Interdisciplinary Pedagogy for Ethical Engineering and Responsible Innovation

by

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This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Statement of Contributions

Alexi Orchard is the sole author for all sections of the dissertation, excluding sections 1.1, 1.3, and 2.1. Alexi is the lead author of sections 1.3 and 2.1, and the second co-author on section 1.1.

This thesis consists in part of five manuscripts written for publication. Exceptions to sole authorship of material are as follows:

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Abstract

Since the early 2000s, North American engineering and technology regulatory associations have mandated that accredited engineering programs in higher education must fulfill teaching outcomes including ethics, equity, and the impact of engineering on society and the environment. Though this mandate propelled more research and pedagogical innovation in engineering ethics education (EEE) over the last two decades, some engineering programs have been slow to acknowledge and incorporate perspectives from outside of the engineering field, such as those situated in the humanities and social science (HSS) disciplines. There is an awareness that HSS knowledge and interdisciplinary expertise is well-positioned to enhance the teaching and research of engineering ethics and related topics, such as equity, diversity, inclusion, and social and environmental justice and, as this dissertation will show, there are multiple beneficial ways that this can happen.

This dissertation examines and demonstrates multiple models for interdisciplinary ethics pedagogy that integrates HSS-based methods and approaches into the engineering curriculum, including workshops and cross-disciplinary curricular interventions. Specifically, this work focuses on how critical design – an arts- and humanities-based research-creation method that emphasizes critical thinking and reflection on the social, psychological, and ecological impacts of technology (Dunne & Raby, 2013) – can be a creative and effective approach to enhancing EEE. This work also incorporates methods and principles informed by the field of Science and Technology Studies (STS), such as responsible innovation (Stilgoe et al., 2013), value sensitive design (Friedman & Hendry, 2019), design justice (Costanza-Chock, 2020), and data feminism (D’Ignazio & Klein, 2020), arguing that they are promising approaches for this purpose as well. A significant contribution of this research is the development of curricular materials using these approaches.

Considering the negative and harmful impacts stemming from the tech industry over the last several years, it is crucial for engineering students to learn and participate in more rigorous ethical deliberation as part of the engineering design workflow. This dissertation argues that by engaging in more interdisciplinary ethics pedagogy, the EEE curriculum will be better prepared to support the ethical development of future engineers.

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Abbreviations	Definitions
AAAI	Association for the Advancement of Artificial Intelligence
ABET	Accreditation Board for Engineering and Technology
ACM	Association for Computing Machinery
AI	Artificial Intelligence
AIES	Conference on AI, Ethics, and Society
ARSGs	Augmented Reality Smart Glasses
ASCE	American Society of Civil Engineers
ASL	AI Social License
BIS	Bachelor of Interdisciplinary Studies
BME	Biomedical Engineering
CEAB	Canadian Engineering Accreditation Board
CML	Critical Media Lab
Co-op	Cooperative Education
CREATE-SEED	Collaborative Research and Training Experience in Sustainable Electronics Design
CRIT	Council for Responsible Innovation and Technology
CSR	Corporate Social Responsibility
CSTV	Centre for Society, Technology, and Values
EAAI	Educational Advances in Artificial Intelligence
ECE	Electrical and Computer Engineering
EDI	Equity, Diversity, and Inclusion
EEE	Engineering Ethics Education
ESG	Environmental, Social, Governance
FAANG	Facebook, Amazon, Apple, Netflix, and Google
FAccT	Conference on Fairness, Accountability, and Transparency
FRT	Facial Recognition Technology
GANs	Generative Adversarial Networks
HCI	Human-Computer Interaction
HSS	Humanities and Social Sciences
ICTC	Canadian Information and Communications Technology Council
IEEE	Institute of Electrical and Electronics Engineering
IPFD	Innovation Problem Finder Dartboard
JRI	Journal of Responsible Innovation
MAANG	Meta, Amazon, Apple, Netflix, Google
MBA	Master of Business Administration
ML	Machine learning

PIMS	Product Intervention Model for Stigma
RI	Responsible Innovation
RPI	Rensselaer Polytechnique Institute
RRI	Responsible Research and Innovation
STEM	Science, Technology, Engineering, and Math
STS	Science and Technology Studies
STV	Society, Technology and Values
SWE	Software Engineering
SYDE	Systems Design Engineering
TRU	Thompson Rivers University
VSD	Value Sensitive Design

Preface

In my senior year of high school, my final book report for English Language Arts was on *The Big Disconnect: The Story of Technology and Loneliness* by Giles Slade. We were meant to choose something from Canadian fiction, but I persuaded the teacher to let me choose this Canadian, non-fiction author who had written on a topic that appeared relevant to what was happening at the time. Reading *The Big Disconnect* was a chance encounter, and I found it while perusing McNally Robinson, still the nicest bookstore in Saskatoon, Saskatchewan. Growing up in Delisle, a town of 1,000 in rural Saskatchewan, I had limited exposure to news and research that investigated the social paradigms around smartphones and social media platforms. Still, I was not immune to the emerging anxieties around how our time and attention was being usurped by digital technologies. By that year, 2014, most of my friends had their own Facebook accounts and cell phones, and we started hanging out with each other, with our phones, sitting silently in the same room while scrolling through photos and watching YouTube videos. This is the first of two parallel stories; the second is related to my path through post-secondary education.

Before knowing exactly what it was, I originally wanted to study Science and Technology Studies (STS) and was accepted to the program at the University of Alberta. This path would have been appropriate to my interests at the time, but an athletic opportunity redirected this plan, and I ended up studying Business Administration for two years at Olds College, Alberta, and then enrolled in the Bachelor of Interdisciplinary Studies (BIS) program at Thompson Rivers University (TRU) in Kamloops, British Columbia. Over this time, the pervasiveness of social media and digital interactions had only increased and, not as a scholar (yet) but as a young person, I was increasingly concerned about how my friends and I were using this technology and how it was impacting us emotionally, psychologically, and interpersonally. We didn't know any better, neither did our Gen X parents, and more research on these issues was just coming to the forefront.

Despite my brief foray into Business Administration, I had not narrowed down what I was interested in studying, which was my motivation for joining the BIS program at TRU. The BIS program required that I have a Concentration (I chose Communications), while also fulfilling breadth requirements. For two years, I took breadth courses in History, Film, Sociology, Political Science, English, Environmental Economics, Business, and others (though mostly in the humanities and social science (HSS) disciplines); in hindsight, these were extremely generative years for a student who would eventually go on to study interdisciplinary technology contexts – I learned something new every day, was constantly challenged to understand how different perspectives viewed problems, and met people who always wanted to chat about thought-provoking and difficult ideas. The final project of the BIS program, an undergraduate thesis that incorporated at least three disciplinary perspectives, was where my growing anxieties around technology and my education converged. My undergraduate thesis, "Perceptions of Data Privacy in the Age of Social Media Addiction" brought together a cross-disciplinary conversation that traversed areas within media studies, behavioral psychology, and privacy studies. In brief, I hypothesized that people who exhibited symptoms of compulsive social media use had lower rates of digital literacy and were less likely to protect their privacy online. Admittedly, this work was not nearly as methodologically advanced as the topic called for. But more importantly, it was a formative experience which convinced me of something that has guided my research trajectory and my thinking about the world more generally since then: complex problems, such as society's continued relationship with and reliance on digital technology, do not belong to and cannot be fully understood within a single disciplinary lens. This argument has been discussed at length in studies on interdisciplinary research.

Before engaging with that literature, which further situates and motivates my dissertation work, I will provide an important clarification: readers of this dissertation who have been trained within the siloed disciplines that tend to characterize the twenty-first century university will likely find the mixture of approaches, writing styles, and research contexts contained within this dissertation to be unsettling at first. Though there is a diverse, potentially uncomfortable, blend of perspectives and methods on display, I hope that the overall payoff is generative and reveals that these are questions and problems that require cross-disciplinary approaches and perspectives.

In this dissertation, I will be primarily focusing on engineering ethics education through my lens as an interdisciplinary, humanities-trained scholar. At its core, this dissertation examines and demonstrates multiple models for developing an interdisciplinary ethics pedagogy informed by HSS perspectives for engineering and technology students. This work is also an extension of my master's research project: "Embedding Ethics and Empathy in the Engineering Curriculum" (2020), in which I analyzed the ethics and social implications-related content and deliverables in two Systems Design Engineering (SYDE) capstone courses at the University of Waterloo. This prior research and the insights I have gained from my collaborators, mentors, and interactions with the tech community more broadly provided essential context and guidance for me to navigate the ecosystem of engineering education at Waterloo as it became my focus of study for this dissertation.

The experience of teaching engineering students firsthand has also been important for this research. In 2022 and 2023, I taught Electrical and Computer Engineering (ECE) students in the first year "Communication for the Engineering Profession" courses. More details on my teaching experience are sprinkled throughout the dissertation, but a critical reflection for me to share at the outset is how much these courses – which are writing and composition courses for engineering students taught by English and Communication Arts instructors – seemed to illustrate the false dichotomy of me being a "humanities person" and the ECE students being "not-humanities people." For these students, this first year course is the only one not in a large lecture hall (only 25 students per section) and where the instructor will have regular personal interactions with each student. This course focuses on writing and communication, skills that are perceived by some as "soft" (though humanities scholars tend to prefer "transferrable skills") and less relevant to the technical, hard science of engineering. Despite the ECE students only having been at Waterloo a few days (as this course typically takes place in their first term), they will have already adopted their new identity as an engineer. To be clear, I hope students feel excited and encouraged to be part of the engineering community. With that said, in my class, and in my research and relationships with other colleagues generally, I try to avoid drawing "us versus them" divisions. As Corey Campion argues, humanities comprise the study of humanity, including human morality, purpose, and experience, and regardless of discipline or background, "all people contribute to and can find meaning in the humanities" (Campion, 2018, p. 434). Engineers are humanities people, though some probably don't even know it. At the very least, I hope never to communicate through my teaching and research that students *can't* be humanities people. At the very most, I hope to communicate to students that regardless of any aspect of their identities, they can contribute to knowledge-making and, furthermore, it is their unique identities that will empower them to expand disciplinary boundaries to learn and discover new things.

During my graduate studies, some people have been confused by or even opposed to my investigation of engineering education, given that I was not engineering-educated myself. This kind of assumption brings me back to the literature on interdisciplinary research. While disciplines are created to focus on discrete subject matters and for institutions to organize their production of knowledge, no subject or activity happens in isolation; whether it is overt or not, disciplinary research has implications across boundaries (Roper, 2021). Despite the awareness that no discipline works in isolation, "disciplinarians" or specialists are typically held in higher regard than generalists, who may be perceived as disloyal to their discipline (Klein, 2008; Ylijoki, 2022). The way that universities are broken into separate disciplines "creates a false impression that the real world is divided into fragmented parts" (Bui &

Baruch, 2010, p. 231). These perceptions about interdisciplinary work and divisions between types of knowledge production are exclusionary and can have a significant impact on whether different kinds of knowledge production can come to fruition and demonstrate their value.

Although the rhetoric of higher education institutions promotes interdisciplinary collaborations, universities typically do little to facilitate these efforts and still emphasize outcomes at departmental levels (Roper, 2021). Lieberknecht et al. and Uddin et al. both found that interdisciplinary research is often more visible and supported in Science, Technology, Engineering, and Math (STEM) fields than in HSS disciplines (Lieberknecht et al., 2023; Uddin et al., 2021). Collaborations can also be hindered by the latent gender division already present in academia: Ylijoki found that women in HSS disciplines were typically given less authority in interdisciplinary collaborations when working with male scholars in technical fields, manifesting their "double marginalization" based on both gender and discipline (Ylijoki, 2022, p. 363). In addition to (or as a result of) structural obstacles to interdisciplinary research, it can be emotionally taxing to sit in what Manathunga calls an "in-between space," that is creative and productive but unrecognized by the elite of one's nearby disciplines (Manathunga, 2009, p. 133; Ylijoki, 2022).

At different times throughout my education, I experienced all these obstacles. But I have also enjoyed the benefits of interdisciplinary learning, such as developing dialectical and systematic thinking, cooperation and collaboration, ethical reasoning, critical thinking, and written and oral communication skills (Moirano et al., 2020; Robinson et al., 2016;

Roper, 2021). Multiple scholars have argued that interdisciplinary methods are essential to support collective creativity and highly relevant to solving open-ended problems and strategic innovation (Moirano et al., 2020; Parjanen & Hyypiä, 2019; Runco, 2017). I present these strengths not just to make me feel good about myself, but also to highlight that while the skills developed through collaborative, interdisciplinary learning can be useful in multiple ways, educators face complex pedagogic challenges in integrating these opportunities and competencies into their curricula (Amor, 2014; Hutchison, 2016; Moirano et al., 2020). To this end, one goal of this dissertation is to provide insight and support for educators who are interested in interdisciplinary pedagogy. The work presented here is not exhaustive, but it is a detailed account of the opportunities, obstacles, successes, and failures that came with attempting to teach and research across disciplinary boundaries.

By sharing these two parallel stories – my early experiences and anxieties with digital technology and my path through post-secondary education – I hope to bring some clarity to the unlikely trajectory and outcome of pursuing a Ph.D. in English on the topic of engineering and technology ethics. It can feel complicated to be in a generation that lived through the cultural transition toward ubiquitous smartphones and social media. These feelings motivated my interest in *The Big Disconnect* and my later explorations around data privacy and compulsive social media use. The design and uses of digital technologies, and the contexts in which they are designed and used, has a tremendous impact on life around the world. With that said, it would be remiss to suggest that the recent impacts on society are unprecedented given that the development of media, or *new* media, from the rise of clockwork during the Industrial Revolution to the present, have always evolved by and through human activity, signalled significant social, economic, and cultural changes, and resulted in some kind of anxiety and cultural disorientation about what it means to participate in social life (Gitelman, 2008; Lister, 2010). But it is largely in the last two decades that engineers and technologists have more rigorously reflected on and questioned the context of their work, even though media theorists and scholars (sometimes found studying in English Departments) such as Lisa Gitelman, Marshall McLuhan, and Sherry Turkle have observed adverse effects of media and digital phenomena for decades.

The culture of engineering and computer science is slowly changing to reflect the critical attitudes more often found in HSS disciplines; this change is driven by the efforts of interdisciplinary computing experts such as Ruha Benjamin, whose book *Race After Technology: Abolitionist Tools for the New Jim Code* has become an essential text for understanding the racist underpinnings of machine bias and directing technologists toward more socially-conscious tech development (Benjamin, 2019). This work has shown that leveraging HSS perspectives, including but not limited to research in media studies, history, and sociology, is critical to uncovering, mitigating, and preventing harm by and through technology design. Engineering educators need to incorporate contemporary approaches to ethical and social considerations in their pedagogy that are informed by Benjamin's and others' novel research. I anticipate that the research and creation of curricular materials through this dissertation will be timely and useful for that task. I hope that both educators and students will gain from bringing interdisciplinary perspectives to bear on their design and engineering problems, which are invariably interdisciplinary themselves.

This dissertation is written in fulfillment of the degree of Doctor of Philosophy in English Language and Literature, yet four of the five published manuscripts in this dissertation were written for engineering education and computer science conferences, and the fifth was written for a social science journal. This dissertation utilizes the integrated or "sandwich" style thesis, where previously published manuscripts are inserted as their own subsections and unpublished interstitial comments, including introductory and concluding sections, are used to provide additional context and connect ideas through each full chapter. Though the previously published subsections represent the versions of record that will be found elsewhere, minor adjustments have been made to confirm to APA and dissertation formatting guidelines, as well as to correct any typos that made it through the editing process unintentionally. I hope that the reader will forgive these small discrepancies.

Lastly, if you are feeling daunted at the prospect of trying to account for multiple angles on this research, there is some good news: this dissertation is written for a broad academic audience with carefully defined jargon and plenty of examples. The only thing that a reader will need is an open mind about how different perspectives can be equally as valid in bringing unique knowledge and expertise to bear on complex problems.

Chapter 1: Curricular, Cultural, and Institutional Factors of Engineering Ethics Education

> "The laboring man has not leisure for a true integrity day by day…his labor would be depreciated in the market. He has no time to be anything but a machine…The finest qualities of our nature, like the bloom on fruits, can be preserved only by the most delicate handling. Yet we do not treat ourselves nor one another thus tenderly." – Henry David Thoreau, *Walden*, 1854

In September 2019, I arrived at the University of Waterloo, where I was drawn to study for my master's degree in English Language and Literature at the Critical Media Lab (CML). Admittedly, I didn't know what to expect out of an English Department initiative that studies technology. In their own words, the CML is "a cross-disciplinary research-creation initiative […] that fosters the creation of new media projects that explore the impact of technology on society and the more-than-human world" (Critical Media Lab, n.d.). Soon enough, I saw that the CML did have some interesting and sometimes radical approaches to studying technology: in the years prior, students at the CML had smashed computers with sledgehammers, written obituaries for their dead cell phones, and made Twitter accounts for a local contingent of tech-savvy dairy cows, among many other compelling projects. It was an introduction to thinking creatively and critically about technology through media theory, critical design, and digital rhetoric in a way that I never had before; in a way that questions, as Thoreau writes, "be[ing] anything but a machine."

Though I was incredibly fascinated and glad to be part of the CML, I thought there must be more ways of thinking about technology and society at the university, including some that engaged with students and faculty in technical domains. In the same term, I emailed the Director of the Centre for Society, Technology, and Values (CSTV) to learn about the opportunities to engage with the topics and people there. The Director, a trained historian of computing and technology, invited me to sit in on their courses at any time. I started auditing the night classes of "Introduction to Society, Technology, and Values (STV)" as a graduate student among dozens of undergraduate, mostly Engineering, students. Through small talk made before in-class group exercises, I learned that many Engineering students enrolled because it is a common elective that fulfills their requirement for a course on the social impacts of technology. Some students were thoughtful and present in class, and others tended to work on assignments from other classes or play Go on their laptops.

Five years later, my perspective is much different, but I remember thinking at the time – how can the impact of technology on society *not* be an engaging and essential topic, especially if you're pursuing a degree that will make you a direct contributor to that impact? But many students in that class appeared to have other priorities. I don't want to paint in broad strokes and color all engineers uninterested in the social and ethical impacts of technology, so to speak – it would be grossly untrue of many excellent people I have met at Waterloo and beyond. Having said that, sitting in this class was like sitting at the edge of a fast-flowing river, where I could spot some students sailing, others swimming, and a few just barely staying above the water. The combination of an intense course load, competition of getting a cooperative education (co-op) job, and pressure to take on innovative side projects was all that could let a student get swept away. Nevertheless, this hustle and grind attitude is expected of Waterloo students.

