



The places they will go: What happens when engineering students critically reflect

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After 10 years in the field of public health practice, Gabrielle has recently returned to academia as a PhD student at Swansea University in the UK. As a social scientist based in the College of Engineering, she is exploring opportunities to bring critical scholarship into engineering education, particularly in the context of sustainable development.

Prior to her return to academia, Gabrielle's work took her Ethiopia, Wales and multiple states across the United States, where she worked to catalyze policy and systems-level change to improve health and well-being across communities. She prioritizes a social justice lens and systems approach in all her work.

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Patricia is a water engineer with a background in both the private and public water sector. She has expertise in the design of flood alleviation schemes and wastewater networks. Patricia leads Academic Programme Enhancement and Development for the College of Engineering. With her background in industry, she is keenly aware that the sector-wide academisation and de-contextualisation of engineering education is leading to an engineering sector that struggles to relate theory to practice.

Patricia teaches creative design modules that give students tools and techniques (Human-centered design, VR collaborative design tools) to find their own brand of creativity in engineering design, while prompting students to consider how their individual privilege and biases impact on their design decisions.

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A Chartered Occupational Psychologist and Senior Fellow of the Higher Education Academy, Catherine draws on over 20 years' operational management experience, to support her academic work. She remains involved in supporting and advising on the work of a number of social enterprises and charities locally. Her main areas of interest and research are in action learning, critical management, social enterprise and all things psychological. As an experienced coach, Catherine is particularly active in the area of leadership and team development, making innovative use of virtual reality technology and critical thinking to develop and enhance leadership competency in M level students. She is also a highly experienced psychometrician.

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Abstract

Over the last 30 years, “engineering for development” initiatives have proliferated across the Western world and have become woven into the fabric of many higher education programs. Despite their good intentions, these programs have been critiqued due to lack of appropriate engagement with communities in co-creating solutions, failing to recognize the limitations of technology in achieving sustainable development goals (SDGs), as well as failing to interrogate structures and relations of power that impact on development interventions. In some cases, these efforts have reinforced social injustices.

There have been numerous efforts to embed social, political and economic context into engineering education, particularly in engineering for sustainable community development, so that engineers better understand the wider impacts that can result from their interventions. One such method is the integration of reflective exercises within engineering course work.

This paper traces the adoption of critical reflection as a core pedagogical strategy in an engineering management program focused on sustainable international development within one UK university. Critical reflection, which stems from a critical scholarly tradition, asks us to question our assumptions, recognize the role that power plays in shaping our social reality, and use reason to advance our emancipatory thinking and action.

Critical reflection is embedded within a program that recruits both engineers and non-engineers, with teaching and learning strategies drawn from the social sciences and humanities and integrated with engineering management and problem-based learning. The program connects students to a project partner in Sierra Leone or Zambia, the students work to understand their partners’ needs and assets and then develop an intervention plan consistent with the aims of the SDGs.

In this paper, we provide results of a critically reflexive thematic analysis to explore the nature of student reflections within the context of this interdisciplinary program. Evidence suggests a range of student interpretation of the purpose and application of critical reflection. Some are able to expose unjust, implicit structures of power that operate within their team and/or project context. Some students continue to struggle to identify their own positionality and privilege. In addition, persistent gendered, racial and ethnic power dynamics seemed to emerge among students across two cohorts. However, the unique combination of critical reflection, interdisciplinary teamwork, real-world design work and intensive mentorship within this program appears to have created space for students to deepen their understanding of their positionality and privilege, and better understand how these issues play out within their practice.

Critical reflection may be a valuable pedagogical strategy for engineering higher education, particularly in concert with problem-based learning, that contributes to ongoing personal and professional development, and has the potential to mount meaningful challenge to unjust power dynamics in engineering for sustainable development.

Introduction

Over the last 30 years, “engineering for development” (E4D) initiatives have proliferated across the Western world and have become integrated into the fabric of many higher education programs [1]. Despite their good intentions, these projects and programs have been critiqued due to lack of appropriate engagement with communities in co-creating solutions, failing to recognize the limitations of technology in achieving sustainable development goals (SDGs), as well as failing to interrogate structures and relations of power that impact on development interventions. In some cases, these efforts have reinforced social injustices. According to critiques of E4D programs, student projects have a tendency to reproduce unjust neocolonial, racist and/or paternalistic power dynamics. Evidence suggests that E4D projects within engineering higher education have been guilty of perpetuating similar dynamics [2].

