WIP: How Students Develop as Critically Conscious Engineers – The Impact of an Engineering Design Course Embedded With Critical Consciousness

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***Abstract*— This Work in Progress paper presents the impact of a mid-year engineering design course in an Electrical and Computer Engineering curriculum on students' critical consciousness and engineering identity. This work addresses two gaps in scholarship and practice, namely, the incorporation of mid-year design into a traditional curriculum where design is only taught formally in the capstone year. Second, the embeddedness of contextual perspectives in design to incorporate a systems-level understanding of design about social, political, cultural, and economic constructs. The contribution to educational practice includes understanding how such a course can sustain or develop student identification with engineering about critical consciousness. Results from this work show that students' critical consciousness gains in the course are not only tied to the learning objectives, but also to the design aspects of the course where the students performed engineering skills and were recognized by peers in the course as engineers.**

Keywords—engineering design, critical consciousness

I. INTRODUCTION

This Work in Progress paper covers preliminary results from a study about the impact of embedding critical consciousness [1] topics to a mid-year engineering design course. The broader motivation for this project stems from the lack of mid-year engineering design courses in most engineering curricula, especially in computing fields, in the United States in and from a need to incorporate humanistic and societal perspectives of design that go beyond human-centered or user-centered design. In this paper, two research questions were addressed to understand the impact of a single course on Electrical and Computer Engineering students: What kind of critical consciousness gains do students experience throughout the course? How is students' identification as engineers impacted by the course? These research questions were addressed using a mixed methods approach; however, this paper focuses on sharing the preliminary results from the qualitative portion of the study.

II. BACKGROUND

Mid-year, second or third-year, engineering courses are sparse in the engineering curriculum, especially in computing fields. Normally, students in computing fields only formally take a capstone course near the end of their degree attainment as their design course

A. Institutional Context

This project implemented a mid-year design course for Electrical and Computer Engineering (ECE) students at a research-intensive institution. The institution is located in a metropolitan, urban setting where the majority of undergraduates attending the College of Engineering (COE) are commuting students. On par with institution demographics, the COE serves a non-majority, diverse population of students. A significant portion of undergraduates in the COE are transfer students and eligible for Pell Grants. Similar to many other ECE departments in the United States, the ECE department at this institution uses the senior design capstone course as the only designated design course in the curriculum. Nonetheless, other courses in the department may incorporate projects with some design components; however, these courses are not dedicated to formally learning about the design process. As a result, the first time that a student learns about the engineering design process is typically in the last year (or last three semesters) of their degree attainment.

B. Course Background

The course discussed in this paper was implemented at the second and third-year levels. Students who had taken at least two of the introductory ECE-curriculum courses and had not yet taken senior design were invited to take this course. The course was offered for the first time in the spring 2023 semester as a 2-credit-hour technical elective, counting towards students' graduation requirements. The class met once a week for a two-hour period. Although this paper focuses on the impact of the course at a single institution, the larger project includes another institution, and more details on the

implementation of the course at both institutions can be found in [anonymized for review].

During the course, each week, students learned about a design topic, a critical consciousness topic, and an engineering innovation that connected both topics. Students were assessed using weekly readings, reflections, a mid-semester video project, and a final project. The mid-semester video project was student-selected and was submitted online. Through this video, students were asked to pick an engineering innovation and discuss a design and critical consciousness topic related to the innovation. For the final project, students worked in teams of 3-4 on a preliminary design addressing a problem statement provided by a local community-based non-profit organization. Students met with the organization as a class three times in the semester via video conference and presented their preliminary design ideas to the community stakeholders at the end of the semester.

C. Literature Review

Although engineering has roots in the military and defense-based motivations for professionalizing the field, engineering has also grown as a social enterprise with a social responsibility [2]. The next evolution to the participation of engineering as a social engine, was an expectation of engineering to become a part of the solution to social issues through the participation of engineers as agents of change or a push to give engineering its proper place in the movements toward a more just society. Costanza-Chock [3] expresses the need to implement "Design Justice" thinking in order to move the humanity of design and the regulation of the "sociotechnical" or technology-infused society.