Waterloo is known worldwide for its Engineering and Computer Science programs, as well as its co-op program – where students can get up to six work experiences (also described as "work terms") at different companies and organizations before graduating from their program (University of Waterloo, 2019a). It has cultivated its reputation as a leader in engineering and technology through its involvement with local tech firms and start-ups, including two large venture capital funds. Waterloo has been described as "Canada's most famously entrepreneurial university" (MacNeil et al., 2024, p. 12), renowned for its technological prowess in both academic and public venues (including the 2023 biographical comedy-drama film on the rise and fall of Blackberry – one of the most well-known tech corporations founded in Waterloo), and is a frequently studied site of entrepreneurial practice and pedagogy (Gillmor, 2012). As part of this community, students are encouraged to adopt the engineering identity of a superior technical problem solver (Downey, 2008). As many researchers, educators, and technology critics have observed, this identity tends to prioritize the question of '*can we do it?*' with less critical reflection on '*should we do it?*'

Despite their economic success, world renown, and narrative of progress, western universities such as Waterloo are driven by capitalist and colonial values (Lodoen, 2021); these values pervade multiple aspects of the student experience, including their coursework, extra-curricular activities, and even dormitory living spaces (MacNeil et al., 2024). The extreme emphasis on technical innovation also tends to overshadow other university initiatives, such as mental health support (Woo, 2019). Lastly, as I experienced in "Introduction to STV" and Chapter 1 will demonstrate, the overall learning environment in which engineering students are immersed during their years of study at Waterloo does little to incentivize students to engage with critical perspectives on the social and ethical impacts of technology (often found in the humanities and social science disciplines) and, therefore, does not prepare them to navigate the complexities and tensions they will encounter in their careers.

These cultural and educational factors have influenced students and educators not only at Waterloo but across North America. In a 2003 survey study, McGinn identified a gap between the levels of engineering-student expectation and practicing-engineer experience with being confronted by ethical issues in engineering work. This study surveyed 516 Stanford undergraduate engineering majors and 285 practicing engineers between 1997 and 2001 (McGinn, 2003). Over 80% of the practicing engineers agreed that engineering students are likely to encounter significant ethical issues in their career and should be exposed to formal education about how to approach them; however, only 14.9% of engineering students indicated that they had learned anything specific about ethics and social responsibility from their engineering instructors, aside from the sentiment that there is "more to being a good engineering professional in today's society than being a state-of-the-art professional" (McGinn, 2003, p. 525). In a follow-up to this survey study in 2018, McGinn argued that this disconnect still exists and more pedagogical methods for engineering ethics education (EEE) are needed (McGinn, 2018). The concerns around inconsistent ethics curricula have persisted in the last decade: other survey and interview studies have also found that engineering students are unsatisfied with their limited knowledge of ethics (Holsapple et al., 2011), feel unprepared to address ethics issues should they arise in the workplace (Cech & Finelli, 2024), and in some cases, appear apathetic about the moral dilemmas that their careers may bring (Goldenkoff & Cech, 2024; Niles et al., 2020).

Since the Accreditation Board for Engineering and Technology (ABET) and Canadian Engineering Accreditation Board (CEAB) introduced new requirements for teaching engineering ethics in the early 2000s,[1] the engineering ethics education (EEE) research community has grown significantly (Bairaktarova & Woodcock, 2017; Burke et al., 2020; Diduch et al., 2012). With this growth, there has been more attention to the design and assessment of learning outcomes and the evaluation of different pedagogical methods to support instructors in EEE; still, more work is needed.

While these problems are not isolated to the Waterloo community, it is appropriate for my research project to be situated at Waterloo – where I researched, implemented, and evaluated approaches for teaching ethics and related topics in the uniquely competitive, innovation-motivated context that is Waterloo. By acknowledging this context, the first

[1] The ABET introduced ethics into their accreditation requirements in 2000 and the CEAB followed shortly after. Prior to 2008, ethics was included under the "Professionalism" Graduate Attribute in the CEAB. In 2008, the CEAB added equity to the requirements, naming "Ethics and Equity" as the 10^{th} Graduate Attribute (Rottmann & Reeve, 2020).

chapter sets the stage for the cross-disciplinary pedagogical interventions developed through the CML in Chapters 2 and 3.

Throughout the dissertation, I will refer to engineering ethics, ethical and/or responsible design, responsible innovation (RI), and related terms that represent social and environmental factors in engineering and design. In some cases, I will use these terms to describe, for example, how a multitude of learning outcomes related to EEE are not accounted for in some curricula. But first, it is useful to provide the standard definition for engineering ethics as it is currently described in academic and professional circles.

Engineering ethics refers to the professional code of conduct and discipline-specific knowledge, sensitivity, and reasoning skills that graduates who complete their Professional Engineering (P.Eng) certification have demonstrated their competency of and willingness to uphold in professional engineering practice (Dym et al., 2014; Engineers Canada, n.d.; Poel & Royakkers, 2011). Most professional engineering societies have a specific code of ethics that contain standards and commitments that engineers agree to abide by with respect to stakeholders including clients, the profession, the law, and the public (Dym et al., 2014). The primary purpose of a code of ethics is to provide guidance for dealing with potentially conflicting obligations to these different stakeholder groups. Across different societies, such as the Institute of Electrical and Electronics Engineers (IEEE) and the American Society of Civil Engineers (ASCE), the codes of ethics are similar in terms of their emphasis on integrity and honesty. The codes tend to diverge, however, with respect to the different styles and disciplines of engineering (Dym et al., 2014). For instance, most civil engineers who work at companies (rather than for a government agency) obtain their work through public, competitive bidding and often encounter conflicts of interest in this space. Conversely, electrical engineers more often work in the private sector developing products. Hence, these practices produce different organizational cultures and ways of expressing ethical standards (Dym et al., 2014).

Additionally, in Canada, one must become licensed by Engineers Canada, the national regulatory body for engineers, to be designated as an "Engineer" in their job (Engineers Canada, 2022); in the United States, this is not required (i.e., one can hold the title of Software Engineer without becoming licensed or belonging to a particular association). Canadian graduates can also become associated with the IEEE, for example, in addition to their provincial or national governing body. I draw attention to the different associations because the student participants in Chapter 1 come from a range of engineering disciplines; having said that, I proceed with the assumption that they are all at least familiar with the Engineers Canada and/or Professional Engineers of Ontario Codes of Ethics. Each subchapter indicates the disciplines of the students that participated and provides additional context on what engineering ethics education and experience they had at the time of the study.

Though it is important for students to know their professional code of conduct, a persistent critique of engineering ethics is that professional codes often convey a narrow definition of ethics that does not address engineers' roles in systemic or environmental contexts (Conlon & Zandvoort, 2011; Davis, 2006; Herkert, 2001; Hipp, 2007; Paul et al., 2023). Though there is a specific definition of "engineering ethics" in a professional context, as described here, I agree with multiple scholars and educators in that the discussion about engineering ethics needs to consider a more holistic framing around what topics EEE can include, such as equity, diversity, inclusion, social impact, environmental justice, and responsible innovation (Love et al., 2021; Paul et al., 2023).

I will also describe two of the Graduate Attributes contained in the CEAB requirements that I refer to throughout this dissertation. "Ethics and equity" is one of the 12 Graduate Attributes included in the CEAB requirements that I will refer to. This term is defined as "an ability to apply professional ethics, accountability, and equity" (Engineers Canada, 2016). "Impact of engineering on society and environment" is another Graduate Attribute relevant to this project, defined as:

> "an ability to analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship" (Engineers Canada, 2016).

Bearing in mind the specificity of engineering ethics across different associations' professional codes, it is understandable as to why these two attributes are described separately in the CEAB requirements. However, I would argue that there is an inextricable relationship between them in that an engineer's ability to enact their knowledge of "ethics and equity" rests on their understanding of the "impact of engineering on society and environment." In this dissertation, I will reserve usage of "engineering ethics" to indicate professional codes of ethics and will refer to "ethics," "ethics and related topics," and more specific terminology where appropriate (e.g., social and environmental justice) to indicate a broader notion of the concepts that are relevant and desirable to include in EEE (Love et al., 2021).

Chapter Overview

Chapter 1 contains three published conference papers, each with a literature review of pedagogical approaches in EEE, descriptions of cross-disciplinary interventions with the goals of enhancing EEE, and survey study results related to Waterloo specifically. These papers branched out from a main project, funded by a Waterloo Interdisciplinary Trailblazer Grant (Responsible by Design: A Bottom-Up Approach to Fostering a 'Tech for Good' Ethos in the Innovation Ecology, 2020-2022, led by Marcel O'Gorman and Jen Boger) that sought to investigate methods for injecting ethics and responsible design into the engineering curriculum. Following each paper, I include interstitial comments to contextualize how each study informed the next iteration of the research project.

In Paper 1, *The Influence of Curriculum and Internship Culture on Developing Ethical Technologists*, we examine the influence of Waterloo's entrepreneurial culture on future engineers and technologists as it manifests through the "Cali-or-bust" phenomenon, the drive for students to obtain Silicon Valley-based co-op placements as if those jobs are the only viable option for employment. This paper also introduces one strategy for embedding the CEAB Graduate Attribute "ethics and equity" in first year Engineering Communication courses at Waterloo: a course design structured as a fictional co-op appointment that requires students to produce a variety of professional communication materials related to accessibility tech. This pedagogical strategy is analyzed through the lens of a survey study of Electrical and Computer Engineering students who participated in these courses between 2018 and 2020.

In Paper 2, *An Analysis of Engineering Students' Responses to an AI Ethics Scenario*, we conducted a second survey study asking Systems Design, Biomedical, and Mechatronics Engineering students about a hypothetical AI ethics scenario wherein a facial recognition model fails to recognize dark-skinned faces. The results show 77.4% of students identified the technical failure of the model while only 17.0% of students identified any ethical concerns related to the scenario. Crucially, the varied responses to this scenario demonstrate the need for a robust sociotechnical ethics pedagogy, one where students are taught how to make explicit connections between technical decision making and the social and ethical considerations that co-exist in the engineering design process.

In Paper 3, *Opportunities and Obstacles for an Embedded STS Program in Engineering*, a final case study examines the curricular, cultural, and institutional conditions surrounding Waterloo's Centre for Society, Technology, and Values. Though the Centre provides the most formalized offering for teaching ethics, equity, and the impacts of technology on society for engineers at Waterloo, this study argues that when ethics is not integrated across the curriculum, students have limited opportunities to see the importance of and learn how to practice ethical thinking in their degree and profession at large. This study speaks to obstacles and opportunities related to engineering ethics, institutional accreditation, and cultural values that are of interest to engineering educators across North America.

Taken together, and considering the broader scholarly literature within which the Waterloo-specific case studies are framed, these three papers illustrate several disciplinary perspectives and pedagogical approaches that guide the teaching of ethics and related topics to North American engineering students at large. The papers in Chapter 1 also observe some of the obstacles facing educators in developing and assessing ethics-related pedagogical methods; obstacles which are compounded by the extreme emphasis on the competitive co-op culture at Waterloo specifically. The overarching research question of Chapter 1 states, "What are the curricular, cultural, and institutional factors of engineering ethics education?" As their direct contributions to this dissertation, these papers and the accompanying interstitial sections provide insight into the factors present at Waterloo between 2018 and 2024 that informed my own and my colleagues' cross-disciplinary, ethics-related pedagogical interventions as detailed in Chapters 2 and 3. These studies all received research ethics clearance from a University of Waterloo Research Ethics Board (REB #42610; REB #43726).

While Chapter 1 comprises of three papers addressed to engineering and computer science audiences (albeit from a pedagogical angle), Chapter 2 focuses on how perspectives from humanities and social science (HSS) disciplines, such as critical design and RI, can contribute to the engineering curriculum through the critical contextualization of ethical issues. Both Chapters 2 and 3 address research questions: "How can humanities and social science (HSS)-based methods and approaches – such as critical design, responsible innovation, value sensitive design, design justice, and data feminism – enhance the engineering ethics curriculum?" and "How do we design specific interventions for this purpose?" Chapter 2 contains one published, co-authored journal article, "Fostering Responsible Innovation with Critical Design Methods" (Paper 4), which argues for the integration of critical design – an arts- and humanities-based research-creation method for thinking critically about the impacts of technology and design – to develop an ethos of RI in engineering ethics curriculum. In this context, we define RI as the "ethical design and development practices that account for social, psychological, and environmental impacts of technology" (Orchard & O'Gorman, 2024, p. 2). By providing examples from workshops and cross-curricular interventions, Paper 4 positions critical design as a novel pedagogical approach to examine values, assumptions, and power asymmetries about and within technology and society, as well as enhance students' creativity, critical thinking, and communication skills.

The research presented in Paper 4 is an extension of the Waterloo Interdisciplinary Trailblazer Grant and was also supported by a Social Sciences and Humanities Research Council Insight Grant (Critical by Design: Fostering Responsible Innovation with Critical Design Methods, 2022-2026, led by PI: Marcel O'Gorman).

Following Paper 4, I explore the intersections between critical design, RI principles, and EEE approaches in an effort to bridge their goals and approaches more explicitly. Researchers have embedded RI into EEE previously, specifically Stilgoe et al.'s conception of “responsible anticipation” (Stone et al., 2020; van Grunsven et al., 2023). Responsible anticipation, the first dimension of Stilgoe et al.’s framework for RI, is defined as “the forward-looking activity of asking ‘what if…’ questions…to consider contingency, what is known, what is likely, what is plausible and what is possible” within the context of the innovation process (Stilgoe et al., 2013, p. 1570). Critical and speculative design methods generate this type of future thinking and, as I will argue, can complement RI pedagogy in the context of EEE. However, some RI scholars are cautious of critical design’s flair for the provocative, having argued that responsible anticipation should avoid dramatic scenarios that are too detached from reality (van de Poel, 2016; Van Grunsven, 2022). This section of Chapter 2 will explore the tension between critical design, RI, and EEE, provide examples to demonstrate their potential alignment, and suggest directions for future research.

In the last chapter of this dissertation, I focus on three pedagogical interventions that I have led during the last two years of my Ph.D., both individually and as part of the CML research team. The first intervention is a value sensitive design workshop that I co-facilitated with Rebecca Sherlock for a first year Management Engineering Communication course in March 2023. The second is a data equity workshop that I designed and conducted individually for third year Systems Design Engineering course in March 2023. These workshops are two of 14 that the CML research team conducted between 2021 – 2023 and represent our ongoing research toward integrating HSS perspectives and methods into engineering curriculum.

In total, Chapter 3 contains one published conference paper, “The Innovation Problem Finder Dartboard: Embedding Critical Design into the Engineering Workflow” (Paper 5). The Innovation Problem Finder Dartboard (IPFD) is a novel critical design pedagogical tool, inspired by Matt Malpass’s definition of critical design as a method of “problem *finding,*” which I invented as a critical thinking exercise for students to envision downstream consequences of technology. This work represents the third pedagogical intervention that I designed and facilitated in the last two years. The dominant cultural identity of engineering is often described as a “problem solver,” though EEE research has underscored the need for engineers to also be problem *definers* who think critically about problem framing, including the social and ethical context and the values, biases, and assumptions of multiple stakeholders in the problem space (Claris & Riley, 2012; Flemming & Johnston, 2020). The IPFD is a direct response to this need, and, in Fall 2023, I implemented the IPFD in my first-year course, Communication for the Engineering Profession, to help students generate topics for their research projects that were related to equity, diversity, and inclusion, and social and environmental justice issues.

My recent work in Paper 5 and the Conclusion brings many of the topics and experiences through my dissertation and Ph.D. to a head. In Chapter 1, I studied multiple individual courses, a program, and the culture at Waterloo that, in their own ways, facilitate and/or impede progress toward embedding ethics into the engineering curriculum more meaningfully. In Chapter 2, I helped design and conduct a critical design-focused, cross-disciplinary curricular intervention and multiple RI workshops with engineering students. In

Chapter 3 and Paper 5 specifically, I describe and evaluate my own curricular approach and workshop interventions as a humanities-based instructor/facilitator in engineering classrooms. In the last four years, my work has engaged, incorporated, and been inspired by perspectives from humanities, social science, engineering, and computer science fields; in particular, I have been motivated by the interdisciplinary areas that operate across them, such as AI ethics, feminist data studies, science and technology studies, communication and media theory, responsible innovation, privacy and surveillance studies, climate science, and entrepreneurship and innovation studies. In this dissertation, ethics and education are the stitches that join these fields and topics together, creating a patchwork of multiple types of knowledge and skills that I hope will help students to become more open-minded, inclusive, and therefore more effective, and successful engineers.

1.1 Paper 1: The Influence of Curriculum and Internship Culture on Developing Ethical Technologists: Case Study of the University of Waterloo[2][3][4]

1.1.1 Navigating Responsible and Ethical Technology Between the Classroom and Industry

Advances in computer and digital technologies have ushered in a new era of late-stage capitalism, which Frederic Jameson characterized in terms of "unprecedented levels of mass production, leading to ever greater profit-margins for multinational corporations" (Jameson, 1991, p. xix). Increased productivity has made technology ubiquitous; according to W. S. Brown, the ubiquity of information technology has increased at an exponential rate since the inception of the internet (Brown, 2016). The omnipresence of digital technologies in quotidian life has also increased academic and public interest in the field of technological ethics, which promises to develop strategies for critically examining, addressing, and mitigating pressing contemporary social problems such as algorithms that exacerbate racial biases, the exploitation and misuse of sensitive user data, and the development or appropriation of technologies for mass surveillance (Brown, 2016; Garvie & Frankle, 2016; Misa et al., 2003; Zhang, 2018). In the face of these issues, educational institutions need to

[2] Truax, C., Orchard, A., & Love, H. A. (2021). The influence of curriculum and internship culture on developing ethical technologists: A case study of the University of Waterloo. *2021 IEEE International Symposium on Technology and Society (ISTAS)*, 1–8. https://doi.org/10.1109/ISTAS52410.2021.9629124

[3] This study received research ethics clearance from a University of Waterloo Research Ethics Board (REB #42610).

[4] See Appendix A for the full study demographic results and survey instruments for Chapter 1 (including Papers 1-3)

prepare future technologists to navigate common ethical design decisions, assumptions, and pitfalls, and to take responsibility for practicing ethical design in the technology industry.