Yet the shortcomings observed in previous efforts towards social justice through E4D projects do not necessarily invalidate future efforts. Rather, of pivotal importance is the ability to continue to reflect on what has gone before, to learn from mistakes and strive to improve future practice. Nieuwsma proposes five pedagogical initiatives that can promote social justice in engineering curricula, including: the integration of liberal education courses into engineering curricula; embedding social justice content into technical courses; increasing critical learning thresholds around social justice through strategies such as discussion-centered teaching, small class sizes and engaging real world problems; experiential learning; and liberative pedagogies [3].

The development of the theory and practice of liberative pedagogy is generally attributed to Paulo Freire, and has been discussed elsewhere within engineering education research by Riley [4], Riley and Claris [5] and Mejia et al [6]. Liberative pedagogy, also referred to as critical pedagogy, involves praxis – the integration of theory and practice – and combines active struggle against “ideological and material” forces of domination, with a hopeful striving toward emancipation from these forces [7]. Freire asserts that *critical reflection*, or “reflection and action upon the world in order to transform it,” is a fundamental feature of critical pedagogical praxis [8]. Van Manen elaborates a definition of critical reflection as a form of reflection that “adds moral and ethical criteria, such as equity and justice,” and locates “analysis of personal action within wider historical, political and social contexts” [9].

There are signs that reflective practice within engineering higher education has received increased attention over time [10]. However, though calls have been made for use of a critical lens in engineering education research [11], [12], few studies exist that document the implementation of *critically* reflective pedagogical strategies. One study of a new engineering design program in Sweden, developed to increase students’ social justice literacy, used textual content analysis to understand if and how students reflected critically on issues of social justice within their final essay submissions [13]. Authors found evidence that students did begin to “see systems” as a result of the program and seem to begin to critically question different stakeholder perspectives and contextualize engineering development practices. However, it is unclear whether students considered their own role as aspiring engineers within the structures of power that they were uncovering through their reflections. In addition, the critical reflection assignment does not seem to follow an established theoretical framework on praxis or critical consciousness development, which may make it less likely that critical reflective assignments would lead toward emancipatory action.

Kabo and Baillie report on the evolution of students' thinking about social justice and its relationship to engineering after taking a class on engineering and social justice at Queens University in Canada. The class was developed with critical pedagogy as its overarching theoretical framework. Students, who came from a variety of disciplines, were invited to critically reflect on common assumptions within engineering practice, and to consider "the creation of alternative practices which are non-oppressive, non-capitalistic, and ecologically sustainable" [14]. Students were exposed to real-world examples of engineering injustices through seminars and a community-based group project. In their 2009 study, interviews and student self-reflections were analyzed to better understand student perceptions of how the course helped them move toward the adoption of social justice as a critical lens. Results indicated that students evolved a more complex and nuanced understanding of engineering practice and its relationship to social justice, questioning the role of engineering in society and the "profit paradigm of engineering." Despite the promising results of these reflections, this was only one elective class within students' undergraduate education, and as Cech argues, one class is not enough to move the needle on developing the necessary "reflexes for social justice considerations" amongst engineers [15].

Kim et. al. worked on a multi-disciplinary team from engineering, psychology and education with the aim to "enable engineering students to become reflective thinkers who develop the habit of critically thinking about the broader social, human, environmental, and ethical context" [10]. Using the philosophical concept of phronesis (ethical judgement or practical wisdom) as a guiding theoretical framework, reflective practice was used to assist students in navigating their development of ethical judgement in the face of ambiguous situations. The course required the students to write an autobiographical essay, reflecting on their "lived experience" to date, with questions including "What was my childhood like?" and "How do I perceive the society I live in?", with the essay framed as a fundamental step in self-development. The course also included discussions about engineering scenarios containing ethical dilemmas or rich context. The authors drew their data from student essays, autobiographies and written reflective pieces, noting in their results that over the course, the students "became more critical and reflective in their thinking and writing by developing the abilities of (1) competence in contextual knowledge, (2) tolerance of ambiguity, (3) and openness to critical reflection" [10]. While this study does locate engineering decision-making within its broader social context, and has been successful in encouraging students to think beyond technical rationality and engaging constructively in what Schon describes as "swampy lowlands" of "confusing 'messes' incapable of technical solution" [16], interrogation of underlying structures of power (a central feature of critically reflective praxis) appears to be absent. In addition, students were remote from the scenarios discussed and considered issues on a theoretical and hypothetical basis, which may limit the development of phronesis, as students were passive observers and did not have the opportunity to learn from experience, including the consequences and outcomes of the scenarios they were exploring.