Several disciplines within engineering have called for the implementation of critical consciousness as part of the curriculum to enhance the programs' outcomes, including in K-12 education [4]. Drake et al. [5] name the phenomenon "critical action" and point to the ABET requirements to teach students to recognize and implement contextualized design projects, not just the engineering criteria. Several other professions with educational requirements similar to engineering have pushed for the need to incorporate similar exposures to their future professionals. Zaidi et al. [6] present the need in the medical field to incorporate critical considerations for their students and the need to train the instructors in the teaching of the methods.

There are isolated instances of groups pushing to investigate the intersections of Freirean constructs of critical consciousness [1] and the world of engineering education. Change in engineering education has traditionally been a difficult task, but there is a high rate of engagement with research-based educational transitions, with a low rate of implementation by engineering educators [7].

A secondary reason to create new pedagogies with critical consciousness foci is the need for the attraction and retention of a more diverse engineering student and workforce population. The transition to improving and implementing curricular and pedagogical strategies in engineering education can be linked to students' identity as engineers or future engineers. In [8], the authors elucidated the need for access to qualified and diverse engineering candidates globally and the lack of engineering students from diverse backgrounds and point to the lack of research around the creation of engineering identities within the undergraduate programs nationally.

D. Conceptual Framework

The conceptual framework that has driven this work from its inception is Freire's [1] critical consciousness concept applied to education. In his writings, Freire posed critical consciousness as a way to make education, particularly literacy, accessible to all and as a result a form of liberation. Critical consciousness entails a nuanced and critical understanding of the world with respect to oneself and to others. This understanding includes knowledge of systems of oppression. This project used critical consciousness to frame how the course was structured and taught and as a framework to guide the research aspects. The research use of critical consciousness is discussed in the methods section of this paper. In short, we assess critical consciousness through the three main tenets of the framework: reflection, dialogue, and action.

These tenets can be understand through Freire's critical consciousness "stages:" semi-transivity, naïve transitvity, and critical transitivity. The concept of semi-transitive state does not indicate that the individual is closed to external influences, rather, semi-transitive consciousness means that perceptions are limited and there is a "near disengagement between [the individual] and their existence" [1, p. 14]. Naive transitivity is characterized by "an over-simplification of problems; by a nostalgia for the past; by underestimation of the common man; by a strong tendency to gregariousness; by a lack of interest in investigation, accompanied by an accentuated taste for fanciful explanations; by fragility of argument; by a strongly emotional style; by the practice of polemics rather than dialogue; by magical explanations" [1, p.14]. Naive transitivity describes the consciousness of an individual who is almost part of the mass and whose capacity to dialogue is still fragile. Critical transitivity is characterized by a more in-depth analysis of problems and an increase in agency, or being in action. There is a "depth in the interpretation of problems" [1, p.15] and a "highly permeable, interrogative, restless, and dialogical form of life" [1, p.15].

Critical consciousness was used to frame how the class was structured and taught. For example, in structuring the units for the 15-week course, the authors paired a critical consciousness topic with a design topic(s) for each week of the course for the first twelve weeks of the semester. Note that the last three weeks of the semester were used for project development. While the engineering design process was discussed in a traditional, linear manner, critical consciousness topics were included in the syllabus in a purposeful way to fit in with the design topic discussed. Table 1 shows a sample of the topics discussed in class. More detail on how critical consciousness is integrated into this class is further discussed [9].

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Week #	Topics	
	Critical Consciousness	***Design***
1	Engineering Identity	Introduction
2	Militarism	History of Engineering
…	…	…
9	Techno-determinism	Engineering Requirements
10	Implicit Bias	Design Alternatives
11	Representation	Testing
12	Decolonizing Engineering	Iteration

TABLE I.

III. Methods

Multiple qualitative methods were used to answer the research questions, including semi-structured interviews, student reflections, and document analysis.

A. Data Collection

Semi-structured interviews were conducted in-person by one of the authors at the end of the spring 2023 semester. There were 11 students who participated in the interviews. The interview protocol was guided by the conceptual framework and split into three sections: icebreaker questions, critical consciousness questions, and engineering identity questions. The questions generally asked students to reflect on aspects of the course that impacted their critical consciousness and their engineering identity. The interviews lasted 28 minutes on average, for a total of 310 minutes across all interviewees. The interviews were audio recorded.

