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Exploring engineering students’ critical consciousness using an ill-structured, project-based learning unit in an engineering mechanics course

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Introduction and Motivation

This Work in Progress paper describes preliminary findings of a qualitative study that explored how critical consciousness (CC) manifested in undergraduate learners in a project-based learning (PBL) unit, specifically in an engineering mechanics class context. The paper explores how the ill-structured characteristic of the PBL contributed to the manifestation of CC in those learners.

Typical engineering mechanics curricula emphasize technical concepts, which reinforces to learners that problem-solving efforts are solely technical undertakings that are devoid of socioeconomic, environmental, and political dimensions [1] [2]. This narrow emphasis fuels asocial, apolitical, and apathetic attitudes in engineering, which is glaringly incompatible with the real-world complexity of engineering activities amidst the increasingly multi-ethnic nature of the nation [3]. These deficiencies have informed leaders in engineering education to call for alternative instructional approaches to prepare engineering learners to undertake engineering activities with broadened awareness of (and motivation to resolve) societal inequities [2] [4] [5].

Engineering educators can adopt ill-structured problems to influence how students approach problem solving. Ill-structured problems include sociocultural contexts, incomplete information, and competing goals; and they can require deliberative learning practices when students work together to reach a final, defensible solution [6] [7]. In engineering education, ill-structured problems are noted for their ability to prepare students for the types of problems they are to encounter in their future employment [8] [9] [10] [11]. Team-based PBL units are often ill-structured, where they require students to collaborate together to gather information, apply that information to solve a problem, and defend a problem solution [12].

Many studies report how ill-structured problems shape learners' critical thinking skills, communication skills, and problem-solving efforts in domain-specific contexts [7] [13] [14] [15] [16]; or influence learners' self-regulation phases [17] [18] or ethics [19]. Yet, no studies have explored how ill-structured problems, specifically used in engineering classroom contexts, promote learners' understanding of their own social realities. Our study seeks to redress this gap in the literature by exploring how the ill-structured characteristic of an engineering mechanics-based PBL unit fostered learner's understanding of the world around them.

We use Freire's critical consciousness (CC) to understand how a learner comes to understand the world, its injustices, and their individual responsibility to resolve those injustices [20]. There are a growing number of quantitative instruments to measure CC [21] [22], yet qualitative methods can reveal nuanced insights into CC. This paper asks: "How does undergraduate engineering learners' CC manifest in response to an ill-structured, engineering mechanics-based PBL unit that uses the *human-centered design (HCD) for communities* approach as a design framework?"

Theoretical Framework

CC has been used in various pedagogical frameworks, including Ladson-Billing's culturally relevant pedagogy, which engineering educators can use to design instructional approaches that support student learning of sociotechnical problems [23] [24] [25] [26] [27] [28]. Several theories explore the extent by which CC can manifest in an individual [20] [29] [30] [31], and this study uses Carlson *et al.*'s 4-stage understanding of CC [29]. Their 4-stage model is similar to the work of others that describe how individuals move from one level of CC to another; for example Freire's 3-levels of consciousness [20], Wallerstein and Sanchez-Merki's 3-stage model of change [30], and Watts *et al.*'s 5-stage model of development [31].

Carlson *et al.* developed their model by authentically engaging a lower income, African-American community in a participatory-based research project [29]. They used a photovoice intervention [32] to generate community dialogue that was analyzed using visual anthropology to find three distinct, hierarchal levels of cognitive-emotional interpretations of engagement: **1)** emotional engagement, **2)** cognitive awakening, and **3)** intentions to act. The lowest level in the 4-stage model, passive adaptation, occurs when no CC is realized (see Table 1).

Table 1 Summary of Carlson et al.'s 4-stage understanding of critical consciousness (CC) [29].

4-Stage Understanding of CC	Brief Description	Brief Summary
Passive Adaptation	While there may be concern for others (i.e., caring), the principal dialogue is rooted in emotional apathy and blame is typically directed unto others.	*Not my problem.*
Emotional Engagement	A low-level form of CC whose principal dialogue evokes an emotional plea to others to become engaged. There can include a call to action by asking who is responsible for the problems at hand.	*Who is responsible?*
Cognitive Awakening	A more advanced level of CC where individuals realize that their own apathy is complicit toward problems. Blame is placed toward themselves by acknowledging that they are part of the problem.	*We are part of the problem.*
Intentions to Act	The highest observable form of CC, whereby defeatism is overcome. Individuals recognize that although they are part of the problem (*cognitive awakening*), they are also part of the solution (*intentions to act*). There can be envisioning of new futures, and emotions pivot from hopeless (*passive adaptation*, *emotional engagement*, and *cognitive awakening*) to hopeful.	*We are part of the solution.*

Instructional Design and Reflective Writing Prompt

A team-based, engineering mechanics-based PBL unit was designed using the *human-centered design (HCD) for communities* approach [4] [33]. The *HCD for communities* approach builds on the empathic precursory steps described in *HCD for users* and Design Thinking [34]. The PBL unit tasked students to design a fictitious truss bridge at one of three candidate sites at a nearby community. The PBL unit was ill-structured in that their selection of any candidate site impacted disparate stakeholders thus requiring research on the community, interviewing real community members to understand their wants and needs, and a deliberative learning process to reach a defensible engineering solution. Additional details of the instructional design are presented elsewhere [35]. Table 2 summarizes the team-based deliverables for the PBL unit. For each deliverable, students were asked to write reflectively in response to a series of prompts. This study examined the generated reflective writings submitted in the first deliverable, which asked: "How did exploring background information about a) the candidate sites and b) the stakeholders inform your thinking about the engineering design process?"