The intention of this paper is to contribute to the literature on the implementation of critical reflection as a pedagogical strategy in the context of engineering education. Our focus is on an engineering master's program in south Wales, UK. In the following sections, we will outline the context within which students critically reflect. We will then share a sample of student reflections, along with our interpretation of the outcome of having students reflect within the context of this program. This work is part of a larger exploratory study tracing innovation in

engineering pedagogy and curricular content within a university engineering department in the UK.

Context

This paper focuses on a new master's program within the College of Engineering at Swansea University, in south Wales, UK, launched in 2017. The program, Sustainable Engineering Management for International Development (SEM4ID), has enrolled between 8 and 13 students each year from both engineering and non-engineering backgrounds, and provides a mix of classes in technical engineering and liberal education topics. While the different disciplines work together, there are separate learning outcomes for the engineers and non-engineers. The engineering strand of the program is accredited by the UK Engineering Council.

Students engage in experiential, problem-based learning (PBL) through international service learning (ISL) projects in Sierra Leone or Zambia, where they are connected to previously established community-based contacts. Throughout the year-long program, students work on interdisciplinary teams of 4-5 to understand their community partners' needs and assets. They have a chance to meet partners in person during a short scoping visit (approximately 1 week). They then engage in an iterative design process where they develop an engineering intervention, pitch their proposals to community partners and Swansea University stakeholders, and, depending on the strength of their proposals, students have received funding toward implementation. Toward the end of the year, students travel back to field sites to test and implement their designs. More has been written about the structure and implementation of the program elsewhere [17].

One aspect of this program that has tied various pedagogical strategies and curricular themes together has been the teaching and assignment of critical reflection. The underlying principles and practice of critical reflection have been taught by two authors and reinforced by the third author on this paper. Catherine Groves developed and delivered the original lecture materials during the 2017-18 academic year and Gabrielle Orbaek White adopted and delivered them during the 2018-2019 academic year.

Reynolds, a critical management scholar, provides the theoretical framework used in the instruction of critical reflection in this program [18]. Informed by the Freirian ideal of using reflection to inform action, Reynolds defines critical reflection as a process that should: question taken-for-granted assumptions; be social rather than individual; be concerned with revealing power relations, and; be directed towards emancipation [19]. Students were directed to additional resources to inform their reflective practice, including Revans [20], Humphreys [21] and Gibbs [22].

As part of Patricia Xavier's concept development courses, which provide a foundation for students' engineering design work, students are asked to submit two critically reflective essays, one at the midway point and one final submission at the end of the year. Students are free to choose the topics of their writing, though suggestions have been provided to help catalyze their reflections. Suggestions have included focusing on a "critical incident" (one that gave them pause or provoked an emotional reaction) [23], or on their performance during a leadership

exercise during one of their classes. Once students decide on a topic, they are invited to use it as a point of departure to:

- Critically analyze their own and their teams' decisions
- Consider other perspectives
- Analyze how they have dealt with structures and relations of power throughout their projects.

Students are required to use the literature, including, but not limited to, peer reviewed journal articles, blogs, religious texts, newspaper articles and social media, to help them more rigorously challenge their assumptions, explore critical questions and extend their understandings of themselves and the world around them. They are discouraged from using the literature to merely validate their claims.

Beyond the structure of the assignment, students are provided with robust guidance and mentorship by faculty involved in the program, including the three authors of this paper. Each project team had a primary academic mentor, but students were encouraged to and often did go beyond their primary mentor to gain feedback and advice about their critical reflection work both before and after assignments were due.

This paper explores the outcomes of student reflections, collected from two cohorts enrolled during the 2017-2018 and 2018-2019 school years.

Methodology

Given the role of the authors as teachers on and researchers of the SEM4ID course, we recognized through our own praxis that the critical reflection work that students were doing was practically and theoretically interesting. Since the launch of this program in 2017, students have approached all of the authors at various moments during their education about the challenge and the value of their critically reflective writing. We observed several students undergo personal and professional transformation throughout their time in the course. Though we cannot draw the causal linkage at this time, based on our experience, alongside our knowledge of literature in this area, we postulated that having students critically reflect on their experience, positionality and decision making throughout the year, may have contributed to these transformations. After two years of intensive engagement with the development of the SEM4ID program and with students enrolled on the program, we were curious to know what was emerging from student reflective accounts. We recognized that a deeper reading of students' critically reflective accounts could teach us a great deal.