1.1.1.1 The Importance of Classroom Ethics Education for the Technologist

The notion of the deontological responsibility of the engineer is not novel – every student who walks through the door of a Canadian technical university is told the story of Theodore Cooper's design missteps that resulted in the deadly 1907 collapse of the Quebec Bridge (Pearson & Delatte, 2006). However, recently philosophers like Michael Walzer and Vivian Weil have argued in favor of shifting the focus of technical ethics away from a theoretical outsider perspective so that students directly engage with ethical design considerations rather than hear about them in the context of past events in which students are not involved (Doorn, 2012). The ethos of this moral approach is to shift the locus of responsibility from outsiders who are meant to hold others [technologists] responsible to technologists themselves who assume individual responsibility (Doorn, 2012). Shifting the responsibility of ethical technology design to individual technologists is, in many ways, a positive progression. However, without sufficient ethical education, individuals risk perpetuating existing patterns of unethical and inequitable technology development. For example, as Wagstaff notes, machine learning researchers who lack training in understanding social contexts often fail to create models that have real world applicability or merit (Wagstaff, 2012); Tomayko similarly notes that computer science education "is a story of academics struggling to fulfill industry needs with almost no support from computer science curriculum designers. It is a story of industry finally winning over some of academia to teach software engineering rather than vanilla computer science" (Tomayko, 1998). As the moral paradigm shifts to expect the individual technologist to assume responsibility for outcomes associated with their technical work, it is imperative that technologists are equipped with a strong foundation in ethical principles that they can apply while working in industry.

1.1.1.2 Defining Ethics and Responsibility

To make an assessment on the quality of technology ethics education, it is important to first qualify how ethical technology is defined. There are myriad competing definitions of what constitutes a sufficient normative framework in the domain of technology, with many of these definitions expressed as engineering principles or codes of ethics. For example, the Association for Computing Machinery's Committee on Professional Ethics lists eight principles that define ethical technology practice; this list paradoxically outlines the need for technologists to develop technology in line with both the public interest and employers' interests, even though they may be at odds with one another (e.g., Facebook retaining user messaging data as a means of furthering their own profits through their advertising business, despite such behavior being at odds with the public interest principle of privacy) (*Software Engineering Code - ACM Ethics*, 2016). Likewise, the Engineers Canada Code of Ethics puts an emphasis on public welfare and employer/employee integrity, without making clear mention of the frequent conflicts that arise for technologists trying to maintain public purpose in their work while weighing profit incentives in a capitalist social structure (Engineers Canada, n.d.). Because these existing points of reference lack nuance, burgeoning technologists must rely on their educational background and (typically limited) professional experiences to understand the complexities that come with developing technology ethically. This task can be especially challenging given that existing ethical mandates often tautologically stipulate that to develop socially minded technology is to develop technology with mindfulness of social welfare (while also maintaining a responsibility to employers).

The Canadian Engineering Accreditation Board (CEAB) provides a standardized reference point in defining engineering ethics in Canada. In Canadian institutions of higher learning, the CEAB is one of the standing committees governed by Engineers Canada which works to regulate engineering and foster growth of the profession in Canada. The CEAB outlines their requirements within the Criteria and Procedures Report of each accreditation cycle, including the 12 attributes in which engineering graduates are expected to demonstrate competency: a knowledge base for engineering, problem analysis, investigation, design, use of engineering tools, individual and teamwork, communication skills, professionalism, impact of engineering on society and the environment, ethics and equity, economics and project management, and lifelong learning (Engineers Canada, 2016). While the CEAB provides a framework for principles of ethical engineering design, the Canadian Information and Communications Technology Council (ICTC) points to more specific definitions in its description of responsible innovation, including Stilgoe et al.'s definition, "taking care of the future through collective stewardship of science and innovation in the present" (ICTC-CTIC, 2021; Stilgoe et al., 2013).

1.1.1.3 Existing ethics methodologies

Institutions and faculties each take their own approach to the content and delivery of ethics concepts and curricula. Depending on their resources, institutions utilize separate ethics courses, technical courses with integrated ethical content, or a mixture of both (Walczak et al., 2010). According to Walczak et al., the most common approaches to teaching ethics are case studies and the memorization of professional engineering codes of ethics (Walczak et al., 2010). The case study approach presents scenarios wherein students use moral principles from paradigm cases that can be applied more widely (Hipp, 2007). In Canada, one of the popular cases is the Quebec bridge collapse; high profile cases in the United States, such as the interstate bridge collapse in Minneapolis, levee failures in New Orleans, and steering and braking failures in Toyota automobiles also draw attention to ethics in engineering nationally and internationally (Walczak et al., 2010). Though these examples express the importance of ethics in terms that are easily comprehended by students, there are weaknesses in the case study approach. This strategy often results in students attributing exclusive considerations to high profile “disaster” cases; as well, it can seem to imply that ethical dilemmas are limited to the catastrophic and removed from the everyday practices of engineers (Hipp, 2007, p. 3). Paradigmatic case studies, while significant to students’ broader standing of engineering risks, are not easily contextualized to students that may not be exposed to a certain area of work in their practice, such as civil engineering; this is particularly relevant as the focus of engineering students shifts from traditional engineering practice to software and computer technology development as computer software engineering continues to consolidate its position as the fastest growing engineering field (Roy, 2019).

One of the benefits to using codes in ethics instruction is that they inform students about their basic responsibilities as a professional engineer, while providing faculty with a starting point to refer to when embedding ethics into their courses; however, Hipp states that professional codes can be somewhat ambiguous to teach (Hipp, 2007). For example, the engineering code of ethics states that engineers are required to “hold paramount the safety, health, and welfare of the public,” but there is limited clarification on who and what “the public” includes (Hipp, 2007, p. 1). Instead, the engineering code of ethics relies on faculty and students to make their own interpretations based on the high-level guidelines it provides. Another caution that Torrence et al. and Watts et al. make of professional codes is that generalized content or superficial application can be ineffective or even counter-productive to ethical development (Torrence et al., 2017; Watts et al., 2017).

This research indicates that traditional methodological approaches to ethics education in tech-related curriculum do not fully address a wide scope of ethical or responsible design scenarios and prepare graduates to practice ethical reasoning skills in rapidly changing careers and industries. While professional accreditation board requirements and curriculum design lay the groundwork for developing ethically competent technologists, and individual faculty members are starting to heed these calls, academic frameworks are not the sole influencers that determine whether responsible practice is learned and maintained. In our case study of the University of Waterloo (uWaterloo),[5] Canada, we have observed that despite new approaches to delivering ethics curricula (as exemplified here in select sections of the Electrical and Computer Engineering's ARTS 190 course in "Communication in the Engineering Profession"), the university's culture of cooperative (co-op) education is a dominant factor in students' capacity to develop as ethical technologists. That culture, we propose, should be recognized as crucial touchpoint of engineers' educational and career development.

1.1.2 UWaterloo: Industry Alignment Through Cooperative (Co-op) Education

1.1.2.1 Co-op: A uWaterloo Innovation with Broader Relevance

The University of Waterloo is often regarded as Canada's preeminent technical university with a strong focus on industry alignment. On LinkedIn, it defines itself as a "renowned talent pipeline" before anything else and describes its primary strategic lever for growth as being its "development of talent for a complex future" (*Connecting Imagination with Impact*, 2019). A large part of uWaterloo's talent development is its co-operative education (co-op) program, in which students alternate between on-campus, coursework-oriented semesters, and four to six co-op terms of 8 to 16 weeks. While "on co-op," students gain industry experience through paid work. uWaterloo was the first Canadian University program to offer a co-op program in 1957, and several Canadian higher education institutions now offer it as a

[5] Paper 1 is the only section that will refer to "uWaterloo;" in all future sections, "University of Waterloo" or "Waterloo" will be the terms used to refer to the institution.

feature in their program (McCallum & Wilson, 1988) Amongst students and employers alike, uWaterloo's industry alignment is its greatest distinguisher, a fact that is emphasized on the uWaterloo website, where co-op and private-industry partnerships appear as the first reasons prospective students should choose uWaterloo over competing schools (*Why You Should Choose Waterloo over Your Other Options*, 2021).

The challenges that co-op students at uWaterloo who are interested in tech-sector work face as they navigate job recruitment—and develop ethical technological skillsets amidst competing value systems—are not unique to this specific university. Whether it be Harvard, McGill, Tsinghua, ETH Zürich, or Cambridge, students at top-performing universities are heavily recruited for technology jobs: at Harvard, 79% of students complete summer internships, with roughly 18% of those jobs being in technology (Guillaume & Halper, 2020); at Yale, 10% of student internships in 2019 were done in the technology industry (Yale Law School, 2019). As outlined in publications like the Yale Daily News (Yale Daily News, 2011), pre-professional sentiment and recruitment dominates campus conversations at universities targeted by employers and becomes a cultural focus amongst students, even in the absence of a formalized co-op program. Therefore, uWaterloo serves as a strong case to better understand the technology industry alignment present at high-performing universities, and how these environments affect students' capacity to develop as ethical technologists.

1.1.2.2 Co-op Education at uWaterloo and Industry Alignment

UWaterloo's co-op-focused approach to strategic growth has been successful; from 2017 to 2021, co-op enrollment at the school grew by 21.2% while non-co-op enrollment fell 3.47% (*Student Headcounts*, 2015). This trend is consistent amongst technology-oriented programs, as students in Systems Design Engineering (SYDE), Electrical Engineering (ECE), and Computer Science programs have grown by 72% over the last 13 years (*Student Headcounts*, 2015). These statistics show that Waterloo's co-op program is not only effective at attracting students, but that the rate of student attraction is accelerating with time (the growth rate per annum between 2017 and 2021 was 5.54% , compared to 5.3% from 2008 to 2021 (*Student Headcounts*, 2015)). The relationship between uWaterloo and industry is symbiotic; while co-op programs have grown, students in the programs have generated $285M in student revenue (*Co-Op Earnings*, 2012) while generating 7,500 new jobs and $2B in revenue for corporations in the past decade alone (University of Waterloo, 2019b). Of the value generated by uWaterloo, the greatest amount is generated in the domain of software and technology. Notably, uWaterloo is the third largest feeder school for Silicon Valley, behind California-based Berkeley and UCLA (Pender, 2018). This culture has been deemed colloquially by students as "Cali-or-Bust": they seek technology work in California as if it is the only viable option for employment (Pender, 2018; whycaliorbust, 2017).

Overall, uWaterloo has had immense success at positioning itself within the technology industry and consolidating a strong industry network, through which it funnels students with rigorous technical training into the private sector. In addition to uWaterloo's ever-growing co-op program, which remains the largest in the world, the school has positioned itself as a hub of development and innovation. Maclean's deemed uWaterloo the "most innovative university in Canada" for 28 years straight (though it recently lost the title to the University of Toronto), a standing reflected in uWaterloo boasting over 700 student-founded startups, and the region of Waterloo having the highest start-up density in the world outside of Silicon Valley (*Quick Facts | About Waterloo*, 2021). In short, uWaterloo's ethos of innovation and entrepreneurial spirit is closely aligned with its industry connections: uWaterloo startup founders have raised $12.9B from investors in industry (*Quick Facts | About Waterloo*, 2021). Through its investment in its co-op program, and the entrepreneurial culture it facilitates on campus, uWaterloo positions itself as a leader in innovative curricula and professional development.

1.1.2.3 Co-op's Focus on Technology Jobs at uWaterloo

Many uWaterloo engineering students, though from different programs, work in software-related positions on their co-op terms, whether explicitly software engineering, or supporting roles (e.g., data science, product management, user experience design). For instance, the class profiles of SYDE and Software Engineering (SWE) graduates from 2017-2020 showed that Software and Project Management were the most popular job roles (Chaudhury, 2017; Ramesh, 2018; Dey & Manson-Hing, 2019; Oegema et al., 2020; syde2020_profile, 2020). Similarly, in the survey we conducted of ECE students, responses indicated that many students in this program have also had co-op experience in software engineering and related roles. While this paper is not an exhaustive account of engineering co-op at uWaterloo, students from across several programs (ECE, SWE, and SYDE, specifically) have closely related experience thanks to their shared drive to secure professional experience in tech and software environments; for the purposes of this case study, we consider the combined insights from these students to provide context to a broader uWaterloo co-op climate.

1.1.3 Faculty-Led Initiatives and Student Perspectives on Ethics Education and Co-op

1.1.3.1 Embedding Ethical Thinking in Engineering Curriculum

As part of a research project investigating ethics interventions in engineering and tech-related curriculum, we surveyed ECE students who (a) were enrolled in a mandatory first-year course titled "Communication in the Engineering Profession" (ARTS190) between 2018-2020, and (b) were placed in sections of the course whose instructors structured their syllabi to explicitly foreground issues related to technology and ethics and to tap into uWaterloo's co-op culture. ARTS190 is part of a university-wide "Undergraduate Communication Outcomes Initiative"[6] at uWaterloo (*Undergraduate Communication Outcomes Initiative, Overview*, 2016). It focuses on developing students' written and oral technical communication skills in contexts relevant to the engineering profession. In the sections of the course selected for this survey, students assumed the simulated role of co-op employees at a fictional engineering company that was focused on accessibility-related tech development.

[6] As of late 2021, this initiative is called the Undergraduate Communications Requirement (UCR) and is referred to as such later in this dissertation.

They were tasked with designing solutions for individuals with specific disabilities, and in doing so, engaged with ideas about accessibility, equity, and inclusion in engineering.

Over the semester, students researched new products and services that the company could develop; completed communication-skills-focused activities and assignments that lead up to a formal report (these course elements included an oral “pitch” to a group of peers, a progress report to their instructor, aka “supervisor ,” an annotated bibliography showcasing their research, and several smaller scale memos for interim steps of the larger assignment sequence components); and discussed, wrote about, and presented on the ethical dimensions of engineering work. ARTS 190 is one example of the type of pedagogical work that is currently being undertaken by individual instructors who seek to foster ethical awareness in undergraduate engineering students, and who look beyond straightforward case studies or professional ethics codes to do so. Other members of our research team are working towards similar ends; they have integrated ethical concepts and interdisciplinary perspectives into select systems design and biomedical engineering courses.

The ARTS190 survey asked students to assess and reflect on their evolving sense of ethics as it related to their professions within the context of course activities. Using a mixed-methods approach, questions prompted students to rank their knowledge of and exposure to ethics in engineering. They elaborated, in short answer responses, on (a) how they might put ethics concepts they encountered in class into practice in other courses, projects, on co-op placements, and/or other industry experience, and (b) the obstacles they had encountered (or anticipated they would encounter in future) to prevent them from doing so. Other questions on the survey asked students to evaluate the effectiveness of this course more specifically, but for the purposes of this paper, we will report only on the qualitative answers that are applicable to ethics, curricular activities, and co-op or industry experience.

Of the 42 respondents, 22 had one or more semesters of coop or industry experience in software, web development, quality assurance, or electrical engineering since taking the course. Responses from 2018/2019 vs 2020 are distinguished in the Results section below, since students who took the course earlier had completed multiple co-op placements prior to the survey. Despite the survey's small sample size, these responses provide insight into students' general perceptions of ethics and its applicability/relevance to their profession. Further research will be needed to fully evaluate the efficacy of ethics outcomes in ARTS190 and other courses like it.

1.1.3.2 Survey Responses: A Classroom/Co-op Ethics Disconnect

The survey asked students, "Have you applied or are you applying principles from this class in courses and/or co-op placements? If so/not, please explain." Regarding coursework or other projects, students reported not yet applying ethical principles. For example:

- "No, none of my courses thus far have required me to design any product where I could apply these principles." (2018/2019)
- "No, I don't think they really apply to courses? I try to think about things like the environment and data information whenever, but I never did anything that big in class that became a potential ethical dilemma." (2018/2019)

- “No, I have not. So far into my undergraduate experience, I don’t think I’ve encountered an opportunity that brought me back to applying the concepts taught in the course.” (2018/2019)
- “No, I am not, many of my courses are very heavy in calculations and theory. We often do not have the opportunity to apply them in the real world.” (2020)

Likewise, in co-op or work experiences, most students reported not having the opportunity or did not see the applicability of ethics to their jobs, although one student did report: “For my positions in research I had to write documents to get approval for the research by ethical committees. Principles from this class would’ve been used.” (2020)

The following question asked, “What are some of the obstacles to incorporating ethics into your projects in other courses, on your co-op placements, and/or your work experience?” Students shared that ethics were not discussed in other courses or were not positioned to interact with ethics in their workplaces. For instance:

- “[I did not] see the opportunities of doing so, especially in the school setting.” (2018/2019)
- “My previous co-op did not allow me to incorporate any ethics as it was just straightforward electrical drawings from other engineers.” (2018/2019)
- “I’ve found it a bit difficult as a co-op student since I take orders from more experienced team members, most of the time ethical issues feel out of my hands.” (2018/2019)

- “The other teachers hardly mention ethics, especially in science and math. The ethics learning seems to have little connection to these fields.” (2020)

Notably, two students suggested that the workplace obstacles are more related to profit incentive structures that conflict with ethical interests:

- “[The obstacle] for most people, [is] probably making more money.” (2018/2019)
- “A lot of companies are driven by profit. If adjusting a product to be more inclusive causes a delay, then they might not want to. Selling user data is very profitable as well.” (2020)

Finally, the students were asked, “What, if anything, has changed about your perspective on the role of ethics within your profession, thanks to the work you did with ethical topics, concerns, issues, and principles in this class?” As the selection of responses below demonstrates, this question prompted generally positive responses but a couple indifferent perspectives, too:

- “The role of ethics in engineering now seems far more profound. I realize now it is an engineer’s duty to ensure whatever product is created, does not result in any discrimination.” (2018/2019)
- “My perspective on the role of ethics has changed since I now recognize the complexity and the number of situations in which ethical issues can arise.” (2018/2019)
- “Not too much.” (2018/2019)

- “They reinforced the notion that the safety of the public is the primary factor in any of the tasks I do.” (2020)
- “I would say that I’m more knowledgeable about how ethics are an important part of creating solutions that benefit an entire population instead of just benefiting a certain type of person. It will make me more aware of any ethical situations that may arise in the future when developing my own solutions to problems.” (2020)
- “Not much.” (2020)

These results indicate that despite students being exposed to principles of ethical technological development through a course like ARTS190, that content is taught in isolation of students’ broader academic educational experience as well as practical educational experience (i.e. co-op work terms). Interestingly, the only student who saw an avenue to practically apply principles from ARTS190 was someone who was working in academia, not within a technical field. Furthermore, the survey responses suggest that the students’ more technical coursework did not mandate a level of ethical engagement wherein students could apply the principles learned in ARTS190. These comments indicate that although several students recognize the importance of ethics to their profession, they experience a disconnect since they do not yet see the applicability of, nor are they able to put into practice, these concepts elsewhere in their training (on campus or through co-op). Without academic opportunities to practically apply and crystallize the concepts learned in courses like ARTS190, students are left to do so in professional environments; however, as shown by student experience, instances that prompt engagement with ethical values like equity, accessibility, or inclusion are not readily apparent in co-op work placement. Indeed, the profit-incentive structure that students encounter when they work in private industry pushes them to adopt priorities that are fundamentally misaligned with principles of ethical technological development.

