engineering in 2020, she taught a first-year seminar that incorporated concepts from cognitive and positive psychology, metacognition, and college student development theory. She later drew on this teaching experience and her doctoral research in education policy and leadership to develop a peer mentoring program for first-year engineering students from traditionally marginalized backgrounds. While not trained as an engineer, she brings experience in first-year teaching, student development, and active learning design to the development and implementation of CRE.

The second author is an associate professor of engineering education and leadership. Though her degrees are in mechanical engineering, she has spent more than a decade focused on engineering education research. Having also designed an introductory engineering course open to all incoming students, regardless of discipline [29], she brings an engineering education research lens to their mutual exploration of how to better support students' professional formation through skills like critical thinking.

IV. Discussion and Instructor Observations

The goal of this WIP paper is to describe ongoing curriculum development efforts and preliminary insights associated with a critical reasoning course situated within a school of engineering at a private, four-year university. This work is motivated by a gap between the broad importance of critical thinking and its limited visibility in engineering education conversations. Recent analyses suggest that critical thinking is rarely foregrounded in prominent engineering education journals, is not explicitly named in ABET outcomes, and appears infrequently in engineering job advertisements. This absence reinforces the need for intentional, theory-informed curricular designs that make critical thinking and reasoning explicit within engineering contexts. The course development documented in this paper highlights faculty efforts to modify an undergraduate critical reasoning and writing course so that it has domain-specific emphasis. In hopes that others can learn from our experience, we share here our initial observations from delivering the course, framing them around our course design framework (CAP) and pedagogical approach (Community of Inquiry).

A. Content design tension: balancing three learning domains

One of the most important observations from early iterations of CRE is the importance of striking a balance between the three distinct learning domains of the course: critical reasoning, academic writing, and engineering-related content. Balancing the breadth and depth of each domain is an ongoing challenge, particularly given disparities observed in students' previous writing experience, confidence, and abilities. Because the course is open to all undergraduate students (not just those studying engineering), its content must remain intellectually accessible to a diverse range of students. For this reason, the course's focus has shifted from engineering-specific case studies to technology and AI more broadly. By focusing on personal examples, such as how persuasive technology design impacts students' thoughts and behaviors, students gain exposure to engineering-adjacent concepts without requiring engineering content knowledge.

Encouragingly, preliminary review of student reflections suggests increased metacognitive awareness and greater sensitivity to sociotechnical and ethical issues related to AI, including concerns about how AI shapes human thinking and behavior and reproduces human biases. Students likewise express an increased awareness of how AI-reliance undermines learning and skill development when it is used to bypass cognitive strain. Informal student correspondence has revealed instances in which students express a newfound appreciation for the importance of genuinely learning the skills associated with their major rather than offloading to AI (e.g., knowing how to write and debug code vs. vibe coding).

B. Pedagogical insight: "what sticks" in a community of inquiry

Consistent with a Community of Inquiry-inspired approach, in-class demonstrations and active learning experiences appear to "stick" with students, and teaching presence also "sticks." Students respond to experiential activities (e.g., demonstrations of heuristics and attention) and to classroom dialogue that supports psychological safety and authentic participation. This aligns with the course's emphasis on building a learning community and using cognitive dissonance as an entry point for critical inquiry.

C. Assessment challenges: writing-based evidence of critical thinking under AI

Although students' contact time is intentionally devoted to discussion and in-class activities, critical reasoning is primarily assessed through writing due to university-level requirements. This introduces two persistent challenges.

First, assessing critical thinking through writing is difficult when students select their own topics. Instructors are not experts in all domains that students may choose (e.g., the music industry and AI), which complicates the evaluation of factual accuracy and the strength of their arguments.

Second, reflective writing is vulnerable to AI shortcutting. For example, in Fall 2025 the final assignment was a low-stakes self-reflection prompt shared on the final day of class, which was also the day the research argument essay was due. Although intended to create a meaningful metacognitive reflection experience, it appeared that a substantial portion of submissions relied on generative AI. A lesson learned from this experience is the importance of strategically timing assignment due dates to reduce extraneous cognitive load and mitigate incentives to take shortcuts. Cognitive Load Theory [30] supports being mindful of workload and timing so that students have adequate cognitive resources to engage genuinely in reflection rather than offloading it.

D. Transferable design implications (WIP "toolkit")

Based on early iterations, we suggest several transferable moves for faculty designing similar first-year critical reasoning experiences:

- Show, don’t tell: use demonstrations so students *experience* cognitive shortcuts [19] rather than only read about them.
- Build psychological safety early [26]: create structures that support social presence [24] and open discussion of assumptions, biases, and presuppositions.
- Blend stable core texts with timely artifacts: maintain consistent foundations while integrating current AI/technology readings that sustain relevance.
- Use carefully designed concept checks: quizzes and prompts must elicit specific use of terms and prevent superficial responses that lack conceptual understanding [22] and cognitive presence [24].
- Be strategic about workload timing: assignment scheduling can reduce extraneous load [30] and improve authenticity of reflective work.

V. Future Work

Spring 2026 marks the fourth semester in which CRE has been offered and is positioned to be the most evidence-informed iteration of the course, with design modifications informed by continued engagement with relevant literature, classroom experience, and student feedback. Future work will pursue two complementary directions. First, the instructional team will explore additional assessment methods that better align with CRE’s primary learning modalities (discussion and in-class inquiry) and outcomes while adhering to the university writing requirements. Second, the team will pursue formal evaluation through IRB-approved data collection to assess changes in critical thinking and critical reasoning skills, including questions about whether we are measuring broad critical thinking competencies or engineering-specific reasoning. Given the increasing interest in oral exams at our institution in response to AI-related validity concerns, one potential direction for this formal evaluation is the development of an oral assessment tool for critical reasoning. This direction may also address a perceived gap in real-time assessment methods for critical thinking in engineering contexts.

VI. Conclusion

This WIP paper describes the evolving design of *Critical Reasoning in Engineering* as a theory-informed, community-centered approach to building first-year students’ critical reasoning capacities in sociotechnical contexts. The course is designed to support the development of metacognitive awareness and ethical engagement with AI through structured dialogue and reflective inquiry, with systematic evaluation planned for future iterations. The framework guiding CRE positions critical thinking as a core competency for the formation of ethical engineers, and future work will strengthen alignment between learning activities, assessment methods, and evidence of student growth.

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