However, since the decision to incorporate critical reflection into the SEM4ID curriculum was pragmatic and grounded in the collective experience of the developers of the program, and because there remains a paucity of studies that delve into the context and content of critical reflection in engineering education, we were unsure what students would produce through their critically reflective work. Therefore, we decided to take a wide and exploratory stance to this research. Our overarching research question that guided our analysis was: ***what happens when students (in this context) are asked to critically reflect?*** We used two years of student critical reflection submissions from the 17/18 and 18/19 school years – a total of 21 essays.

Informed by Braun and Clarke's thematic analysis, each author completed a "close reading" of students' essays. We did initial coding individually, then came together in person to organize our thoughts and reflections into broader themes [24].

To begin to answer our research question, we decided to take an inductive, reflexive and interpretive approach to characterizing students' work. We were inspired by Alvesson and Sköldbberg's *reflexive interpretation*, which is a critical and multi-dimensional form of reflexivity, whereby the researcher creatively, yet systematically, reflects on data alongside theory. This theoretical framework involves systematic interpretation of potential underlying meanings; critical interpretation of ideology, power and social reproduction; and reflection on text production and language use with regard to our own textual development, claims to authority and selectivity of voices that we chose to represent in our text [25]. Though systematic, the aim is to stay "light of foot" – not becoming bound to one theoretical position or another, but relying on the researchers' best judgement, intuition and ability to see and point out what they believe is important. This style of interpretation recognizes and allows for our innate human capacity to reflect and interpret at multiple levels.

Prior to delving into this study, the authors critically reflected on their position in relation to this research, along with their relationship with their own praxis related to the program, to make the boundaries of their interpretive repertoires, or their theoretical and positional sensitivities, more transparent to themselves as well as to their co-authors [25]. We offer an insight into our interpretive repertoire to the reader now, as well as within the Discussion section of this paper, as we believe this transparency is an essential part of critical praxis:

Gabrielle Orbaek White is a PhD candidate within the College of Engineering at Swansea University. Before beginning her PhD, her work focused on identifying and strengthening opportunities for more fair, just and equitable public health and health care systems in the US and UK. Informed by formative personal and professional experience, particularly time spent working in sub-Saharan Africa, she is driven by a commitment to social justice and applies a feminist, anti-racist and critical theoretical lens to her research and teaching.

Catherine Groves is a senior lecturer in the School of Management at Swansea University. She became involved in the design of the course through her work in leadership coaching and critical management education. The critically reflective approach that characterized her leadership module has seeped across the program and continues to inform the ideology of other areas of the course, and ultimately, the nature and content of the capstone assessment. Catherine works with Patricia to supervise Gabrielle's PhD and continues to provide mentoring support for several engineering faculty on the program. Catherine's theoretical approach is characterized by anti-oppressive and liberal perspectives, and her writing and teaching have coalesced around critical reflection, critical thinking and action learning.

Patricia Xavier is an associate professor in the College of Engineering at Swansea University for Programme Enhancement and Development. She is a Civil Engineer and prior to her academic appointment, Patricia worked as a flooding and drainage engineer in the water sector. Her industrial experience has led her to seek a better link between theory and practice in engineering education through active learning, engaging students in contextualized, open-ended problem definition and solution. Her theoretical perspective is in part informed by her role as College

Student Engagement lead with its remit to champion student voices in College policy, where she is motivated by the concept of students as partners, which “foregrounds qualities that put reciprocal learning at the heart of the relationship, such as trust, risk, inter-dependence and agency” [26].

Though we want to increase transparency of our interpretive lens to the reader, we also challenge modernist validity arguments, where the subject of research (ourselves and the students) is somehow linear and knowable. Instead, through iterative, critically reflexive interpretation, we attempt to move toward a postmodernist interpretation of ourselves and our students (and their work), whereby we acknowledge the contextual, situational, and changing nature of our own interpretations of our subjects (including ourselves) [27]. Therefore, we do not attempt to make any fixed truth claims about the students’ work or our own interpretations of their work in this paper. Instead, the aim of this paper is to provide an interpretive offering to fellow educators about the application of critical reflection in engineering classrooms, in response to growing trends in the use of reflection in engineering education.

Results

In the following results, we provide direct quotes from student journals, which emerged to us as exemplars of the overarching themes presented below. It is important to note that these are not definitive themes – the authors discussed and debated the characterization of these exemplars at length. The characterization we provide below are the result of analysis completed to date, though this work is still ongoing and may evolve.