1.1.4 Cultural Religiosity and Co-op

1.1.4.1 The Cultural Religiosity of uWaterloo's Co-op System

For students in engineering at uWaterloo, co-op is a required component of the curriculum and plays a major role in student experience and broader professional enculturation. Indeed, uWaterloo's co-op program dominates engineering students' life and campus conversation. On the dedicated uWaterloo Reddit message board (which has seventy-one thousand members), there is a perpetually pinned thread for discussion about co-op recruitment, interviews, and salaries (thylakoids01, 2021). As evidenced by discussion on the uWaterloo Reddit message board (whycaliorbust, 2017), the institution's pre-professional environment is so pervasive that it begets a culture of distinct beliefs, values, and practices. The overall culture is helpfully illuminated by concepts more commonly associated with religion. In their paper on *Worship, Faith, and Evangelism: Religion as an Ideological Lens for Engineering Worlds,* M. G. Ames , D. K. Rosner, and I. Erickson define a quasi-religion as a series of faith-like practices with four elements: evangelism, mythology, worship, and doubt (Ames et al., 2015). Each of these four elements plays a significant role within the co-op-dominated culture that uWaterloo's engineering students inhabit.

At uWaterloo, evangelism takes the form of rhetoric around co-op and its upsides. Every four-month term, uWaterloo hosts tens of on-campus recruiting sessions for major companies like Twitter, Google, and Microsoft, wherein students listen to "preaching" about the benefits of joining the companies and are enticed to attend by the free perks given out at such sessions. Events like these are not exclusive to the campus either. The Disrupter Job Fair, put on by Syndesus, provides students with free food and drink, alongside the promise of getting at least 20 students hired to positions in Silicon Valley (Czikk, 2014). The influence on student culture is clear: on uWaterloo's Reddit, students frequently make posts asking for advice on how to get hired to Silicon Valley (Czikk, 2014) and "why you should Cali-or-Bust" as they are vying for technology jobs based out of California (whycaliorbust, 2017).

Mythology, like evangelism, is inherent to religious practice, and in Waterloo's co-op culture myths often focus on high-salaried jobs. For example, there is common mention on uWaterloo's subreddit about a student who was able to secure a multi-million-dollar commission after securing a major contract for their co-op employer (gluedtomychair, 2015); whether this happened remains unclear, and even if it did, it would be a unique case. Further, tales of exceptional cases are amplified and become a competitive fixation for most students at uWaterloo with less focus on how the money is made; on the pinned uWaterloo Reddit thread discussing co-op recruitment, high-paying companies with salaries of up to $12,000 per month are consolidated in a long list pinned to the top of the thread, with no mention of the nature of the work being done by the respective employers (thylakoids01, 2021).

The third element of any quasi-religion, worship, refers to the ritualized practice of homage to beliefs important to an ideological framework. At uWaterloo, the high-paying big tech jobs at FAANG companies (Facebook, Amazon, Apple, Netflix and Google) mythologized by co-op lore are what is worshipped, as evidenced by the aforementioned colloquial "Cali-or-Bust" mindset omnipresent at uWaterloo, the practice of “Leet Coding” (doing coding online exercises to hone skills) in anticipation and preparation of recruitment, and the fixation on high-salaried technology jobs pinned to the recruitment thread on uWaterloo’s Reddit thread (whycaliorbust, 2017). The attainment of these jobs dominates campus conversation both in humor and earnest, and their status as the ultimate student goal becomes a cornerstone of the student experience.

The final attribute of any religion, doubt, runs rampant at uWaterloo. Doubt, as experienced by students, pertains to uncertainty about the fixation on “Cali-or-Bust," or working for a high-salaried company irrespective of its social impact or workplace culture. Many of these concerns pertain to questions around the trade-off between financial and mental health caused by students putting so much pressure on themselves to be hired for said jobs. Financially, students at uWaterloo are a success; however, that success does not necessarily translate to overall measures of happiness (to take SYDE statistics for an example, the average graduating salary for 2020 exceeded $100,000; yet over 40% of graduating students experienced extreme anxiety throughout their degree, with 6.6%

reporting suicidal ideation, far above the American national average of 3.9% (syde2020_profile, 2020). Articles and online discussions, such as “The Cali or Bust Conundrum,” reflect student uncertainty about the payoff of fixating on working in the Bay Area and the compromises necessitated by obsessively pursuing that goal (Peng, 2018).

1.1.4.2 Adopted Industry Values and Spheres of Justice

Like any religious system, Waterloo’s co-op pantheon has its own normative ethical framework, in this case, one aligned with industry (since uWaterloo’s co-op program looks to appeal to private industry and realize its first strategic growth lever). However, with different incentive structures in place, the developmental motivation of the private technology industry diverges from the of the development of responsible innovation as defined by the ICTC (although they are not necessarily mutually exclusive), thereby resulting in subsequent normative ethical frameworks that are not necessarily aligned. Walzer’s notion of spheres of justice provides a conceptual framework to better map this misalignment (Walzer, 2010).

Walzer’s theory argues that there are so-called “social spheres” (that may share fundamental ethical beliefs), within which normative values of justice or ethical righteousness may differ depending on the incentive structures and hierarchies by which they are governed (Walzer, 2010). Within the uWaterloo campus sphere, the aspired ethical system outlined by CEAB is concerned with developing technology transparently, democratically, and in social interest (Engineers Canada, 2016). Yet, this system exists in stark contrast to the one worshipped in uWaterloo’s co-op pantheon, which adopts normative values emanating from the sphere of justice in the technology industry, and more specifically, in Silicon Valley. Publicly traded companies like Google are constantly aiming to increase profit due to the incentive structures inherent to capitalism, thereby anointing profit as the highest good in such spheres of justice. This incentive structure is rarely aligned with CEAB's definition of ethical technology. The words of Timnit Gebru, technical co-lead of the Ethical Artificial Intelligence Team at Google, are particularly salient here: "You can't set up a system where the only incentive is to make more money and then just assume that people are going to magically be ethical" (Schwab, 2020). More broadly, Smith outlines that when technology development is subsumed by the valorization imperative, the aspiration to maximize technology use—not by fulfilling need, but by creating it as a means of bolstering profit—results in exploitative social relations (Smith, 2010). Thus, the emphasis on co-op at Waterloo, and the cultural religiosity that it nurtures, results in a distortion of the ethical framework endorsed by the CEAB. The profit-incentivized normative ethical values from the technology industry's sphere of justice seep into the uWaterloo campus and overshadow the work that professors undertake in their courses to cultivate ethical approaches to tech innovation.

1.1.5 Discussion and Future Work

This paper began by examining how ethics education methodologies in higher education, concerned with both theoretical codes of conduct and paradigmatic case studies, are inexhaustive and insufficient in enabling students to develop robust ethical frameworks (Hipp, 2007; Torrence et al., 2017; Walczak et al., 2010; Watts et al., 2017). In the absence of a practical context to understand the concepts outlined in theoretical codes of conduct, students often feel confused about how to abide by and apply the principles that these codes stipulate in real-life settings (Torrence et al., 2017; Watts et al., 2017). Case-study methodologies may provide some of that “real-life” context, but they do not fully solve the problem, as they are often preoccupied with disastrous, paradigmatic cases that are unrelated in both context and magnitude to the ethical decisions that students tend to face in quotidian workplace tasks (Hipp, 2007).

In this study, we find that ARTS190 curriculum serves as a promising model for overcoming some of these limitations by engaging students with ethical considerations (such as accessibility, inclusion, and equity) in contextually relevant scenarios. In their survey responses, students indicated that this course helped them to recognize the role and importance of ethics in engineering. To enable students’ further progress in practicing ethical concepts, it is now a matter of embedding them across the curriculum. ARTS190 is not an isolated example of these efforts at uWaterloo. For instance, within technical SYDE design courses, another instructor has incorporated “tech ethics”-related assignments, guest lecturers from the humanities on Critical Design, and collaborative workshops with English and Anthropology students to discuss the ethical dimensions of student projects. To bolster these faculty-led initiatives and continue developing students’ ethical frameworks throughout their degree, there needs to be a collective buy-in from administration and faculty to reinforce the importance of ethical and responsible considerations, as well as support for instructors who want to embed these concepts but lack resources to do so.

There has already been extensive research on various integrated ethics education methodologies, which have shown success in instilling ethical values amongst training technologists (ten Have, 2021). One promising student-centered approach is a model at the Georgia Institute of Technology, wherein students worked through design phases for a local client in a controlled academic context, whereby they considered the ethical design values at each decision point of the project (Fu et al., 2017). Other promising approaches leverage a hybrid model for teaching computer science students principles of ethical design, wherein students learn abstract ethical theory in a lecture that is complemented by a subsequent workshop where they are shown how to apply the taught ethical design principles (Skirpan et al., 2018). Future work should certainly continue to investigate, assess, and synthesize findings related to the varied models currently being developed for teaching principles of ethical design and making them "stick." However, as shown through the microcosm of ARTS190, the limited opportunities for students to apply relevant principles of ethical technological development in their technical academic coursework, or be shown how they could be applied, hinders students' abilities to develop as ethical technologists. Perhaps more importantly, the disconnect between ethical thinking and tech-sector work is exacerbated by the cultural dominance of private-industry value system on campuses. While continued investigation into new pedagogical methodologies is vital, this paper has shown that with the cultural dominance of industry connections at higher education campuses like uWaterloo, it is imperative to pursue buy-in from industry (whether through incentives or university coop/internship mandates) to reinforce the principles of ethical technology design taught in classrooms. We therefore hope that future research will do more than continue investigating the validity of student-centered, iterative ethical education in the context of self-directed design projects and hybrid case-based and workshop-complemented learning; it should also investigate avenues for pursuing employer buy-in with respect to reinforcing principles of ethical design.

Further ethnographic research should seek to better comprehend the student experience in navigating the co-op culture that exists at uWaterloo—and the internship culture that exists at schools with similar models of integrated work-study—as a means of understanding the ramifications of such environments on students' developing an understanding of ethical design principles. Equipped with this knowledge, institutions that seek to be leaders in talent development, innovative pedagogy, and ethics will be better positioned to provide a strong foundation in and reinforce the value of ethical thinking and responsible design for their students—and the graduates who emerge from these institutions will be more able, willing, and committed to practice ethical engineering confidently in their careers.

1.2 From Cali-or-Bust to Ethical by Design

The research in Paper 1 was supported by a Waterloo Interdisciplinary Trailblazer Grant received in 2020. This project took inspiration from *Ethical by Design: A Manifesto,* co-authored by the grant's co-PI, Jennifer Boger (Mulvenna et al., 2017). One objective of the Trailblazer project was to inject arts- and humanities-based methods into the teaching of ethics across multiple Engineering courses, including first-year Engineering Communication (ARTS 190), first-year Engineering Design (SYDE 161), third-year Engineering Methods (SYDE 361 and 362), and the Systems Design Engineering Capstone courses (SYDE 461 and 462). The interventions in the SYDE courses took the form of collaborative workshops where students applied critical design, value sensitive design, and responsible innovation frameworks to their ongoing projects. More details of these workshops are presented in Chapters 2 and 3.

There is potential in many of the individual efforts made by Waterloo instructors, as shown by the research done in ARTS 190 and the additional SYDE courses listed above, as well as the pedagogical interventions presented in Papers 4 and 5. However, without broader institutional support – and because they are working against the Cali-or-bust mentality and other industry-driven ideologies – it is difficult for these initiatives to gain traction. These challenges represent a main through-line of this dissertation. In the following papers, I will discuss these challenges across multiple disciplinary perspectives, including AI ethics (Paper 2), science and technology studies (Paper 3), responsible innovation, engineering ethics education, and critical and speculative design (Papers 4 and 5).

Based on our findings in Paper 1, we revised our hypotheses and survey instrument for the second iteration of this project, so that we could extend our research beyond the Engineering courses and cohorts that our research team had immediate access to through our teaching. To gain a broader sense of how students engaged with and understood ethics in engineering and design – outside of the context of the course or workshop they participated in through our interventions – we added a section on hypothetical scenarios to the next iteration of surveys. We constructed six hypothetical scenarios, each of which included ethical dilemmas in multiple educational and professional settings (e.g., a research lab where the postdoctoral researcher is fudging data to meet a deadline; a renewable energy company where the supervisor is unwilling to modify a project to meet the target community's environmental and economic constraints) (See Appendix A for the full scenarios). One motivation for having hypothetical scenarios distributed to multiple Engineering majors was to explore whether students from different majors would answer the questions differently based on their exposure to traditional engineering or technologist-oriented engineering at school and co-op placements. Unfortunately, we did not recruit enough students from any particular major, let alone multiple majors with representative sample sizes, to address this hypothesis fully. However, we were able to collect 53 responses to the AI ethics scenario specifically, which provided ample data for Paper 2, *An Analysis of Engineering Students' Responses to an AI Ethics Scenario,* to be written. In this article, we argue that the use of AI is so pervasive across disciplines that whether the students' majors appear to be AI related is not necessarily reflective of their engagement and knowledge of the technology. This position has stood the test of time, given that this article was written before ChatGPT and other generative text and image models were popularized in late 2022, an event that has rapidly changed the landscape of teaching and assessment at universities and the norms and processes in workplaces around the world. Since then, there has been an even greater need for educators to consider their own and their students' knowledge of AI and its potentially negative impacts, not only in engineering but across multiple domains (Fui-Hoon Nah et al., 2023; Goldenkoff & Cech, 2024).

The study design, data collection, analysis, and manuscript writing for this second study took place over 16 months, between September 2021 and December 2022. Over half of the participants in Paper 2 were recruited through instructors and faculty in the Systems Design and Biomedical Engineering departments. The remaining participants were recruited through the instructor of the AI and Society course offered through the Centre for Society, Technology, and Values in Spring 2022.

The AI ethics scenario in Paper 2 draws attention to the perpetuation of racism through algorithmic bias and systemic discrimination by prompting the participants to determine their course of action upon learning that the facial recognition model they trained does poorly at identifying dark-skinned faces. While 77.4% of survey respondents identified the technical issue with this model, only 17.0% called it an ethical concern. These results indicate the need for a sociotechnical approach that bridges the gap between technical decision making and the downstream ethical implications of engineering design. Exploring the existing research on sociotechnical AI ethics pedagogy, Paper 2 compares two approaches that have been implemented in AI and machine learning courses previously (Krakowski et al., 2022; Saltz et al., 2019) and makes recommendations for future curricular development on this topic. In the context of this dissertation, Paper 2 offers a comparative analysis of where and how different approaches to AI ethics pedagogy can improve in aiding students to gain a nuanced understanding of what it means to think critically and design ethically as engineers.

1.3 Paper 2: An Analysis of Engineering Students' Responses to an AI Ethics Scenario[7][8]

1.3.1 Introduction

With the rise of significant ethical problems in the technology industry, such as algorithms that worsen racial biases, the spread of online misinformation, and the expansion of mass surveillance (Noble, 2018; Vraga et al., 2020; Zuboff, 2019), it is important to engage topics relating to ethics, fairness, psychological impact, social and environmental justice, and equity, diversity, and inclusion in artificial intelligence (AI) curriculum. To accomplish this, we must examine how educators and institutions prepare future graduates to identify and address ethical problems.

Scholars agree that the historically isolated ethics ecosystem of engineering and tech-related disciplines, combined with ongoing social injustices exacerbated by irresponsible tech design in industry, points to a need for ethics to have a more rigorous presence in the engineering curriculum (Antoniou, 2021; Nasir et al., 2021; I. D. Raji et al., 2021). Many institutions have introduced AI ethics courses in recent years; since 2019, educators and

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[7] Orchard, A., & Radke, D. (2023). An analysis of engineering students' responses to an AI ethics scenario. *Proceedings of the Thirty-Seventh AAAI Conference on Artificial Intelligence and Thirty-Fifth Conference on Innovative Applications of Artificial Intelligence and Thirteenth Symposium on Educational Advances in Artificial Intelligence*, *37*, 15834–15842. https://doi.org/10.1609/aaai.v37i13.26880

[8] This study received research ethics clearance from a University of Waterloo Research Ethics Board (REB #43726).

researchers have crowd-sourced and catalogued upwards of 400 AI and/or tech ethics (including content on machine learning and AI algorithms) syllabi from North American institutions (Fiesler et al., 2020; Nasir et al., 2021; I. D. Raji et al., 2021). Educators have proposed and implemented individual modules, workshops, and heuristics for teaching AI ethics in tandem with their standard coursework (L. Cohen et al., 2021; Furey & Martin, 2019; Saltz et al., 2019). Some of these curricular interventions received student feedback that the content was relevant and interesting, and they would like to learn more throughout their program (L. Cohen et al., 2021; Grosz et al., 2019). To this end, the amount of resources and tools for teaching AI ethics has grown steadily in the last decade; meanwhile, educators are still in the early stages of evaluating these pedagogical strategies and measuring student perceptions, retention, and interest in the topic.

Our study enters this conversation by analyzing 53 survey responses from engineering undergraduate students on an AI ethics problem wherein a facial recognition model fails to accurately identify dark-skinned faces. In qualitative short answer responses, participants were prompted to explain how they would respond and what they think are the most and least important considerations in the given scenario. Our results indicate that students are often able to identify and suggest actions for mitigating the issue from a technical standpoint but rarely connect it with broader ethical and societal implications.

This paper reviews various pedagogical approaches to teaching AI ethics, and relates these methods with our analysis of student knowledge, attitudes toward, and considerations of AI ethics from the survey responses. Our survey also asked participants to describe any obstacles they have experienced in learning and applying AI ethics concepts in their curricular and work experiences. We propose that teaching AI ethics with a sociotechnical pedagogical model would complement students' existing technical skills and enhance their ability to ask critical questions in mitigating complex ethical issues. By observing and reflecting on student responses in conjunction with current ethics pedagogy and research, we anticipate that this paper will inform future pedagogical design and strategies for integrating AI ethics into the engineering curriculum.

1.3.2 Background

1.3.2.1 Engineering and Computing Ethics

Ethics was included in the American Board of Engineering and Technology (ABET) accreditation requirements in 2000; the Canadian Engineering Accreditation Board (CEAB) added a similar attribute nearly a decade later (Roncin, 2013). "Engineering ethics," in accreditation contexts, describes a rather narrow understanding of what ethics entails; for example, the code states that engineers are required to "hold paramount the safety, health, and welfare of the public," but there is limited clarification on who and what "the public" includes (Hipp, 2007).