Table 2 Summary of the ill-structured PBL unit, noting major deliverables.

Design Framework	Design Context	Deliverable 1	Deliverable 2	Deliverable 3	Deliverable 4
Human-centered design (HCD) for communities	Design a vehicular truss bridge using statics	Conduct relevant background research	Draft problem and value proposition statements	Create a prototype (analytical and/or physical)	Present and defend your recommended solution

Methodology

Two-cycle coding was used to analyze the students' reflective writing [36]. The first cycle inductively inspected the data to generate descriptive codes on how students interpreted the role of the candidate sites and stakeholders in their problem-solving efforts. The second cycle refined and axially coded those initial codes, and concurrently categorized them using Carlson *et al.*'s 4-

stage understanding of CC as a baseline framework. Two-cycle coding is a sequential coding process that provides for richer perspective on the same data set, and this specific analysis was undertaken "… to determine which [codes] in the research are the dominant ones and which are the less important ones…" in answering the study's research question [36, p. 218] [37, p. 109].

Study Context and Participants

The study was conducted in a course at a primarily undergraduate institution (PUI) and predominantly white institution (PWI) in the Mid-Atlantic region of the United States. The course was a 16-week (sophomore-level) engineering mechanics (statics and dynamics) course offered in Spring 2021 in a remote learning environment due to the COVID-19 pandemic. Thirty-six students submitted reflective writing prompts. Three students were removed from the analysis for either deviating from the prompt or exceeding the typical word count that most students generated. This resulted in 33 reflective writings being analyzed as part of this study.

Results

The *HCD for communities* approach tasked students to undertake empathic steps in how they viewed the role of the candidate sites and stakeholders in their problem-solving efforts. The first cycle of coding generated 120 quotes across 43 descriptive codes. The second cycle narrowed the data set to 53 quotes across 15 descriptive codes, and the 15 descriptive codes were assigned into 4 hierarchal categories. Table 3 summarizes the number of students (*n*) and descriptive codes (*italicized* hereafter) that were categorized into the 4-stage understanding of CC model.

Table 3 Summary of two cycle coding results across 4-stage understanding of critical consciousness (CC) model categories.

4-Stage Understanding of CC	No. of Unique Students (*n*)	*n* as % of Population	No. of Descriptive Codes	No. of Quotes
Passive Adaptation: ***Not my problem.***	13	39%	3	24
Emotional Engagement: ***Who is responsible?***	11	33%	7	14
Cognitive Awakening: ***We are part of the problem.***	8	24%	4	13
Intentions to Act: ***We are part of the solution.***	1	3%	1	2
		Total	**15**	**53**

Passive Adaptation. Thirteen students (39%) articulated the need to empathize with stakeholders to solve the problem at hand, which demonstrates care for others. Yet, in describing stakeholders' roles in their problem-solving efforts, these students *engaged in superficial empathic efforts* or relegated *empathy as a step in the design process*. One student wrote: "The engineering design process requires the understanding of stakeholders." Here, the onus of understanding stakeholders is not intrinsic within the engineer (as a person); rather, any understanding of stakeholders is embodied externally in the engineering design process. This emotional detachment – separating the role that engineers have in understanding stakeholders as persons – conveys superficial care toward others yet is undergirded by emotional apathy (i.e., not my problem). Three total descriptive codes were categorized in the lowest level of the 4-stage model, meaning an interpretation that CC had not manifested in the students.

Emotional Engagement. Eleven students (33%) showed emotional engagement by remarking how empathic efforts informed their understanding of the stakeholders as people. Some students *put themselves in the stakeholders' shoes* to gain insight. A student reflected: "One thing that stood out to me was putting myself in the life of someone using the bridge... After a while I really got a sense of how important this bridge could be to the local community..." This remark suggests the student used empathic efforts for more than simply a step in the engineering design process because the student themself emotionally engaged with the stakeholders. Other students took this empathetic effort further by *drawing insight from the stakeholders* to inform their problem-solving efforts. Another student wrote: "I learned that some people don't think the addition of a bridge in certain areas would be beneficial..." The student acknowledged that they had not considered outside perspectives in informing their problem-solving efforts initially but through empathic efforts had come to realize the fictitious PBL unit was misaligned to stakeholder interests. None of the quotes in these seven descriptive codes demonstrated a clarion call for social problems to be remedied by asking "Who is responsible?"; yet these seven descriptive codes hierarchically bridged the first and third levels of the 4-stage model.