We provide notes on students’ identity, as they have served as points of departure for some of our reflections and reactions to students’ submissions. As appropriate, we use the commonly used British acronym BAME, or Black, Asian Minority Ethnic people. Though the use of “BAME” is contentious within racial and ethnic minority communities, we use it in this paper as it remains the convention in the UK, and we believe it is sufficiently general that it reduces the risk of providing specific identifiers that may breach confidentiality.

Evidence of transformation

Upon close reading of student submissions, we came to find compelling, thoughtful and insightful reflections across a range of topics. Many students reflected on scenarios through the lens of history of development and colonization. Some questioned their role as early career development practitioners. They challenged previously held notions that they were “there to help” and instead, began to recognize synergies that can come from co-production, relationship building and respect. They also challenged the role of institutions, like Swansea University, in participating in what they considered may be an extension of colonial development regimes.

Learning about and questioning Western-led, (neo)colonial development

"The connotations of Sierra Leone’s colonial past are ever-present both officially and unofficially (DFID/ UKAID) and this permeates to create an inextricable link that transcends multiple issues such as race, identity, power dynamics and team dynamics. Of course, it is difficult to accept initially that the legacy of our colonial past to a large extent has framed the complex operating conditions in which we are working. I have long been

aware of the implications of colonialism due to my background in Modern History and International Relations and interest in development economics. Yet, until I witnessed that first hand, I had never really appreciated its significance and how it is translated in day-to-day interactions." – Student 11, (male, white, non-engineer)

Questioning their role in development practice

"And how exactly were we able to build something to help these people? We were all students with no practical experience.... We did not want Sierra Leone to be our "playground", a liberated space in which the usual rules do not apply (Cole 2019)" Student 1 (female, white, engineer)

"I have found myself questioning many things, but mainly if development in this context is aimed at helping the 'receivers' or the 'givers' to develop. This is something which has been questioned before, whereby trips of this nature have become 'about us, rather than for others' (11). Mary Lundy states that service learning is aimed as a mutual benefit to students and the community (12), however in this context I believe the benefits for the students are achieved through the lives of others that may not see any gains" Student 7 (female, white, non-engineer)

"The trip created many negative feelings for me, and made me question whether our intervention was worthwhile. Will we really affect people's lives? In addition, if not, is it really ok to implement these projects in developing countries - simply as a learning experience for students? Isn't that exploitative?" Student 12 (male, BAME, engineer)

Updated, more critical sense of professional identity and direction

"If life will offer me another opportunity to work in a developing country, I will go there with an open heart, without trying to "save the world", with many lessons learned about their country and culture and just as many to be learned. I would be ready to collaborate with the community without being scared of uncertainties, but rather be curious and excited about them. If we were "lucky" enough to implement a tangible project for the beneficiaries the first time, the next project will include even more community engagement and collaboration with the residents involved. They know better than us anyway." Student 1 (female, white, engineer)

"These experiences also surfaced for me a sense of hypocrisy for concentrating my efforts of development work abroad as opposed to my nuclear community. In doing so I begin to unearth deep-rooted feelings of confusion and anger in the search for my own identity and purpose in development." Student 21 (male, BAME, engineer)

Notably, some of the engineering students articulated new perspectives they had developed through their projects on the importance of social and political context of their work. In some cases, they acknowledged that the social and political context may be more important than the engineering intervention itself.

"As a novice practitioner in the field of development, and coming from an engineering background where working with rigour and structure to systematically work through

problem solving resolutions has been my experience, I have come to realise and appreciate the importance and value of the context in which development takes place and how social science and other concepts play an equally important role in development projects around the world." Student 4 (female, white, engineer)

"When I travelled to Sierra Leone and visited the slum, I felt that development is an almost entirely social and political issue – engineering was just a way to facilitate the social and political change required for progress." Student 12 (male, BAME, engineer)

Through the narration of their experiences and reflections in their essay submissions, we found evidence of students moving through various stages of a journey toward a more critical mindset. We characterized these transformations in thinking as *development of critical consciousness*. We arrived at this conclusion through the exploration of theoretical perspectives. Both Gabrielle and Catherine have been informed by an Action Learning perspective, from the standpoint of the social nature of learning, and the imperative to apply questioning insight to programmed knowledge in order to arrive at true learning. However, the authors recognize the influence the ‘conscientização’ of Freire, and the emancipatory pedagogy of hooks, which seeks a democratic and engaged way of learning, within the Action Learning literature. Thus, all the authors agree that the learner (both teacher and student in the traditional classroom) develops critical consciousness through an insistent probing of assumptions and working to understand the impact their own lens has on their interpretation of situations. In the classroom, this means learners are engaging with questions around structures of power and a social perspective aiming for emancipation.