The what and how of integrating ethics into engineering, computer science, and other technology-oriented programs has been discussed for many years: prior research debates the merits of technical courses with ethics added in, nontechnical courses characterized by philosophical or moral debate, and other approaches that engage humanities and social science perspectives (e.g., Science and Technology Studies, Critical Data Studies) (Herkert, 2000; Hess & Fore, 2018). Institutions often utilize a combination of these approaches depending on their resources (Walczak et al., 2010). Engineering students are typically exposed to ethics through professional codes of conduct and case studies (McGinn, 2018; Walczak et al., 2010). Engineering graduates who become licensed by their professional association are held accountable to a Code of Ethics. Typical case studies include the 1907 Quebec bridge collapse, the Space Shuttle Challenger disaster, and Bhopal Plant disaster.

The emphasis on ethics within computing and engineering programs has increased in recent years (Green, 2021). One 2021 syllabi review compiled 254 AI ethics courses at 132 North American universities (I. D. Raji et al., 2021). The AI ethics research community, too, has grown with conferences such as the ACM Conference on Fairness, Accountability, and Transparency (FAccT) and the AAAI/ACM Conference on AI, Ethics, and Society (AIES). While this paper focuses on engineering students and courses, we recognize there is considerable overlap with computer science in regard to notions of computing and tech ethics. However, we emphasize the distinction between engineering ethics and computing and tech because of the professional associations and codes that engineering graduates frequently belong and adhere to. The nearest equivalent in computer science is the codes of ethics presented by professional computing organizations such as the IEEE and ACM but their codes are not enforceable, nor are they required to be taught (Mittelstadt, 2019).

Computing and tech ethics are illustrated in ethical and responsible design manifestos, declarations, and principles produced by academia, industry, and government entities (*AI Principles*, n.d.; *The Mozilla Manifesto*, n.d.; Mulvenna et al., 2017). These documents advocate for principles such as beneficence, autonomy, fairness, sustainability, and privacy (Morley et al., 2021), and can also be used for teaching engineering and tech ethics. According to the Global Inventory of AI Ethics Guidelines, managed by Algorithm Watch, there are now more than 160 documents in existence (last updated in 2020) (*AI Ethics Guidelines Global Inventory by AlgorithmWatch*, 2020). Though these documents may be well-intended, a major criticism is that they are often too abstract to be actionable and may be used for corporate "ethics-washing" more so than addressing real issues when innovating (Green, 2021). The broad framing of AI and tech ethics here makes it difficult for students and instructors, and those in industry, to learn and apply ethical and responsible design in their respective contexts.

1.3.2.2 Obstacles and Considerations in Ethics Education

1.3.2.2.1 Instructors

Though there are a wealth of pedagogical resources and methods for teaching ethics, there are a number of obstacles for instructors. Engineering instructors, in many cases, do not have a background and are therefore untrained in or uncomfortable broaching ethical topics (D. Johnson, 1994; Walczak et al., 2010). In many cases, instructors are not incentivized and supported by their institution (and, in turn, the accreditation boards) to incorporate more ethics into an already tightly packed curriculum (Walczak et al., 2010).

Multidisciplinary, collaborative ethics teaching (e.g., cross-faculty team-teaching) has shown promise in exposing students to complex sociotechnical discussions (Hoople & Choi-Fitzpatrick, 2017) but these efforts meet logistical challenges related to scheduling, accreditation, and institutional policy (Walczak et al., 2010).

1.3.2.2.2 Content.

Krakowski et al. observes that, much like engineering and computing ethics content generally, AI ethics training is done separately from technical coursework, resulting in a decontextualization of ethical concerns from real-world consequences and a de-emphasis of ethical issues in comparison with technical content (Krakowski et al., 2022). Integrating ethics across the curriculum, through additional readings, modules, and non-technical instructor expertise, has been successful previously (Grosz et al., 2019); however, other studies observe that individual efforts (without consistent framing and support of ethics' relevance and importance from more than one source) could suggest that ethics content is supplemental rather than fundamental to students' training (E. A. Cech, 2014; Garrett et al., 2020). Achieving this kind of cross-curricular integration relies on the coordination of instructors, faculty, and administrative figures to support such an initiative.

In a review of AI ethics syllabus design and teaching methods, Tuovinen and Rohunen emphasized how ethical questions and topics must strike a balance with technical content to allow for students to see the significance and applicability of the ethical content (Tuovinen & Rohunen, 2021). Some aspects of ethics can be presented as facts, such as the safety record and current legislation governing a technology's development and use, but ethics content on a deeper level is inherently subject to ambiguity and debate (Tuovinen & Rohunen, 2021). As such, instructors must consider the delivery of this content, in addition to the content itself, to best facilitate the learning process for students.

1.3.2.2.3 Students.

Though all the above-mentioned obstacles influence students, we recognize that experiences outside of the classroom also shape students' engagement with ethics in their education and career. Cooperative education (co-op), referred to as internships or work-integrated study at some institutions, is a driving motivation for many students – particularly engineering and computer science students on the verge of becoming high income earners in the tech industry. Truax et al. observed that while coursework aided students in recognizing the importance of engineering ethics, they seldom saw the opportunity to apply the concepts in other projects or on co-op jobs (Truax et al., 2021), a theme also discussed in our study's results. Though the consideration of ethics is an essential part of engineering, there are still many barriers hindering the impact of ethics in the curriculum.

1.3.3 Teaching AI Ethics

1.3.3.1 Frameworks for Teaching AI Ethics

In a typical AI ethics course, instructors may discuss relevant ethical principles (e.g. found in a professional code or a tech ethics manifesto) and their interpretation in practice, broader societal implications (e.g. implications of facial recognition technology (FRT) for mass surveillance), or downstream developments and consequences of future technology (e.g. artificial general intelligence) (Fiesler et al., 2020; Tuovinen & Rohunen, 2021). Themes found in AI ethics courses include data ethics, privacy, AI literacy, legislation, and accountability and transparency, among others; these concepts are often disseminated through articles, stories, film, and discussion-based exercises and assignments (Tuovinen & Rohunen, 2021).

Educators have also explored the development of new or adoption of existing frameworks for identifying ethical issues. For instance, Saltz et al.'s framework includes a list of questions (i.e., "How might an individuals' privacy and anonymity be impinged via aggregation and linking of the data?") for students to address ethical issues in their machine learning (ML) projects. This framework was designed to be directly inserted into their existing technical ML modules on logistic regression, random forest classification, and various kinds of deep learning models. Their results show that students can easily apply an explicit set of questions to a ML project, focusing specifically on "ethical issues that are actionable by members of an ML project team, and not those that are societal in nature" (Saltz et al., 2019).

Krakowski et al. also presented a framework that prompts students to (1) determine whether AI is an appropriate tool for the defined task, (2) question the data being used, (3) consider the affordances and limitations of the AI system's design, and (4) consider how the AI system's output will impact real world systems (Krakowski et al., 2022). They measured this approach with pre/post surveys, interviews, and focus groups that prompted students to identify areas of concerns about a proposed AI system or its deployment. Their results indicate an increased level of sophistication in the students' abilities to integrate ethics concerns with technical features of an AI system (Krakowski et al., 2022). Though this framework was initially tested with high school students, who do not have the same technical background as undergraduate engineers, it appears to be a promising entry point that could be integrated and expanded into more advanced curricula.

Krakowski et al.'s framework has a broader scope of what constitutes an ethical issue than Saltz et al.'s, while Saltz et al. provides a direct entry into technical ML curricula; nevertheless, aspects of each approach could be derived to suit the focus of different curricular designs. The Discussion section will put these frameworks into conversation with the FRT scenario used in our study.

1.3.3.2 Case Study: Facial Recognition Technology

Facial recognition technology is a broad term to describe biometric software that can be used for facial detection, analysis, and verification or identification of a human subject. For example, it can be used to determine physical or demographic traits like age, gender, or facial expression. In this section, we provide a brief overview of technical and ethical considerations of algorithmic bias in FRT. This overview will provide context for how an AI ethics framework could be applied to the FRT scenario used in our study.

1.3.3.2.1 Bias in Deep Learning Models.

Facial recognition models are typically taught within the scope of supervised deep learning, where the model fits to a given dataset and can be used to extrapolate decisions about new data from a similar distribution. This is done by training the model on the dataset, repeatedly tuning the model's numerical parameters to obtain higher accuracy. One way a model can become biased is by learning to perform a task significantly better on a subset of the data distribution. The reason why this happens can be difficult to understand; however, one cause may be an unbalanced dataset (i.e., more examples of a particular group). Attempting to mitigate bias with unbalanced data is an active area of research within AI, and some solutions can be divided into two broad categories: modifying the original dataset or modifying the learning process.

One method to mitigate the problem of learning bias from unbalanced data is to obtain more data of under-represented classes; however, this may not always be possible when data is sparse. One could then enrich under-represented classes using data augmentation, the process of generating artificial data from a smaller set of existing real samples (Taylor & Nitschke, 2018). A more advanced technique to generate data utilizes Generative Adversarial Networks (GANs) (Goodfellow et al., 2020) to learn the dataset's underlying distribution and generate new realistic samples for a smaller class (Cubuk et al., 2019; Perez & Wang, 2017).

Other methods directly impact how models learn from potentially unbalanced datasets by limiting the amount that parameters fit to over-represented groups (Sabbagh et al., 2023). Another approach stems from research on techniques to help train deep learning models with less data (Erhan et al., 2010; Ioffe & Szegedy, 2015; Srivastava et al., 2014; Weiss et al., 2016), meaning the model could then learn from a smaller, but balanced dataset. In AI education, students typically learn several of these techniques to overcome challenges when training models.

1.3.3.3 Ethical Implications of Facial Recognition Technology

Learning to identify and mitigate bias and unbalanced data is a common outcome in a technical AI course. However, being able to recognize potential consequences of such an issue requires more analysis of the social and ethical context of the technology itself. Many applications of FRT, whether on social media, at a border station, or medical scanning (Hare, 2019) are susceptible to misuse and can result in discrimination against marginalized groups (Benjamin, 2019). Some of the main ethical tensions of FRT include privacy and representation, intersectionality and group-based fairness, and transparency and overexposure (I. Raji et al., 2020). For example, though we may aim to account for diverse representation in a dataset, this can present privacy risks, issues of consent, and perpetuate marginalization of certain populations (Hamidi et al., 2018; Hoffmann, 2019; Mozur, 2019). Furthermore, it is difficult to achieve equal representation among underrepresented subgroups and, in the case that some balance is achieved, it may come at the cost of elevating other risks (I. Raji et al., 2020).

Algorithmic audits, one method for detecting issues of fairness and accountability, are "assessments of the algorithm's negative impact on the rights and interests of stakeholders, with a corresponding identification of situations and/or features of the algorithm that give rise to these negative impacts" (S. Brown et al., 2021). There has been growing attention to algorithmic auditing in AI ethics research in recent years (Mittelstadt, 2016; I. D. Raji et al., 2020; Vecchione et al., 2021); integrating it into AI ethics curricula is an area for future research. In summary, building, modifying, or expanding a dataset to mitigate bias demands critical questioning about its purpose and potential implications that need to be considered alongside deep learning techniques.

1.3.4 Methods

1.3.4.1 Survey Instrument

This study utilizes a mixed-methods qualitative and quantitative survey with sections dedicated to three hypothetical scenarios and personal definitions of ethics and responsible design. This study is one part of a larger project investigating engineering and tech ethics more broadly, so other scenarios in the survey are placed in different engineering contexts; in this paper, we only analyze the responses from the AI ethics scenario. Additionally, this survey is not in response to any specific pedagogical intervention but instead serves as a baseline measure for engineering student knowledge of an AI ethics problem. We discuss our plans for interpreting the baseline results in the future research section. Students are prompted to describe how they would respond to this scenario:

> For a final project, you acquire a dataset to build a facial recognition model to predict a subject's age. You train a model, and your initial results achieve 95 percent accuracy on the testing set. When you dig into the 5 percent incorrect samples, you realize that

> the accuracy is very high for lighter skinned individuals but very low for darker skinned individuals. Your project's intended population is mostly accounted for within the test set. You know that your project will surely receive a high grade if you report your initial results.

Prior research on the use of hypothetical scenarios finds they are useful for emulating potentially sensitive ethical topics (Aguinis & Bradley, 2014). When teaching ethics, scenarios should be relevant and familiar yet generalizable (Hishiyama & Shao, 2022; Weber, 1992).

In this scenario, we sought to find a balance between the relatable context of coursework and a real-world concern by proceeding with the assumption that the issues associated with facial recognition technology are well-known and documented in both the tech sector and popular news outlets (Van Noorden, 2020). This was done to avoid drawing on the paradigmatic case studies of catastrophic design failures often used in ethics training (Hipp, 2007), while still gesturing towards authentic considerations in AI. Other details in the scenario, such as the 5 percent error, the intended population, and the project grade, represented factors that could influence the participants' actions, much like design constraints, pressure to meet deadlines, and workplace dynamics might also factor into a real world context.

The short answer section asks participants to describe how they would respond and what they think are the most and least important considerations in the given scenario. They were also asked to describe any obstacles they have previously experienced in applying ethical concepts in their coursework, projects, and co-op workplaces. Short answer responses are measured by the quantity and type of considerations raised and measured sample-wide thematically.

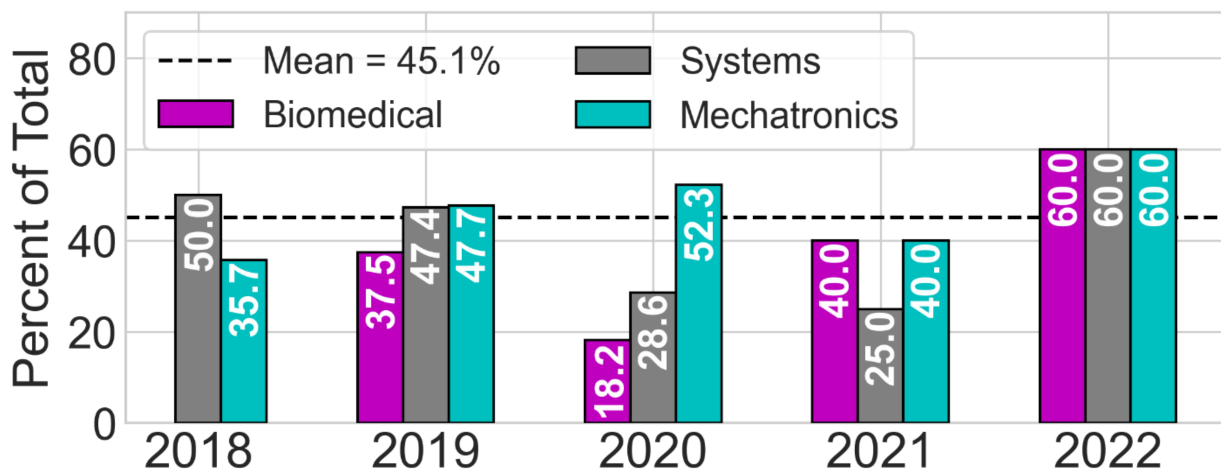
1.3.4.2 Participants

This study targeted students across various Engineering programs during the Winter 2022 term. They were invited to participate in connection with our larger research project; none of the instructors who volunteered to advertise this survey to their courses are part of the research team nor do they necessarily teach any ethics content themselves. The survey was distributed to two specific program cohorts, Systems Engineering and Biomedical Engineering, and an elective “society, technology, and values” course which contained multiple different engineering majors. We received a total of 53 participants from a variety of majors within engineering (see Table 1). The majority of participants were from three majors: Systems (34.0%), Biomedical (30.2%), and Mechatronics (18.9%) Engineering. Other (17.0%) participants originated from a combination of Electrical, Software, and Chemical Engineering, to name a few. During the study, participants from Mechatronics (18.9%) and Other (17.0%) were enrolled in a “society, technology, and values” course. They received identical pre- and post-surveys at the beginning and end of the course (the same survey as Systems and Biomedical received once). However, there were limited students who completed both surveys (per unique codes), so we were unable to do paired data analysis. According to the course calendars for all engineering majors represented in this sample, all participants will have taken a mandatory first-year concepts and/or communication course that introduces them to engineering professionalization, which includes reviewing professional codes of engineering ethics. Participants in Systems will have taken a second-year human factors course and participants in Biomedical will have taken a third-year biomedical-specific ethics course.

Table 1: ***Engineering Majors of Participants***

Major	Responses	Year	% Total
Systems	18	3	34.0
Biomedical	16	3	30.1
Mechatronics	10	1-4	18.9
Other	9	1-4	17.0
Total	53	-	100.0

Figure 1: ***AI Related Capstone Projects***



Note. Percent of Systems, Biomedical, and Mechatronics Engineering capstone projects that are related to AI in each of the last five years.

Across the entire sample, 98% of participants had cooperative work terms, mostly in the software (35.1%), medical (11.5%), and robotics (8.1%) industries. In the past five years, 45.1% of capstone projects from Systems, Biomedical, and Mechatronics engineering cohorts contained AI related models, including 60% of projects in 2022 (Figure 1).[9] We see a 5.1% decrease in total AI related projects from 2020 to 2021. We suspect this may be a result of the COVID-19 pandemic, which made it difficult for students to meet and produce more labor-intensive projects. By tracking the percentage of AI related capstone topics, we are able to see how the use of AI is pervasive across disciplines such that whether the program majors appear to be AI related is not indicative of the students' engagement with the technology.

Based on our participants past curricular and work experiences, we can expect that they have had some exposure to these non-technical areas, in addition to a basic knowledge of artificial intelligence and machine learning.

1.3.5 Results

1.3.5.1 Scenario Responses

In the short answer responses, we identified three themes: (1) participants identified a weakness or limitation in the facial recognition model; (2) participants discussed possible actions to improve the model; (3) participants identified how a biased model is a result of or could cause an ethical issue.

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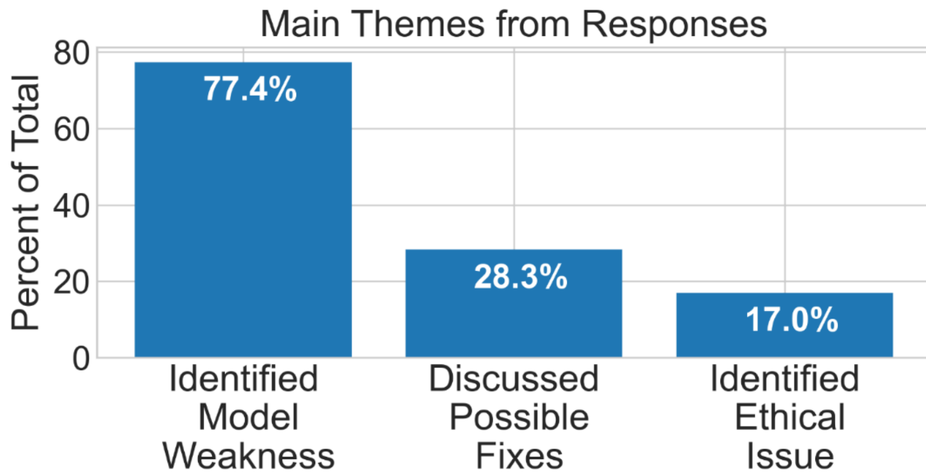
[9] https://uwaterloo.ca/capstone-design/project-abstracts

Figure 2: ***Main Themes from Responses***



Note. Percent of responses that identified the model's weakness, discussed possible methods to improve the model, and identified underlying ethical issues.