Student reflections were collected as part of the course in the first 13 weeks of the semester. These reflections asked the students three questions to reflect about the week's topics, how engineers can implement/use the knowledge learned, and how their understanding of critical consciousness changed. Students were asked to take at least 10 minutes to complete them. The reflections were distributed via Qualtrics.

As part of document analysis, students' final reports and presentations were collected. These documents were completed as part of students' final projects in the course. In total, there were four final reports and four final presentations that were analyzed.

B. Data Analysis

The semi-structured interview data was given priority and was analyzed first. Two authors engaged in memoing of the interview data prior to coding. Memoing was done to get familiar with the interview data, note any inconsistencies in the students' answer, and to start developing a codebook. After a draft codebook was developed, the authors met to discuss the codes and begin individual coding. Coding was done in two stages, first the authors engaged in a round of individual coding using the draft codebook. After individual coding was completed, the authors met to engage in group coding. Group coding was done over video conference where the authors reviewed each of their codes and finalized codes only when consensus across the authors was reached. This process was facilitated by the use of MAXQDA software.

After group coding was completed, the authors used the Summary tool in MAXQDA to review codes across interviews and write summaries for all prevalent codes. Preliminary findings were documented using the QTT tool in MAXQDA. The reflections and final reports/presentations were used as secondary data after preliminary findings were finalized. One author reviewed the reflections and final reports/presentations to triangulate with preliminary findings.

IV. Preliminary Findings

The preliminary findings are grouped in two sections to answer each research question respectively. Students' quotes are presented in italics font.

A. Engineering Identity Development

This section covers the preliminary findings that answer the research question: How is students' identification as engineers impacted by the course?

In the interview, students were asked about recognition as engineers. Many students lacked self-recognition as engineers when they were directly asked if they identified themselves with engineering. Answering this question, 9 out of 11 students would state the reasons they could not yet consider themselves engineers (e.g., still need credentials/diploma, not enough experience with real-world problems, or other conditions:

> *"I think I'd feel more like an engineer in probably like the senior design class just because it's more like hands-on and where you're actually making a solution, not just designing it."*

At the same time, 10 out of 11 students stated they have some sort of recognition from other people (e.g., friends, family), and this was often related with performance (such as providing academic help with STEM-related subjects, helping to fix things, etc.). Seven students mentioned that they felt recognized as engineers during this engineering design course, mostly when they were working in teams on the final project and used engineering skills such as problem-solving and critical thinking and interpersonal skills such as communication and teamwork.

Eight out of 11 students were coded as lacking competence, while seven out of those 8 were also coded as confident in their abilities. In other words, students said that at the moment of the interview, they lacked something (e.g., courses or experience outside of courses) to work as engineers. Still, they felt confident in their abilities to do that in the future

> *"Definitely feel capable of becoming an engineer", "Me being confident that I can make something work … is what's pushing me to keep going."*

Competence in their abilities or confidence that they can become engineers were not spoken of with respect to the course.

Ten out of 11 students were coded as having community in engineering (including community within major and community in classes). Some aspects of the class that were related to students' mentions of having a community were having or making friends in class and having an opportunity to speak to other students and engage in a dialog (unlike other engineering classes, where students don't often talk to each other:

"*If it wasn't for this class, I would have never…had that connection because this is a smaller class where you're forced to interact with more people. It's more of a face-to-face, and… you recognize them instead of going to a lecture, …[when] you don't see each other because you're just going there to get lectured at."*

B. Critical Consciousness Gains

Critical consciousness gains were coded and analyzed using three stages of critical consciousness: semi-transitivity, naïve transitivity, and critical transitivity. These gains were analyzed from both a retrospective frame (interviews) and a longitudinal frame (reflections and course documents). Note that when students discussed aspects of critical consciousness during the interview, they often provided a retrospective reflection (e.g., "Before this class..").