Bumps along the way

Development of critical consciousness is not a linear or finite process. Opening the door for students to critically reflect on their experiences did not mean they were able to find resolutions. As mentors, we encouraged students to allow some of their issues to remain unresolved – that they were dealing with “wicked problems” [28] that may not have clear beginnings, middles or ends. One issue that emerged from students’ journals was a tension between engineering and social science. On one hand, there was a recognition of the importance of social and political context across students’ disciplinary backgrounds. However, this did not necessarily mean it was simple or straightforward for students to integrate these perspectives into their work.

“There was certainly a belief that I was on the team to ‘do the social stuff’ required on the course, from both myself and my fellow team members. There was an underestimation of the significance of the social science, in the fact that social science principles must be applied to any development project, in a sense they must precede engineering ... Whilst there were attempts to implement social sustainability from the outset, in terms of a community engagement strategy and stakeholder communications plan, these documents were largely ignored when we were actually doing the project.” Student 15 (female, white, non-engineer)

“It was before the first trip to Sierra Leone when one of the social scientists in my team had a strong belief that the engineering project must be the social scientists’ choice rather than a common decision, and the same with any social aspects of the project. They

insisted that the engineers should look for technical solutions while the social scientists talk to the community, conduct interviews and communicate with other stakeholders. This division of tasks blocked team communication numerous times, mainly because most of the skills taught this year were social skills and modules focused more on the social aspects of an intervention and I was advocating for a common action. My reaction contradicts Leydens, Lucena and Schneider (2012) who suggest that engineers have the tendency to focus on isolated divisions of labour rather than collective decision-making or collaborations. Borrego, (2006) also suggests that engineer's type of collaboration is a reflection of the division of labour characteristic to engineering activities. But my position was different. Why was I learning these things if I was not using them? And why I believed that I was entitled to take part in those actions while others didn't?" Student 2 (male, white, engineer)

In spite of it all...

Though we found many examples throughout student reflective work that indicated the development of critical consciousness, we found perhaps an equal number of examples that we interpreted as naiveté, for instance, in a lack of acknowledgement of the complexities of building authentic partnerships with community stakeholders or of navigating structural issues of race, post-coloniality or gender:

"I found it very easy to talk to the workers in Home Leone. It didn't take long for MB, the main welder to become my friend. Our relationship was mostly pushed by the circumstances, but it was based on mutual respect and most important on having similar personalities." Student 1 (female, white, engineer)

"This isn't to say that I was dealing with dramatic race issues while I was down in Zambia. This couldn't be farther from the truth. The Siavonga community respected my knowledge, work ethic and knack to speak in the local language. An entire community's perspective can change quite quickly when each morning you say good morning to fifty different people in their language on your walk to work." Student 5 (male, white, non-engineer)

".. I find gender roles to be an interesting topic. In many ways, our team has obliterated gender stereotypes in an engineering project with two female engineers and one dominant and one quiet of each gender. But in terms of the job roles that we have assumed in the team, Will [a pseudonym] being the presumed leader and me the organiser, I find it interesting to observe where we have naturally slotted in." Student 6 (female, white, engineer)

Acceptance (however subconscious or unintentional) of dominant ideologies that maintain status quo

"What's the point of any of this, if the beneficiary continues to take and never learn? The whole point of this agreement was for their own betterment and empowerment. The beneficiary is clearly taking advantage of the donor." Student 5 (male, white, non-engineer)

"I asked if he would teach me because I wanted to learn and to contribute. He looked at me with a certain amount of amusement, but said yes. I spent the whole day watching him work and trying to input where I could but, contrary to his agreement to teach me, he effectively ignored my presence" - she later reviews this 'But actually as I contemplated this, I thought that I wasn't really offended by N, more frustrated with myself for not already knowing how to be practical" Student 6 (female, white, engineer)

Discussion and lessons learned

What happens when students critically reflect?

Upon reflecting on the results we present above, we were able to reach some tentative answers to our research question: *what happens when students (in this context) are asked to critically reflect*. Principally, we realized that some students in the SEM4ID program showed signs of an evolution toward critical consciousness, or a gradual recognition of their role in broader systems of oppression and structures of power, and the change in actions and decisions they reported due to their new awareness. We use the terminology *critical consciousness*, as it is consistent within Freire's theoretical framework on critical pedagogy. While we have used this characterization of students' experience here, we recognize there may be other metaphors or conceptual frameworks, such as spiraling [29], sense making [30] or threshold concepts [14], to explain the learning processes the students report.