1.3.5.1.1 Identified Model Weakness.

The short answer question asks participants to "Please explain how you would respond in this scenario." In our analysis, we classified responses identifying the model weakness as instances where participants acknowledged that the imbalanced accuracy on the testing dataset was problematic. Our results showed that 77.4% of participants were able to identify this weakness (Figure 2 left bar), with the majority noting that the cause may be the distribution of the training dataset. This suggests that the participants were aware that classification accuracy imbalance is an issue and of how supervised learning models adopt the bias of the data they are trained on.

1.3.5.1.2 Discussed Possible Fixes

In the same short answer space, only 36.6% of the number of participants that initially identified the model weakness (28.3% of all participants) discussed any method of how they could improve the model to mitigate bias (Figure 2 middle bar). While most participants identified a model weakness, the significant decrease in those that suggested model improvements indicates that the majority of the participant group chose not to respond by proposing a remedy. Of those participants who discussed possible fixes, 73.3% blamed the issue on insufficient dataset distribution. We cannot assume whether participants are familiar with other methods for balancing this distribution or modifying training techniques, as discussed in the Background, but in the Discussion section we elaborate on assumptions of dataset modification.

1.3.5.1.3 Identified Ethical Issues

By identifying and expressing the importance of a potential ethical issue in this scenario, participants demonstrated their knowledge of and engagement with issues in facial recognition technology. Only 17.0% of participants expanded on how this problem could be resulting from or, if the model was deployed, could result in negative ethical implications. Some participants suggested the model could reinforce racism and discrimination:

- "The consideration of racial bias is extremely important as it's led to severe consequences for racialized communities in the past, and I think it's important to investigate racial disparities in the dataset used to build the model."

- “There needs to be individual reflection on how results like this in industry and academic research can lead to enforcing societal problems (racism and discrimination of many other forms).”

Other participants highlighted questions about details of the scenario, such as assuming the intended population:

- “Do I understand that this model is potentially racist? Is this project actually going to see implementation? Would I change it if it was implemented in the real world, as this could affect many individuals in society with its racism? Why is the intended population in the design not including darker skinned individuals? Why am I getting a high grade if this model is potentially racist?”
- “The least important consideration here is the fact that you have your intended population ‘mostly’ accounted for. Instead, the dataset should equally cover all demographics to ensure the fairest results are produced by the model.”
- “Even though most of the intended population is accounted for, there are still other people that should be considered to increase inclusivity of the model.”

Going beyond identifying the model weakness, these responses demonstrate more critical thinking about the purpose and scope of the AI model itself.

1.3.6 Ethics Curriculum and Co-op Responses

Participants were also asked to reflect on how ethics is included in other coursework and co-op contexts and any obstacles they have experienced in using ethical concepts.[10] One participant said there hasn't been any use for ethical reasoning in their technical courses, while another had it integrated into their capstone project:

- "My other courses are technical and there hasn't been a need to include any ethical reasoning."
- "I have applied concepts like these in the Machine Learning fourth year capstone project I am working on such as looking into bias from the dataset we used and how we would be transparent with our future users and also how we would store their data to protect their privacy."

Participants were also asked if they had seen these concepts in their previous co-op placements:

- "I showed off [my knowledge of] these concepts and got a co-op placement."
- "I frequently work with data, privacy, and security concepts at my co-op workplace."

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[10] Only participants who were from the society and technology courses (identified as the Mechatronics and Other participants in Table 1) answered questions on ethics curriculum and co-op responses as described in section 1.3.6.

Though some participants have implemented these concepts, they also perceived obstacles to incorporating them into other courses, projects, or co-op placements:

- "There is often no opportunity to apply these concepts in school assignments."
- "Some obstacles could be the fact that projects at school are usually controlled environments where we aren't subjected to real world issues, such as algorithmic bias. It would be useful to have projects that do have these pitfalls in order to exercise our ability's to navigate them properly."
- "It hasn't happened before, but if my supervisor is largely dismissive of these ethical concerns then I would likely follow along to some extent."
- "A big obstacle is the fact that I'm a co-op student. Usually since I have this title I'm given less respect compared to other team members, so when I raise a concern usually they are weighted less compared to other (more senior) team members."

In summary, though many participants were able to identify and discuss how to mitigate the technical aspect of the issue in the scenario, few made connections with broader ethical or societal implications. Participants discussed the limited opportunities to apply ethical thinking in settings such as technical coursework and co-op placements, some obstacles being the lack of emphasis on ethics in their courses and their junior role in work placements.

1.3.7 Discussion

In their responses to the FRT scenario, most study participants linked the model weakness to insufficient dataset distribution and less than half discussed possible fixes, which included modifying or replacing the dataset to mitigate bias. Meanwhile, only 17.0% of participants noted how this issue could be resulting from or result in negative ethical implications such as discrimination. Nevertheless, the participants who noted potential ethical concerns raised critical questions about the purpose and implementation of the model. Teaching students to question the assumptions of a model's design and use should be a primary goal of any AI ethics course; the question is, how can educators best develop and instill this practice across the curriculum such that ethical inquiry is more embedded in the engineering workflow? A main obstacle observed by participants is the limited opportunities to practice thinking ethically in their technical courses and co-op workplaces. One participant suggested that "It would be useful to have projects that do have these pitfalls in order to exercise our abilit[ies] to navigate them properly."

Our results, in combination with evidence from our literature review on ethics education, suggest that sociotechnical pedagogical models would complement students' existing technical skills and enhance their ability to ask critical questions in mitigating complex ethical issues. Ideally, as noted by (Fiesler et al., 2020; Grosz et al., 2019; Tuovinen & Rohunen, 2021), a sociotechnical approach would be emphasized across the curriculum and not discussed in isolation from technical coursework. To explore how our FRT scenario could be addressed with a sociotechnical framework, we consider approaches proposed by

(Saltz et al., 2019) and (Krakowski et al., 2022). Saltz et al.'s question framework, designed for easy portability into technical ML modules, shows promise in supporting instructors who want to add ethics into their courses. It is practical for teaching alongside techniques for artificially modifying a dataset or how a model learns and asks questions that are applicable across different areas of AI. However, one limitation of this approach is its focus on ethical issues that can be addressed in the confines of their ML project and are not societal in nature – taken to mean that students are not explicitly prompted to more deeply consider the real world impact of their work.

Krakowski et al.'s framework, unlike Saltz et al.'s, is not connected with specific AI techniques, due to its initial application in high school curricula, and is thus less readily transferable to university courses. One advantage of Krakowski et al.'s framework is it contains broader questions about whether AI is an appropriate tool for the defined task, the data being used, the model's design, and how its output will impact the real world. This approach increases the potential for ethical inquiry, allowing for deeper engagement with different social contexts and concerns. This framework also resonates with responses to our study where participants questioned the intended population of the model and mentioned potential consequences for racialized communities. As noted by (I. Raji et al., 2020), striving for equal representation by adding more real samples of diverse individuals, for example, may contribute to greater privacy and consent issues and perpetuate discrimination of marginalized populations. Notably, of the participants who discussed possible fixes to the FRT scenario model, 73.3% blamed the issue on an insufficient dataset distribution and suggested modifying or replacing the dataset. The implications discussed in (I. Raji et al., 2020) and others is the type of ethical context that would be beneficial to discuss in a technical course because it makes clear the relevance of the social context to the technical solutions. Simply opting to modify or replace a dataset, though it might appear to address the issue at first glance, could elicit further undesirable consequences.

Connecting these two spheres of knowledge, as observed by (Tuovinen & Rohunen, 2021), is crucial in signifying the importance of ethics to students. Shown by (Krakowski et al., 2022), the ability to formulate critical questions demonstrates a more formal understanding of ethical concerns.

This is not an exhaustive review of sociotechnical pedagogical approaches; nonetheless, we envisage that a combination of Krakowski et al. and Saltz et al.'s frameworks could produce very interesting and constructive AI ethics curricula that enhances students' abilities to address problems with complex sociotechnical considerations.

1.3.7.1 Limitations and Future Research

By surveying engineering undergraduates from across multiple subdisciplines, primarily Systems, Biomedical, and Mechatronics, we are not able to generalize about the kinds of AI education they have been exposed to. Our sample composition does not reflect all disciplines that utilize AI; however, their engagement with AI is demonstrated by 45.1% of capstone projects from 2018–2022 containing AI related models. Regardless of whether AI and machine learning is a prominent topic in their undergraduate curriculum, many students across engineering have been, and are likely to be, engaged with this technology. For this reason, we suggest that AI ethics be a required component in technical classrooms across different disciplines. One limitation is that a paired analysis for the elective course was not possible; as a result, we are unable to comment on whether the elective course had any influence in participant responses. To this end, we can only reference their experience in the mandatory first-year professionalism course, as with all other participants.

Our survey design contained open-ended prompts (e.g., "Please explain how you would respond in this scenario") that did not explicitly prompt participants to provide solutions or explain the ethical concerns of the scenario. As such, we cannot assume that any participants who did not elaborate on ethics are unaware of these concerns. Krakowski et al. surveyed their participants on a similar FRT scenario but instead used phrasing "What questions do you have?" in their design – appearing to cue students to apply the framework they learned (Krakowski et al., 2022), when measuring a specific learning outcome, future work may consider survey questions with similar framing. Placing our scenario in a curricular context was beneficial, as participants were familiar with the stakes and options when responding, but also a hindrance when participants dismissed the significance of addressing an issue that would not have "real world" impact because it is only coursework. Future work could explore using a co-op, workplace, or community-based context with various stakeholders.

As with any voluntary study, there may have been selection bias in who participated based on interest or experience. Future research should continue to investigate findings on the various integrated ethics education methodologies; special attention should be paid to mitigating obstacles for and supporting instructors who want to embed more ethics in their technical teaching but lack resources to do so. This study is part of a broader project dedicated to integrating ethics across the engineering and tech curriculum at our institution. These results will contribute to informing the study's next iteration focused on first-year students. From there, we aim to scaffold ethics outcomes throughout undergraduate engineering programs. Our next steps also include collaborating with more engineering instructors to implement, assess, and compare ethical frameworks and other pedagogical strategies, particularly those with a sociotechnical approach.

1.4 Case Studies in EEE Literature

Following my presentation of Chapter 1.3 (Paper 2) at EAAI 2023, an audience member asked about my thoughts on the use of case studies for teaching ethics. Though it is one of the more commonly used approaches by engineering instructors, as observed in Hess and Fore's 2018 systematic review of EEE (Hess & Fore, 2018), case studies as an instructional method for EEE is a debated topic.

Multiple scholars favor case studies for their capacity to introduce the complexities of real-world ethical problems and allow students to define priorities and decision-making protocols based on the information provided (Harris et al., 2009; Lovrin & Vrcan, 2009; McGinn, 2018; Stephan, 2002). However, McGinn and Bucciarelli do not support the use of *hypothetical* scenarios (rather than case studies, which are based on real events) that seek “tidy solutions to ethical problems” (McGinn, 2018, p. 365); Bucciarelli is more interested in exposing engineering students to “the social complexities of engineering practice” than teaching about how to solve ethical issues (Bucciarelli, 2008, p. 144). On the other side of the argument, Yadav and Barry argue that there is “little empirical research on whether the use of cases is the most effective teaching method in promoting ethical understanding for engineering students” (Yadav & Barry, 2009, p. 142). Some scholars have moved away from case studies and hypothetical scenarios toward discussing current events, open-ended questions, and multi-disciplinary readings (Hitt et al., 2020; Zhu & Jesiek, 2017).

Acknowledging these mixed opinions, my dissertation draws inspiration from multiple approaches to case studies and hypothetical scenarios. In Paper 2, the FRT example is hypothetical yet based on current events and contains open-ended questions. In Paper 4, one of our critical design workshops introduces a hypothetical scenario in a futuristic context; in this instance, we are intentionally using a speculative design fiction approach to spur students to engage with ethics-related topics and technological implications. In Paper 5, the four case studies are real events to be used for inspiration as students think critically about the context that their course projects occupy. This is to say, I agree that a well-formulated case study or hypothetical scenario is a viable approach to introducing students to new perspectives, provided that the details do not tread so far from the students’ knowledge and experience that they are unable to assess the situation meaningfully.

The EEE literature on case studies and recent research in AI ethics informed my design of the FRT scenario in Paper 2. The negative impacts of FRT have been well-documented across disciplines for multiple years, making it a topic that is well-established in AI ethics literature. For example, Joi Buolamwini, Safiya Noble, Ruha Benjamin, and Wendy Chun are some of the influential scholars in the field of AI ethics, having published extensively about computing and race in the last decade. Gender Shades, a project led by Joi Buolamwini, is considered a groundbreaking achievement for its investigation of gender and skin-type bias found in gender classification models that misidentified dark-skinned women over 30% of the time (Buolamwini & Gebru, 2018; Hardesty, 2018). Based on the notoriety of this example, having a FRT scenario included in the survey seemed appropriate to establish a baseline of student awareness of AI ethics.

Despite the shortcomings of FRT being well-documented, I was intrigued by the results of Paper 2. Given that only 28.3% of participants described possible fixes and 17.0% of participants identified any ethical issues, I felt a sense of worry that participants, most of whom were in the third year of undergrad, had not been exposed to conversations about bias in AI.[11] However, as noted in the Discussion section of Paper 2, the survey did not explicitly prompt participants to describe any ethical issues – only to describe how they would respond and what they think is important to consider. While the study does not conclude that students are unaware of ethics, it nonetheless illustrates that the ethical dimensions of this type of scenario are not at the forefront of their thinking. Ideally, students wouldn't need to be

[11] Other researchers have similar findings: in another study using scenarios to benchmark students' recognition of ethical dilemmas, Shuman et al. found that engineering students could recognize the most obvious dilemmas but struggled to see more subtle, "gray" areas of concern and consider multiple perspectives (i.e., all key stakeholders) in the scenarios (Shuman et al., 2004, p. 11).

explicitly reminded to consider ethics but would do so intuitively. The results and discussion of Paper 2 indicate there are opportunities for growth in terms of designing a curriculum that engages students in ethics and related topics more directly.

1.5 Teaching Ethics of Generative AI

Since the research in Paper 2 was conducted, another form of AI technology has harnessed the attention of students and educators across the entire university: namely, generative AI tools such as ChatGPT and DALL-E. Generative AI – as a recent example of AI technology that perpetuates bias, misinformation, and discrimination of marginalized groups – presents unique challenges to all educators. Generally speaking, educators are concerned about students using it to complete or supplement their assignments in a manner that undermines learning outcomes and standards of academic integrity (Coffey, 2024). I have considered the implications of generative AI in my day-to-day professional life as a writing and composition instructor. I also acknowledge the ethical concerns about teaching with generative AI, such as its environmental footprint, the privacy and security of students, and the risk of perpetuating bias and misinformation (Wilkes, 2024). In this section, I am going to focus on how the topic of generative AI could be framed as a case study in engineering ethics education.

As educators of AI ethics, we need to consider a bigger picture when using generative AI as a case study based on recent events. Educators need to make a transition rather than merely *suggesting* to students that technology is biased (through a case study or scenario), we need to develop strategies for allowing students to *discover it themselves* and then equip them with the critical thinking skills that will allow them to evaluate technology as it evolves in the future.

For instance, the spring 2023 offering of Marcel O'Gorman's undergraduate "Technocritical Writing and Design" (ENGL 494) course invited students to experiment with generative AI in their assignments. In one assignment, a student prompted DALL-E 2 to generate a "1960s magazine ad for a hair clipper where a white man is giving a black man a haircut" (McAlmont, 2023; O'Gorman, 2023). But this prompt would not compute. Instead, DALL-E 2 produced a collection of awkward images with two men and a hair clipper arranged in different positions… none of them visually represented the prompt exactly as written. As O'Gorman writes, the image generator "struggle[d] against the constraints of its own racist data set" and could not produce an image from which there is no historical precedent (O'Gorman, 2023). This assignment exemplifies a more participatory discovery process where students learn to assess technology firsthand, rather than through a more passive analysis of a case study. Anecdotally, I have spoken with other instructors who have also experimented with assignments that invite students to engage directly with generative AI; in one case, the students had to fact check information produced in a large language model for their research project. Afterwards, the students bemoaned how much more difficult this task was than conducting the research and evaluating their own sources to begin with. One of the benefits of this type of activity is that it prompts students to consider the labour that is involved in ethically engaging with generative AI.

In Paper 2, I noted that more research on algorithmic auditing has been coming out in recent years and that inserting it into AI ethics curricula is an area for future work. Shortly after the paper was published, I learned of a spring 2023 AI ethics seminar led by Daniel Estrada at New Jersey Institute of Technology wherein students performed external audits of ChatGPT, DALL-E, and DALLE-2. Inspired by the algorithmic auditing framework developed in (I. D. Raji et al., 2020), Estrada's course contained a five-week project that separated students into teams dedicated to different scoping and testing mechanisms in the audit framework (Estrada, 2023). Afterwards, the teams wrote a summary report in which they reflected on the results and completed their ethical analysis of the generative AI tools. Again, this is a fantastic example of hands-on AI ethics pedagogy.

Notably, O'Gorman and Estrada's courses were both listed as humanities courses. Though they may have been accessible to students outside of humanities departments (which I confirmed was the case for O'Gorman), the likelihood of Science, Technology, Engineering, and Math (STEM) students self-selecting into a humanities elective remains low. Based on the research I conducted for Papers 1 and 2, I would propose that these types of interventions would also have value in more technical contexts, such as those designed by (Krakowski et al., 2022) and (Saltz et al., 2019). Having said that, I recognize the challenges of offering a course that demands such breadth of interdisciplinary expertise on the part of the instructor.

Since generative AI gained popularity in late 2022, educators have shared their resources across online pedagogical communities (Estrada, 2023; Holmes & Pelletier, n.d.;

The AI Pedagogy Project – metaLAB (at) Harvard, n.d.). But even with the combined efforts of educators from around the world designing new assignments and assessment criteria, I share educators' anxieties that the university curriculum will struggle to keep up with the changes implemented by the companies who build generative AI tools and the students who use them in creative and novel ways (Schroeder, 2023).