Cognitive Awakening. A smaller number of students (8; 24%) demonstrated cognitive awakening by describing how empathic efforts helped them *change their own perspective* about the nature of the problem. One student wrote: "The most eye-opening part of this project was how strongly the community members recommended a course of action that was not even considered in the initial stages of the project." This student acknowledged that their own preconceived understanding of the problem could be challenged by stakeholder input. Underlying this comment is an absence about how, if unchallenged, the engineer could proceed forward and be complicit in propagating engineering solutions that are at odds with stakeholder interests. Another student acknowledged the *hierarchal relationship between engineers and stakeholders* by writing: "Talking to, interacting with, and learning from people is the best way to make sure a solution is engineered for the stakeholders, not the engineers." This student demonstrated awareness that engineering solutions can be produced without stakeholder input, and it is engineers themselves who have a role to play in developing outcomes that are not problematic for stakeholders. These quotes expressed an awareness that engineering efforts can overlook stakeholder interests (i.e., engineers are part of the problem), which led to the assignment of four descriptive codes into the third level of the 4-stage model.

Intentions to Act. Only one student (3%) expressed intentions to act by stating how their inspection of the three candidate sites helped them *envision a new future* when considering the impacts on the community. The student wrote: "By seeing the way that roads would form and expand led to a mental image in mind of new traffic patterns as well as ways that it would both positively and negatively impact the surrounding community." The student envisioned alternate futures, and this mental map positioned the engineer as a person who frames problems and solutions to envision both negative and positive outcomes for others. Only one descriptive code was categorized into the highest level of the 4-stage model.

Discussion

We discuss the extent to which CC manifested in learners in response to an engineering mechanics-based PBL unit, which was ill-structured and based on the *HCD for communities* approach, and how those characteristics impacted that manifestation.

Extent of CC Manifestation. Students' CC was mostly manifested at lower-levels of the 4-stage model, where most students exhibited *passive adaptation* and *emotional engagement* (39% and 33%, respectively) and less students exhibited *cognitive awakening* (24%). This observation suggests that engineering learners, when tasked to empathize with others, do so in performative or superficial ways. Students at these low-levels view stakeholders as constraints to problem-solving rather than as partners in solving problems, which compares to other findings [34]. In our study, only one student (3%) engaged in envisioning an alternate future, demonstrable of the highest form of CC. We surmise that the 4-stage understanding of CC is capable of categorizing the manifestation of CC in engineering learners.

(In-)Ability of the Ill-Structured Characteristic to Promote CC. The exploration of disparate candidate sites and stakeholders to inform an engineering mechanics solution constituted the ill-structured characteristic of the PBL unit. In our study, most students manifested at the lower-levels of understanding of CC, suggesting that engineering students can be ill-equipped to inspect the social realities of the world around them despite the PBL unit representing a real-world scenario. As such, instructors cannot simply rely on the ill-structured characteristic of PBL units alone to promote the development of CC in their engineering learners. Active facilitation and sustentation of CC [29] from instructors is likely required to aid student navigation and understanding of sociocultural nuances in the real-world. Otherwise, students can come to find affirmations from their instructors that the real-world sociocultural complexity of engineering activities are irrelevant to their engineering problem solving efforts.

The HCD for Communities Approach as a Design Framework. The *HCD for communities* approach tasks empathic effort in its earliest steps to understand stakeholder wants and needs. Nearly all students in our study wrote about the role that empathy had to play in their engineering problem solving efforts, yet their writing mostly mapped toward the lower-levels of the 4-stage CC model. This observation suggests that students and instructors are underutilizing the role that empathic efforts in the *HCD for communities* approach have in developing awareness of the world around them, its injustices, and a resolve to right those injustices. Similar to the ill-structured characteristic of PBL units, it is insufficient for an engineering educator to use the *HCD for communities* approach alone to foster student awareness of the world around them. Additional instructional support in approaching engineering problem solving efforts as a sociotechnical process is needed to support the development of CC in engineering learners.

Conclusions and Ongoing Work

This study explored how learners' CC manifested in response to an ill-structured, *HCD for communities*-based PBL unit in a sophomore-level engineering mechanics course. Using the 4-stage understanding of CC, we found that most students engaged in lower-levels of CC whereby empathic efforts in the *HCD for communities* approach was engaged in superficial ways. We also found that the ill-structured characteristic of the PBL unit was limited in fostering the high-level development of CC in engineering learners. There remains ongoing work to explore the extent by which the final design solutions demonstrate CC and to triangulate our preliminary results with survey results, class observations, and semi-structured interviews. Ultimately, refining these types of instructional practices is paramount in preparing future engineers to be proactive agents in resolving social, economic, and environmental injustices that exist in our complex world.

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