We emphasize that we noticed this evolution in *some* students, not all. While some students appear to use their critical reflection assignments as a way to avoid reproducing unjust relations of power, others seemed to resist change or recognition of their role in reproducing structural injustices.

Taking this further, we were curious to see if there was a relationship between students' academic background and the degree of "criticality" of their reflections, or the extent to which they were able to apply critical theories and analyze their own experience through them. We had initially assumed that engineers may struggle to in their ability to get critical, due to a culture of disengagement in engineering education, reported within the US [11]. Ultimately, we did not find a distinction between the degree of sophistication in critically reflective analysis between students with engineering versus a non-engineering background. We considered that the engineers who self-select into the SEM4ID program may be outliers, in that their level of social and political engagement may be higher than the average engineering graduate. We also appreciate that there may be varying levels of ability across students from all backgrounds to engage in critical concepts and conduct in-depth critical analysis.

These insights assume that critical reflection journals were sites where students would provide honest, transparent and effortful accounts of their thoughts, feelings and experiences. However, during our analysis, we acknowledged that student submissions may have been shaped by the power relations between student and teacher. Therefore, is possible (and likely) that that we might not have gotten the "whole story" – that students were writing what they thought we wanted to hear, that some writing may have been more "academic" in style or tone than if students were left to reflect on their own without the requirement to submit it as an assignment, or that students simply weren't invested or couldn't invest in being critically reflective for other

reasons. We considered how racial and/or cultural dynamics may have played a role in shaping students' submissions, for instance. In the case of the 17/18 and 18/19 school years, faculty who assigned and graded the critical reflection submissions were white and British. We therefore recognized it was possible that students of color may have held back in their reflections around race or coloniality.

There are likely many other factors that influenced the level of honesty and transparency in student submissions that we have not accounted for. We proceeded with demarcating some interpretive closures in part because in almost all the student accounts, there seemed to be some degree of either controversial, emotional, and/or raw accounting, which initially signaled to us that students were bringing their "full selves" to this work, and that we may interpret it as such.

Interviews or carefully constructed focus groups with students, perhaps facilitated by faculty outside of the program or non-faculty, may have helped clarify to what degree students were providing open and honest accounts of their inner workings. With that said, we are predisposed to question the extent to which the researcher could ever fully know their subjects or represent them through the research process. We therefore want to emphasize to the reader that we do not intend for our interpretations of student reflections as direct representations of their original meaning or intent. We recognize that we will never fully understand the experiences of the students who wrote these reflective journals. Instead, we use our critically reflexive interpretation to inform practice. Given the significant rise in the use of reflective practice in engineering education, we hope this contribution will help illustrate the possible benefits *and* limitations of implementing critical reflection in engineering classrooms.

Our relationship to the research as educators

In critically assessing our own role as educators and researchers, we began to recognize some of our own cultural and epistemic biases, particularly in relation to students' critical reflection assignments. For instance, Gabrielle acknowledges that her feminism, fueled by her bisexuality and regular critical questioning of patriarchal and heterosexual norms, led her to have increased sensitivity to gendered language while reading students reflective diaries. She may have been more suspicious of the level of critical consciousness development among students who she found using gendered tropes. Patricia, a product of European colonialism, whose parents and grandparents were raised variously in Myanmar, India and South Africa (from originally German, British and Portuguese heritage), has developed increased sensitivities to neocolonialism within engineering education and practice. An early participant and former trustee of Engineers Without Borders UK, Patricia viewed engineering as a practical way of redressing global inequalities. Having been involved with several short-term pro-bono engineering international development initiatives, Patricia became uncomfortable with the paternalistic and product-driven aims of the schemes in which she was involved. She therefore may have been more suspicious of white, Western students' reflections that discounted or ignored the role of coloniality in shaping their experiences.

We provide accounts of our relationship to this research for many reasons, but primarily to make clear that our aims are not neutral: we aim for a more just world, and believe we have a responsibility as educators to contribute toward this goal. Studying the liberatory practices of Freire and hooks, for instance, we have worked to emulate their styles of democratic and critical

pedagogy, including assigning, as a way to build students' habits, toward scholarly practice of critical reflection and building their critical consciousness.

However, we also must recognize that students came to this program, and to their reflective work, with their own lenses and biases from all over the world. Their "lenses" are informed by the cultures and power dynamics that exist within their own communities. From our Western perspective, suggesting that students use critical theory and structuralism to question and analyze these power dynamics has felt natural to us. However, we recognize that these theoretical perspectives were born and developed in the West, and that theories and epistemic perspectives born in other parts of the world may feel more natural to students from other parts of the world.