Using and analyzing the outputs of generative AI is how students will learn their affordances and limitations firsthand. Generative tools might also illustrate compelling case studies for speculative thinking about sustainability, for example, such as the Products of Place and Regenerative Futures projects featured at the Space10 Design Lab (Space10 Design Lab, 2023). Moreover, I reiterate my position that case studies and hypothetical scenarios are useful for teaching ethics if they are contemporary, relatable, and intentionally chosen for the students' academic and professional contexts. Case studies, as well as alternative approaches to ethics pedagogy, should seek to foster critical thinking skills that will enable students to question and evaluate the future technologies that will arise over the course of their careers and lifetimes; this is true, even if future technologies do not have the same features or uses as the exact examples (e.g., a facial recognition model or generative tool) that they study during coursework activities.

So far, the papers in Chapter 1 have focused on communication-based and case study methods for teaching ethics in select courses and cohorts. As Papers 1 and 2 have shown, bringing more ethics into engineering curricula and embedding it in sociotechnical contexts can be challenging for individual educators if they are not required and/or encouraged to do so. How might a dedicated teaching unit for ethics and related topics in an engineering department approach these challenges? Additionally, how might a program or department be structured to reinforce the importance of ethics to students through course offerings, cross-curricular programming, and sociotechnical collaboration and leadership with educators and scholars from multiple disciplines? In Paper 3, I expand the scope of this research to the program level in a study of the Centre for Society, Technology, and Values at Waterloo. Paper 3 focuses on how CSTV is situated as an "embedded Science and Technology Studies (STS) program" in the Department of Systems Design Engineering that acts as a teaching unit for engineering students to fulfil the CEAB attributes for "ethics and equity" and the "impact of engineering on society and the environment" (Engineers Canada, 2016). While the previous subchapters have focused on more individual interventions, courses, and cohorts, Paper 3 observes the curricular, cultural, and institutional opportunities and obstacles that come with a centralized teaching unit for teaching ethics and related topics to engineers and non-engineers through an STS lens.

Paper 3: Opportunities and Obstacles for an Embedded STS Program in Engineering[12] [13]

1.5.1 Introduction

Since the early 2000s, the Canadian Engineering Accreditation Board (CEAB) and the Accreditation Board for Engineering and Technology (ABET) have required Engineering graduates to demonstrate knowledge of engineering ethics and the social and environmental impacts of technology. Accredited engineering programs in Canada must demonstrate that their courses fulfill the CEAB requirements for students to gain proficiency in the 12 Graduate Attributes, including #9, "impact of engineering on society and the environment" and #10, "ethics and equity." Depending on an individual institution's resources, they may have a variety of ethics course offerings – some taught within a technical context and others from a humanities-based, philosophical perspective (Herkert, 2000; Hess & Fore, 2018).

Another model for providing ethics and social impact instruction in engineering is the "Embedded STS Program," where the institution's Science and Technology Studies (STS) program is housed directly within their Engineering or Computing faculties (Seabrook et al., 2020). In the last twenty years, engineering ethics scholars have discussed how STS, a field rooted in the humanities and social sciences, can inform engineering ethics scholarship and pedagogy (Bucciarelli, 2008; Conlon & Zandvoort, 2011; Herkert, 2006; Kline, 2001; J.

[12] Orchard, A. (2024). Opportunities and Obstacles for an Embedded STS Program in Engineering. *Proceedings of the Canadian Engineering Education Association (CEEA)*. Paper 67.

[13] This study received research ethics clearance from a University of Waterloo Research Ethics Board (REB #43726).

Pritchard & Baillie, 2006). The University of Virginia and Concordia University are two institutions with embedded STS programs. The Colorado School of Mines, University of Toronto, North Carolina State University, and Rensselaer Polytechnique Institute, among others, also have STS instructors and/or integrated STS courses in their engineering programs.

Our institution, the University of Waterloo, has an STS-like teaching unit – the Centre for Society, Technology, and Values (CSTV) – housed within the Department of Systems Design Engineering (SYDE). The motivation of this paper is to describe the challenges and opportunities observed through the CSTV embedded program, including some of the limitations of this type of program and the infrastructural conditions that are necessary for its success. We contextualize this discussion with our own survey study of students who took a CSTV course in 2022. The 43 responses, from across seven CSTV courses, provide qualitative feedback on how students perceive the relationships between the course concepts, their other technical courses or projects, and their cooperative (co-op) work placements.

There are clear arguments for and observed benefits to embedding STS pedagogy in the engineering curriculum. Based on prior literature in this area and our analysis of the CSTV program, we conclude that for an embedded STS model to be effective, there needs to be resources, leadership, and collaboration among the institutional and departmental stakeholders at large.

1.5.2 Background

1.5.2.1 Engineering Ethics Education

Engineering ethics is commonly taught in standalone courses, technical courses with integrated ethics content, or a mixture of both (Herkert, 2006; Hess & Fore, 2018). Standalone ethics courses can be taught within the engineering department or outside of engineering by philosophy or other humanities-based faculty (Walczak et al., 2010). The dominant approaches to engineering ethics pedagogy, namely, the focus on professional codes and paradigmatic case studies, have been criticized for their emphasis on the individual's responsibility and actions. Donnelly and Boyle argue that these two approaches are insufficient for preparing students to address complex engineering problems (Donnelly & Boyle, 2006). We agree with Conlon and Zandvoort in that the narrow conceptualizations of social, environmental, or ethical responsibilities presented to students may need to be changed for engineering to actually contribute to public welfare (Conlon & Zandvoort, 2011).

Still, the engineering curriculum is very full and it can be difficult for instructors to find extra time in the curriculum to engage topics that are not explicitly required to be taught (Walczak et al., 2010). It is more common to see the "ethics and equity" Graduate Attribute attached to courses that are not focused on the technical aspects of engineering training.

We also note the significance of department and instructor origin as a factor for student engagement: when ethics is taught outside of the department and/or by a non-engineering instructor, students may perceive ethics topics to be less relevant or applicable to their technical coursework and professional obligations as an engineer (Colby & Sullivan, 2008; J. A. Leydens & Lucena, 2017). Multiple researchers have suggested that integrating ethics content across the curriculum such that students are exposed to and learn to apply concepts in a variety of technical and non-technical contexts is a promising approach (Fiesler et al., 2020; Grosz et al., 2019; Hipp, 2007).

However, not all engineering instructors have been exposed to ethics in their own training and lack the expertise and confidence to broach ethical topics in the classroom (Burke et al., 2020; D. Johnson, 1994; Walczak et al., 2010). While it is beneficial for students to have engineering instructors who emphasize the importance of ethics and equity (Agnes d'Entremont et al., 2022), the inverse sentiment also has merit: exposing students to expertise from the humanities or social sciences helps them to envision and relate to other stakeholders and perspectives (Fiesler et al., 2020).

1.5.2.2 Science and Technology Studies

In the 1970s, STS emerged from fields including history, sociology, philosophy, and anthropology with the objective of developing "an empirically informed view of the social nature of scientific knowledge" (Jasanoff et al., 1995). STS has evolved through four phases, with foci on (1) the impact of technology in society, (2) technology as a social construction, (3) technological literacy for engineers and non-engineers, and (4) participatory processes in science and technology (J. A. Leydens & Lucena, 2017).

During the late 1990s and early 2000s, STS served as a complement to engineering ethics education (EEE) literature in the context of developing integrative, sociotechnical approaches that engage both engineers and non-engineers (Neeley et al., 2019). In recent years, EEE research has continued to be interested in developing more assessment methods for sociotechnical, humanities-informed engineering ethics instruction (Neeley et al., 2019).

Engineering ethics scholars have suggested that STS methods and concepts are well-suited to help address some of the known obstacles to EEE (Conlon & Zandvoort, 2011; Herkert, 2006). Scholars argue the engineering classroom should be open to more discussion and debate about the social and political interests that shape the technology that engineers produce (Bucciarelli, 2008; J. Pritchard & Baillie, 2006). There are multiple STS perspectives that could facilitate this engagement, including liberation pedagogy (hooks, 1994), feminist theory (Åsberg & Lykke, 2010; Riley et al., 2009), and democratic engagement from STS (Lee Kleinman et al., 2007; Odumosu et al., 2018). There is clearly potential for STS programs to make strong contributions to EEE.

Johnson and Wetmore argue that STS concepts and theories can help engineers recognize their role in building sociotechnical systems (D. G. Johnson & Wetmore, 2008). With that said, Patrick notes that it is not enough for students to be aware of the sociotechnical systems they work on, but they must also respond to the impact of their work on society (Patrick, 2021). To this end, Hodson advocates for an action-oriented STS curriculum wherein students ask critical questions about how science and technology could be conducted differently and how action can be taken at individual, group, and community levels to influence policy and practice (Hodson, 2020). For example, the University of Maryland offers STS service-learning opportunities for students to collaborate with engineers and scientists on projects related to education, robotics, infrastructure and safety, and communication (*Science, Technology and Society Program | College Park Scholars*, n.d.). It is relevant that these service-learning activities are connected to the STS program, as it allows students to put their classroom learning into another context.

In addition to making experiential learning[14] connections, it is beneficial for students to relate STS content to other technical courses in the curriculum. Multiple educators reinforce the importance of integrating discussions of ethics and social impact across the curriculum (Colby & Sullivan, 2008; Fiesler et al., 2020; Lonngren, n.d.; Neeley et al., 2019). However, Hess and Fore found that micro-insertion – directly embedding ethics content into technical curricula – is rarely used in engineering education in the United States (Hess & Fore, 2018). Some reasons for this trend might include the already full curriculum and lack of buy-in from instructors (Walczak et al., 2010).

1.5.2.3 What is an Embedded STS Program?

An "Embedded STS Program" refers to a unit that exists organizationally and sometimes physically within a larger engineering space (Seabrook et al., 2020). It is a way for institutions to fulfill the ethics- and society-related accreditation requirements by making space for

[14] Cooperative education is an example of an experiential learning opportunity offered by the university; we do not use "experiential learning" in reference to educational research found in (Kolb, 2015), for instance.

instructors with expertise in technology and society (and often in engineering education) to work within the context of the Engineering department.

Some strengths of this type of program are that STS scholars are able to influence curriculum design, hiring, and tenure committees, as well as engage intellectually with the Engineering faculty (Seabrook et al., 2020). By maintaining the connection between Engineering and STS, the program suggests to students there is reason for and value in understanding the social impacts of Engineering, as opposed to an arrangement where the courses are external to the department and possibly framed as 'supplementary' to the technical aspects of the program (Cech, 2014). An embedded program will ideally help to overcome disciplinary silos and discourage beliefs about the superiority of technical versus non-technical expertise.

As noted in the Introduction, there are multiple schools with embedded STS programs to which to compare with Waterloo's model. The University of Virginia, for instance, has embedded STS outcomes throughout their undergraduate engineering program. Starting in first year, students take a four-course sequence that prepares them for a major STS project in their final year (Foley & Gibbs, 2019). In their final year, students write "a STS research paper that uses concepts from HSS [humanities and social sciences] to develop a deeper understanding of a social/ethical issue related to the development of a new technology" (Odumosu et al., 2018). This paper is reviewed by faculty members in the Department of Engineering and Society.

Seabrook et al.'s examination of Concordia University and the University of Virginia suggests that their embedded programs are not merely a teaching service for the Engineering department (Seabrook et al., 2020). Embedded STS educators would ideally have pedagogical autonomy, maintain participation in the governance of the faculty and institution, and pursue independent research agendas in addition to interdisciplinary research and outreach efforts (Seabrook et al., 2020). Additionally, by incorporating STS educators in the department, it would ideally discourage the perception that they are a service unit that "handle[s]" the teaching of ethics so that other Engineering faculty do not have to (Seabrook et al., 2020).

1.5.2.4 Connecting the Ethics Curriculum to the Workplace

In recent years, engineering education scholars have turned more attention to the benefits of experiential learning (cooperative education and internships), focused mostly on student skill development (Burke et al., 2020; Chen et al., 2018; Dansberry, 2012; Gordon et al., 2017; Harsh et al., 2015; Liu et al., 2020). There is little research discussion (so far) around the ethics curriculum and experiential learning specifically.

Two survey studies on Waterloo Engineering reported that students found few opportunities to engage with ethical discussions in their co-op workplace because they felt a lack of seniority; thus, they felt a lack of confidence with identifying issues (Orchard & Radke, 2023a; Truax et al., 2021). Some students also felt that their coworkers or employer would not care about those concerns in favor of profit and efficiency (Orchard & Radke, 2023a; Truax et al., 2021). These findings are concerning, though unsurprising, in light of the fact that

Waterloo is one of the top feeder schools to Silicon Valley (Pender, 2018). The ultra-competitive, "Cali-or-bust" mindset does little to incentivize students to engage further with social and ethical issues (Truax et al., 2021).

The lack of emphasis on social and ethical issues at the undergraduate level can have significant ramifications as students move into the workplace. At a "Responsible Engineering" event held by the Waterloo Engineering Alumni Association in January 2024, one panelist described their post-graduate work experience as an unfortunate awakening to how much social justice is overlooked in the workplace and how unprepared they felt to address these concerns. Upon witnessing and being unable to address these issues, the panelist admitted to quitting their job. In their words, the courses on society and technology that could have helped them make sense of these issues were not taken seriously, and instead were perceived as "secondary and unimportant" (Waterloo Engineering, 2024). The panelist reflected that there is a need for a cultural shift about these courses and ideas before engineers can learn to be accountable for social justice and related ethical issues. As an affirmation of this type of anecdotal evidence, our study suggests that the ethics curriculum at Waterloo does not resonate with the co-op and work experience and thus reinforces the expectation that learning about ethics is less important to engineering generally.

1.5.3 Study of the Centre for Society, Technology, and Values

1.5.3.1 Study Context

At the University of Waterloo, the CSTV program teaches over 600 students each year, primarily from Engineering programs (*Society, Technology, and Values Option*, 2016). CSTV courses are Complementary Studies electives that apply historical and philosophical lenses to topics in engineering, design, and technology; their pedagogical approaches are similar to those found in STS.

Students from any program across campus are eligible to enroll in CSTV courses but they are primarily geared toward Engineering. The CSTV also offers an "Option" for students to receive credit for completing five courses and a final research project in the program. Few students enroll in the option as they do not typically have time in their schedule for this commitment. Furthermore, because Engineering students have only four electives throughout their degree, and only one of them needs to be related to the impact of technology and engineering on society (University of Waterloo, n.d.), it is possible that a CSTV course is many Engineering students' first (and potentially, only) semester long curricular exposure to learning about the social impacts of technology.

1.5.3.2 Participants

This study targeted students who were enrolled in a CSTV course during the 2022 calendar year (Winter 2022, Spring 2022, and/or Fall 2022 semesters). The seven CSTV courses surveyed include: Introduction to STV (offered twice, Fall and Spring terms); Design and

Society (offered twice, Fall and Spring terms); Artificial Intelligence (AI) and Society; The Computing Society; Cybernetics and Society. The instructors who volunteered to advertise this survey to their courses are not on the research team.

We received 43 total responses: 33 students majoring in Engineering and 10 students majoring in other disciplines. The top two Engineering majors represented in this sample are Mechatronics (18%) and Chemical Engineering (18%).[15] Other majors include Software and Mechanical Engineering. Notably, there is only one Systems Design Engineering (SYDE) participant in this sample. Though CSTV is in SYDE, it provides its own Human Factors course to address CEAB requirements; therefore, CSTV sees few students from its home department.

The non-engineering majors include Health, Math, Computer Science, and others. Across the entire sample, 69% of participants had already completed one or more cooperative work terms, mostly in the software, automotive, and manufacturing sectors (see Table 2). Table 2 shows how many co-op terms have been taken in total across the participant group (e.g., one student may have worked in Software for one term and Automation for one term, for a total of two terms that contribute to the totals in the left column). The majority of the survey participants are in their second and third year of the degree and have thus taken multiple co-op terms. Note that engineering students typically have six co-op terms over the course of their degree.

[15] This is a calculation error in the published version. It should read 23.3% for these two majors, rather than 18%. A full table of the participant demographics can be found in Appendix A.

Table 2: ***Full Sample: Number of Co-op Terms Taken by Participants in Type of Industry***

Co-op Terms Taken	**Type of Industry**
8	Software
6	Automotive
6	Manufacturing
5	Medicine/Healthcare
4	Automation
3	Consulting
23	Other Industries
Total: 55	

1.5.3.3 Survey Instrument

This survey was part of a larger study investigating the impact of engineering ethics and responsible design curriculum at the University of Waterloo. The survey asked short answer questions related to participants' experiences in the CSTV course. We initially planned for a pre/post survey but did not harvest enough participation to complete the paired analysis. The results presented are post-course survey responses only.

1.5.4 Results and Analysis

The first short answer question "What concepts did you learn in this course?" elicited high-level summaries of the participants' main takeaways from the course content. For example, participants listed privacy, algorithmic bias, equity, security, fairness, and transparency as main concepts in the AI and Society course. We included this question to help prompt participants' recollection of the course before inviting them to reflect on it. We include a summary of the responses in this paper to provide context for the reader (see Table 3).

Table 3: ***Course concepts summarized by participants.***

Course	**Course Concepts**
Introduction to STV (STV 100)	Technological determinism; social shaping; designer's values; techno-optimism; techno-pessimism; history of technology; technological momentum; cultural impacts of technology
Design and Society (STV 202)	"Good design"; moral responsibility of designers; social contracts; activism; fairness; justice; rational design; social psychology; unintended consequences of design
AI and Society (STV 208)	Facial recognition; algorithmic bias; privacy; equity; security; governance; AI in policing; model of threat; abuse of AI technology; transparency
Cybernetics and Society (STV 205)	Technological dissonance; transhumanism; surveillance capitalism; impacts of automation
The Computing Society (STV 210)	Anti-trust law; technology patents; funding technology; how world events impact technological development; history of technology

The next questions asked participants (n) if they had applied CSTV concepts in other courses or their co-op workplace (Yes/No response), and to explain any obstacles in doing so. In coding this data, we were able to categorize responses by their initial Yes/No and then identify themes based on their description of the opportunities in which they've applied concepts and/or the obstacles that have prevented them from doing so. Table 4 shows a summary of the most frequent obstacles students saw in applying the CSTV course concepts to other courses or projects and in a co-op or other workplace environment.