For the semi-transitive stage of CC, three codes were the most frequent in the analysis: minimal awareness (coded in 8 students out of 11), minimal reflection (5 students out of 11), and being complacent (4 out of 11). Minimal awareness was mostly noticed when students talked about discrete issues of injustice in engineering (some in relation to design) but didn't discuss what they could do to change these issues or their role in it. The issues that were brought up were mostly those discussed in class, and students did not go into depth on the issues. This can be seen in tandem with the minimal reflection codes, where students did not provide an understanding of their own role in the issues brought forth. Students discussed "engineers" and referred to them as "they" as opposed to "we":

"So the engineers have, I will say, a very important role in designing everything around us, whether it is technology, whether it is community services or whatever. Engineers take a role in that position. So they're very critical in today's world."

Being complacent is discussed in retrospect (before class) or in relation to other classes or other aspects of engineering (outside of class). Students discuss the culture of doing as told and not questioning what they're being asked to do – this relates to other courses in their curricula and post-graduation life (i.e., military, industry), not directly a reflection of this course.

"*We didn't… learn how to think critically…we design things based on what our boss or, you know, the teacher told us to do."*

For the naïve transitivity stage of CC, students demonstrate awareness (coded in 10 interviews out of 11) when they discuss particular issues (and their importance) that they've become aware of and the need for change. The use of the word "we" seems to be done to absolve any individual reflection on the issue and rather to seek a broad way to assign responsibility without the need to delve into one's involvement in the problem or the solution.

"When engineers go into the whole social, we have to take into many considerations. How would it impact communities, for instance? How the technology could be used? Because nowadays technology, when we invent something, it could be used in so many ways.").

Only one student discussed individual, personal growth that they've had or become aware of through the class, while the rest discussed more general growth or awareness:

"And then I learned about…the military jobs that you'd get from engineering. And then it … made me think about how these things are. You'd invent… [something] to be used to probably do bad things to other people. So it's just kind of like knowing what you're signing up for. [It] opened my eyes to the fact that you could get employed for a job, and then they'll vaguely tell you what it is, or you won't really know what the end product is like. Oh yeah, here, make this chip. And then you find out that it's like used and like, I don't know, a death machine. So just kind of it was very eye-opening to get told about all these things."

Everyone else provided examples of what they've learned and why it's important for their engineering careers. Another popular motif that we attribute to naïve transitivity was self-reflection (coded in 10 interviewed students). The main difference here from semi-transitivity is that students mention more points of their role in the engineering design process and their role as engineers in the possible solutions that could solve the mentioned issues,

"It's not enough for me to listen to what my employers are telling me. I have to go and look into things on my own, which is a hassle. And like, you really shouldn't have to do that. But I guess you have to be aware that you have to think further beyond what the job description is or what you're being told, and you have to investigate on your own."

While the reflection is more nuanced than in the semi-transitivity state, the reflection still does not account for anything beyond the individual (e.g., systems of oppression). Eight out of 11 students also demonstrate some oversimplification of problems such as when discussing issues in design that threatened people's livelihoods (e.g., cobalt mining) and suggesting the solutions assuming that one stakeholder (e.g., a company) could solve it all via one simple action (e.g., paying people more money)

"We had a conversation about this in class…The miners didn't have that very good situation;…the companies weren't providing very good… work environment. Like they had no mask in the mines; the mines were like too tiny… physically move around."

The nuance and in-depth understanding of the issue, and reflection of the systems at work (not just one entity) is largely missing from this stage of thinking about design and the role of engineers within design.

V. Conclusion

The mid-year design course that incorporates critical consciousness topics impacted students' engineering identity development and critical consciousness gains over the course of one semester. In particular, students' performance in the course during the final project, which was completed in partnership with a community organization, led to recognition from others as engineers and to community building. These aspects of engineering identity (i.e., performance, recognition, and community) were developed via the completion of the project. Critical consciousness gains throughout the course were found primarily from semi-transitivity to naïve transitivity. While students gained an understanding of their roles and responsibilities as engineers in relation to design and innovation, their systems-level reflection was lacking. In particular, most students did not discuss systems that made engineering innovations unjust or unfair. They tended to focus on individual roles and responsibilities.

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