Therefore, a lesson we take away is that when critical reflection is taught and assigned, it must be made clear that students should be encouraged and facilitated to draw from whatever frameworks make most sense to them. In effect, teachers must also be open and willing to learn from their students and adopt principles of critical pedagogy in teaching and learning, recognizing that development of critical consciousness is a continual process for all involved.

Critical reflection as assessment

At this point, we want to highlight that teaching, assessing and grading critical reflection assignments can be a radical epistemological and methodological departure for engineering faculty, who may be unfamiliar with critical theoretical perspectives [31]. In the early days of encouraging reflective practice in her students, Patricia admits she was expecting and modelling what she now recognizes as an instrumental form of reflection, distant from the questioning insight approach which necessitates exploration around moral or ethical judgement, and without a focus on surfacing implicit power relations. At the time, she did not have a solid framework or language for this critical aspect of critical reflection. Having been educated in the depoliticized, value-neutral engineering education paradigm, where questions of ethics and justice were seldom actively engaged, she found herself forced on a rapid and destabilizing journey towards more critically consciousness practice through engagement in this course. In practice, this occurred through being challenged by Gabrielle (through her role as "critical friend") about her privilege, talking with the students about their field experiences, and reading the student reflections (which gifted her powerful insights into the lived experiences and struggles of students with personal histories and identities very different to her own).

Two years on from establishing critical reflection as a core method of assessment within the SEM4ID course, all of the authors acknowledge that each new batch of critical reflections is challenging and time consuming to engage with. Reading and assessing the critical reflections of the students requires us to be fully present, engaged with our values, maintaining awareness of our interpretative lenses, and looking always for the underlying story and indications of power dynamics emerging beneath the words that are written, and whether the students are identifying these.

Furthermore, what we read from our students often re-orientates our own outlook. Traditional engineering design, both academically and in industry tends to be dualistic and requires objective and progressive trimming down of available information to the key factors that are pertinent (and ideally quantifiable!). The process of critical reflection is the opposite: it is personal in focus, and opens up so many more avenues of thought and perspective – the questioning of underlying

assumptions constantly moves the goalposts, the dimensions and nature of the field of play. We have found that this explosion of interpretation can be paralyzing at times, both for students and teachers. We have leaned on frameworks, such as Pillow's "reflexivities of discomfort" to help us navigate these challenging waters [27].

For all its good intentions, the SEM4ID MSc course itself started by reproducing an underlying attitude of Western superiority with implicit connotations of African passivity and dependence, and, in part, it was the students' reflections that helped us to see this more clearly. We did not initially ask our students to research the history of the regions, nor did we ask them to reflect on the consequences of the UK slave trade that is still very raw to some of the community members the students were working with. However, these are some of the reflections that have emerged. Though it has not always been easy to look at ourselves in the mirror and recognize our contribution to systems of oppression, we have made a conscious decision to do so, and have worked continuously to make changes within the degree program to avoid repeating our mistakes. We also acknowledge the important role that critical reflection will continue to play in holding ourselves accountable toward the goal of social justice.

Conclusions

This critically reflexive, thematic analysis indicates that assessing students through critical reflection may be a particularly valuable pedagogical strategy in contributing to the development of future engineering professionals who are better prepared to mount meaningful challenge to unjust power dynamics in their practice.

However, we acknowledge that critical reflection assignments are likely not enough on their own. Real-world, project-based work, under challenging conditions, appears to have catalyzed many of the "critical incidents" upon which students based their critical reflections.

The lessons learned from this research and our teaching praxis provide support for Nieuwma's assertion that a combination of pedagogical strategies – integrating liberal education courses into engineering curricula; embedding social justice content into technical courses; increasing critical learning thresholds around social justice through strategies such as discussion-centered teaching, small class sizes and engaging real world problems; experiential learning; and liberative pedagogies – can promote social justice in engineering curricula.

We made strides in this direction with the SEM4ID program, through a combination of liberal education coursework, small class sizes, experiential, project-based learning and critical reflection assignments. Our experience leads us to believe that embedding critical reflection into engineering curricula is necessary to push students to do the work of deconstructing dominant ideologies on their own, in their own way. Additional research would be valuable to understand whether students' critical "reflexes" remain with them after they graduate, as they progress as practitioners.

In addition to our analysis on critical pedagogical strategies, we hope this honest accounting of our methodology helps to extend the work of qualitative research in engineering education research and give future engineering education researchers an opportunity to explore and expand on postmodernist approaches to reflexive qualitative research.

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