Table 4: ***Engineering Participant (N) Responses***

Obstacles to Applying Course Concepts	**Quotations Representative of Each Theme**
To Other Courses or Projects	
Theme 1: Concepts are not applicable to other courses (11)	"Definitely not in other courses as it's not very applicable." "No, it has not been relevant to other projects."
Theme 2: No opportunity in other courses to discuss or apply these concepts (5)	"I have not yet applied concepts of this course because I haven't had many opportunities to relate to design and society. I am in engineering and most situations involve calculations."
In the Workplace	
Theme 3: The workplace does not prioritize social or ethical issues (7)	"Time constraints: considering this stuff would add time to the design phase." "The theories I've learned are very interesting but not fully applicable to the types of jobs I'll be getting." "In Mechanical Engineering, the impact of technology on society isn't often considered, it is not an argument that is considered when designing a new product. An important aspect is often cost."
Theme 4: No power as a co-op student or junior employee (6)	"As a co-op student, you aren't in the position to make decisions that have a large ethical significance." "[A potential obstacle is the risk of] conflicts with management or coworkers [or] potential loss of work."

In the right column, we include a sample of participant quotations corresponding to the themes identified. Note that these quotations were taken only from Engineering major participants in our sample.

In Table 4, the main themes from the Engineering participants' responses are that (1) course concepts are not applicable to other courses; (2) there are no opportunities to discuss or apply these concepts in other courses; (3) the workplace does not prioritize social or ethical issues; and (4) students do not have any decision-making power or seniority as co-op or junior employees. We differentiated between themes (1) and (2) because a student's view that concepts are not applicable could be interpreted to extend from the perception that ethics and social implications are not relevant to Engineering, whereas a student who does not see the opportunity to apply the concepts may be accepting of the concepts being in other contexts but have not applied them there.

Four Engineering participants mentioned seeing the opportunity to consider CSTV concepts in another course: in a capstone design course (2), in a course on Organizational Behavior, and in another CSTV course. Five Engineering participants stated they have not connected CSTV course concepts to their other coursework or workplace experience, but the CSTV course did inspire them to think about bias, decision-making, and perspective-taking in the context of their everyday lives.

We found that non-Engineering participants do not show a marked difference from Engineering participants in terms of applying course concepts in other contexts. Seven of the ten non-Engineering participants indicated that they had not seen opportunities to transfer CSTV course knowledge into their other courses, projects, or workplaces. A fourth-year Health student noted that they've learned some of the concepts elsewhere and the CSTV course "provided a good refresher" and a "more technological view on concepts I already know." A second-year Astrophysics student lamented the lack of opportunity to apply these concepts in their other courses, stating "I barely even write three sentences in most of my projects unfortunately…but I love what is taught in CSTV classes and finding a way to merge the two [Astrophysics and CSTV] would be interesting."

The non-Engineering participant responses about workplace obstacles were similar to those of the Engineering student responses. Two students from Health (Year 4) and Science (Year 3) suggested that coworkers may not value the concepts from the courses. The Math student responded that software developers "rarely analyze what they're building."

These results indicate that students across different disciplines see the challenges of bringing STS knowledge to bear on their professional status as a co-op student and question whether the course concepts would be suitable to discuss in the workplace.

1.5.5 Discussion

1.5.5.1 Making Cross-Curricular Connections

One of the main themes in the Engineering participants' survey responses is that CSTV content does not often relate to other courses. Some participants possess the view that these concepts are not relevant to engineering generally. Some Waterloo Engineering students will take only one (required) course related to the ethics and values of technology during their degree. One participant writes, "In Mechanical Engineering, the impact of technology on society isn't often considered, it is not an argument that is considered when designing a new product. An important aspect is often cost." This comment suggests a lack of engagement with some of the political and social interests that drive the demand for a Mechanical Engineering profession in the first place.

The Math participant also noted that it is “rare” for software developers to need to analyze the design of what they’re building; given that Math is adjacent to Engineering disciplines and career paths, it is alarming that a student would believe this about the nature of their work. We suggest that a single term’s exposure to select STS concepts, with no explicit connection to other courses or the workplace, is not enough for students to grapple with the relationship between their career, technology, and society.

In Table 4 under Themes 1 and 2, we see 11 participants responded that CSTV concepts are not relevant to other courses, while five participants said that there is no opportunity in other courses to discuss or apply these concepts. These are two separate problems and they have a reciprocal effect on each other: (1) if students do not have the opportunity to discuss these concepts elsewhere, they are less likely to see the relevance and applicability of them in broader contexts, and vice versa, (2) if the concepts are not already visible in other contexts, students may not see the relevance of taking a CSTV course in the first place.

1.5.5.2 Facilitating Ethical Engagement

To what extent is it an STS unit’s obligation to align their curriculum with what technical instructors are teaching? And secondly, what role do Engineering instructors have in engaging with ethics and social responsibility, particularly if it is not their explicit duty per the accreditation requirements? These questions connect back to Seabrook et al.’s formulation of an ideal embedded STS model in that the unit would be not merely a teaching service for other program-specific engineering departments. To extend that, the ideal embedded STS model would not be a “check box” for fulfilling accreditation but a model where STS educators have pedagogical autonomy, participate in department governance, and conduct independent research activities.

One opportunity for CSTV to be better integrated with Engineering programs could be by connecting with their capstone design course requirements. All capstone projects must examine the social and ethical implications of their work to fulfill CEAB Graduate Attributes. Aligning CSTV course content with capstone project outcomes would increase the relevance of CSTV to Engineering students, even if, for some, it is a primarily extrinsic motivation to improve their score. This idea is similar to having a final STS paper part of the final thesis project at the University of Virginia (Odumosu et al., 2018). Like Virginia, it would also be beneficial to scaffold the CSTV course requirements strategically so that students will have built up some experience with STS before their final year. To accomplish this, the relationship between an embedded STS program and the Engineering faculty must be mutually cooperative, which can only be accomplished with the appropriate organizational structure and top-down messaging that reinforces how social and ethical impacts are an essential part of Engineering.

It is important to recognize, however, that instating this type of requirement on students means that the staff and faculty of the CSTV would need to grow significantly in order to support approximately 1,500 students doing capstone projects each year (2023 final capstone term enrolment) (*Student Headcounts*, 2015). Depending on the level of interaction that students would have with the CSTV (outside of taking a course initially), simply adding this requirement without investing in the growth of the CSTV would likely result in the faculty being overloaded and unable to provide adequate consultation. This would again put more onus on CSTV members to keep up with Engineering enrolment and curricular requirements rather than there being a supportive relationship that reinforces the significance of social and ethical implications to students. Through this program, the departments and institution themselves need to demonstrate and champion socio-technical leadership and collaboration.

Based on past research (Neeley et al., 2019; Odumosu et al., 2018; Seabrook et al., 2020), the embedded STS model has potential to enhance learning outcomes related to ethics, social justice, and responsibility. At the same time, we do not discount the benefits of a cross-curricular ethics program (Grosz et al., 2019) – which may well be the gold standard. Having said that, the cross-curricular ethics program is a demanding approach that requires a higher level of stakeholder coordination. However, it takes leadership, resources, and buy-in from departments and institutions to manage the curricular obstacles that hinder students in engaging with these concepts in a meaningful way.

1.5.5.3 Connecting Curricula to the Workplace

Multiple participants in this study, from both Engineering and non-Engineering majors, have not encountered CSTV concepts in the workplace, and suggest that there are conflicting priorities (e.g., time constraints, profit-seeking) that would discourage them from initiating that type of conversation as a student. As recent research in entrepreneurship indicates, this type of perception is fairly widespread: in multiple cases, the culture of engineering and tech workplaces does not readily embrace the integration of social and ethical considerations into technical contexts either (Ali et al., 2023).

We also acknowledge when we talk about "ethics in the workplace," this could mean different things in different contexts. In this study, it is clear that we are not referring to ethics as it relates to, and is sometimes conflated with, equity, diversity, and inclusion (EDI). Lessons about EDI could be extrapolated from course discussions about values, fairness, and transparency, for example, but it was not the focus in this study. Rather, we refer to the high-level summary of topics that students provided (see Table 3), including technological determinism, social contracts, algorithmic bias, privacy, and anti-trust law. Some of these topics are more abstract, such as technological determinism, and it is understandable why students might not have conversations about it in the workplace. The topic of algorithmic bias, on the other hand, is a prevalent issue and students should be aware of how it could impact their work and workplace.

With that said, it our opinion that not every STS concept is or needs to be "productive," in the traditional sense, for the workplace. To this end, STS concepts do not only promote critical thinking *in* engineering practice but also *about* engineering, including expectations and norms in the profession at large (Claris & Riley, 2012). For example, students – not only as engineers but as citizens who can participate in political and cultural conversations – would benefit from learning about the history of technology to more broadly understand topics such as decolonization, eugenics, and sustainability. We maintain that it is important for future graduates to understand how to practice ethical engineering, while also having the ability to think critically about historical precedents that have led the engineering profession to exclude, discriminate, and disregard certain peoples and issues in the past and present.

Although this paper observes both educational and professional workplace factors, as researchers and educators in the academy we have limited access to the co-op and internship workplaces that are discussed. That being so, it would be beneficial for educators and students to be able to connect learning outcomes with work experiences. For instance, the co-op program at Concordia University runs a mandatory reflective learning seminar for all students on co-op; in describing the intent of this seminar, Harsh et al. note that “experience alone may not lead to planned learning outcomes, so finding creative ways to promote reflection on experience becomes critical” (Harsh et al., 2015, p. 1). In future research and work, educators, administrators, and the university co-op/internship personnel should consider how they can improve the student experience with learning about the ethical and social impacts of technology.

1.5.5.4 Limitations

One limitation to this study is the relatively small sample size and unequal representation of all Engineering majors that take CSTV courses. We included the non-Engineering participants in this sample to see whether they would have different perspectives on the course or their workplace experiences. Some non-Engineering participants had been exposed to the course concepts elsewhere beforehand and were open-minded toward the ideas. We argue it is a benefit that the CSTV courses are open to any student on campus. A study of an interdisciplinary ethics course suggested that a mixed cohort may foster community building across disciplinary divides: Tang et al. noted that the students learned they needed to understand the methodological basis behind the views of their counterparts to have productive collaboration (Tang & Lee, 2020). Multiple studies have also found benefits to students' critical thinking, problem solving, and creativity through learning and collaboration between engineers and non-engineers (Borrego & Newswander, 2008; Lattuca et al., 2017; Yazici et al., 2020). Because the CSTV courses are open for enrolment to any student on campus, the program is already equipped to offer a interdisciplinary, multi-stakeholder learning environment well-suited to STS pedagogy. This would provide an opportunity for students in Engineering-adjacent disciplines, and other backgrounds, to explore the intersections of their studies, STS concepts, and other expertise across the university. It is an interesting area for future curricular development and research.

1.6 Accreditation

Paper 3 is not syllabi review of the existing CSTV courses; however, based on the course summaries (see Table 3), a cursory review of the learning outcomes, and course requirements found in the Undergraduate Calendar, it is not guaranteed that any given CSTV course will specifically address Graduate Attributes "ethics and equity" and/or "impact of engineering on society and the environment." Because CSTV courses are considered Complementary

Studies electives, among multiple other courses across all faculties at the university, it is not clear if they are thoroughly vetted to actually contain these Attributes. Though CSTV courses are described colloquially by students and faculty as the “ethics” or “social impact” courses for Engineering, CSTV courses can have a broad range of topics, as shown in Table 3. Therefore, it cannot be guaranteed that any given Engineering student will graduate having taken one full course (at minimum) that specifically relates to the intersections between engineering, ethics, and social and environmental justice, unless their program has a dedicated “ethics” course (e.g., SYDE and BME). Despite CSTV being an embedded STS program in an Engineering department, their courses are not subjected to the same rigorous accreditation process as other technical courses. I do not suggest that, as Seabrook et al. warned against, CSTV should be reconfigured as a teaching service for Engineering programs to fulfill the CEAB Graduate Attributes. However, hundreds of Engineering students each year are taking a CSTV elective that has limited connection to the Graduate Attributes yet is being passed off as the “ethics” course during their degree. Having said that, I do not attribute the study’s findings to the CSTV curriculum being of poor quality. Prior research, as documented in the Background section, demonstrates the merit of bringing STS perspectives into EEE; however, for there to be a mutually supportive relationship between Engineering programs and CSTV, there needs to be more specificity as to which of CSTV courses can be explicitly linked to the Graduate Attributes.

1.7 Chapter 1 Conclusion

1.7.1 Curriculum

The studies in Chapter 1 provide a breadth of insight into the EEE curriculum at Waterloo. Taken together, the studies present a through line that illustrates the different ways that students are exposed to conversations about ethics and related topics. While these studies and student responses do not encompass a complete vision of the EEE curriculum at Waterloo, they do provide a constellation of individual touchpoints that illustrate the variety of strategies through which individual instructors, courses, and small-scale program initiatives attempt to reach engineering students on ethics-related topics.

Paper 1, *The Influence of Curriculum and Internship Culture [...],* discusses a mandatory communication course taken by Electrical and Computer Engineering students that embedded ethics and equity into the course theme by mimicking the professional environment of an accessibility tech company. Taking an ethics and equity lens to communication courses is not required by accreditation; it is the labor and initiative of individual English and Communication Arts instructors who bring humanities and social science expertise to their teaching. In Fall 2022 and Fall 2023, I taught this course with the ethics-related content included as well. With that said, only the students who happen to be enrolled in one of these tailored courses (as there are multiple sections of ARTS 190 with instructors who can design their courses to their liking) will have this extra opportunity to encounter how engineering work can contribute to equity, inclusion, and accessibility.[16] This is not to say there will not be more opportunities for students to engage with these topics, but this study of ARTS 190 demonstrates a unique model for educators to introduce ethics content early on and thus, provide a foundation from which they can build as they move into more advanced courses.

Paper 2, *An Analysis of Engineering Students' Responses to an AI Ethics Scenario*, includes the survey responses to a hypothetical AI ethics scenario but did not include a review of the courses that the SYDE and BME students had participated in previously. Though a syllabi review could have enabled a more granular analysis of EEE curriculum for these disciplines, the scope and purpose of Paper 2 was to establish a baseline for a sociotechnical understanding of an AI ethics scenario regardless of which major students were enrolled in. Though 77.4% of participants described the technical failure of the FRT model, only 17.0% of students identified the ethical concern. From this study and the discussion on generative AI in section 1.5, I conclude that the need for sociotechnical AI ethics pedagogy that is not bound to specific disciplines or case studies, but instead provides

[16] The majority of technical, scientific, and engineering communication textbooks used in courses such as ARTS 190 contain some discussion of ethics, so this is not to say there is no discussion of ethics in classes not specifically targeted toward that. For instance, I have used *A Strategic Guide to Technical Communication* by Heather Graves and Roger Graves (Graves & Graves, 2011). However, this textbook and others like it more often focus on ethical issues related to plagiarism and copyright, for example.

students with the critical thinking abilities to question the design and use of AI. This need does not apply solely to studying AI but can apply to all ethics of technology curriculum.

Paper 3 takes a birds-eye view to EEE and the institutional infrastructure around CSTV. Multiple other institutions across North America have embedded STS programs or interdepartmental STS instructors that teach the ethics and social impact of engineering. At Waterloo, CSTV offers important critical perspectives for engineering and non-engineering students alike; still, the Centre's status as a teaching unit in Systems Design Engineering almost prevents – perhaps not actively, but passively shelters – it from having a greater institutional impact.

As noted in section 1.7 on accreditation, the "hand-wavy" regard in considering CSTV a teaching service overlooks the potential value in having an explicitly cross-disciplinary, STS-like program that not only teaches the ethics of technology but also champions responsible design and sociotechnical collaboration at Waterloo. The efforts of individual instructors – not only of ARTS 190 but also in Computer Science, Sociology, History, Systems Design Engineering, and English Departments,[17] to name a few – exemplify the interest in having cross-disciplinary technology ethics-related curricula, research, and collaboration. Yet, Waterloo has failed to establish access to these opportunities from a

[17] This is a non-comprehensive list of cross-disciplinary technology ethics-related courses offered at Waterloo. Since 2019, I have enrolled, audited, and/or been part of collaborations in *Surveillance and Privacy* (SOC 701/CS 858), *Critical Design Methods* (ENGL 701/SYDE 760), *Digital History* (HIST 640), *Engineering and Peace* (PACS 315), and *Social Implications of Computing* (CS 492). Notably, CS 492 has been team-taught by two Computer Science instructors with legal expertise since 2016. Their course enrolment has more than doubled since, with their highest enrolment in Winter 2024 at 186 students (via the Waterloo Undergraduate Schedule).

centralized place. To fill this gap, a group of 13 faculty members from across disciplines formed the Council for Responsible Innovation and Technology (CRIT)[18] in 2019. Despite good intentions to advance responsible innovation through teaching, research, policy, and outreach initiatives, CRIT could not expand without institutional support and ceased operating in 2021.

In summary, these studies provide significant evidence that there is more work to be done at a curricular level in terms of incorporating ethics and related topics into learning outcomes and deliverables, as well as situating ethics as relevant and important to engineering work. To accomplish these goals, departmental and institutional support for instructors not only in the CSTV program but across the university is valuable and necessary.

1.7.2 Cooperative Education

Another through line in Chapter 1 is how the values espoused by cooperative education and internship culture conflict with some of the approaches and objectives of EEE curriculum. In all three papers, participants are asked about how their course concepts relate to other courses or projects and to their past or future work experiences. For example, the surveys ask participants to describe any obstacles to bringing ethics concepts into the workplace. The participant responses to this question largely fall into two categories: they have not or would not bring up ethics concepts in the workplace because (1) they are junior employees with not enough seniority to have input on those issues; or (2) the workplace is a profit-motivated

[18] https://uwaterloo.ca/research/resources/council-responsible-innovation-and-technology

entity where ethics, broadly construed and not limited to the specifics of *engineering ethics*, is not considered a top priority. These are both difficult obstacles that prompt different responses based on the workplace, the nature of engineering work, and the cultural and economic context lived in.

One example that speaks to the tensions around exercising ethical and responsible design in a co-op workplace occurred at an event hosted by the Critical Media Lab in 2022. In February 2022, the CML invited Wendy Hui Kyong Chun, author of *Discriminating Data,* Canada 150 Research Chair in New Media at Simon Fraser University, and Director of the Digital Democracies Institute, to present as part of the Critical Tech Talk speaker series (University of Waterloo, 2023). During the panel discussion, Dr. Chun was asked about how to empower engineering students who encounter practices or behaviors in their co-op workplaces that conflict with their values, beliefs, and learnings from university. In her response, Dr. Chun shared an anecdote from a co-op experience during which a male coworker offered a crude, misogynistic metaphor to help her remember the correct soldering procedure. In her initial disbelief, she had no way to respond as co-op student; instead, Dr. Chun discussed how she held onto that experience as she sought to explore, through studying HSS later in her undergrad, how technology is embedded with values (42:30 – 42:45): "Part of the reason I turned to the humanities was because I didn't have the skills from what I was being taught in engineering to respond to these [situations] adequately." For students who encounter difficult situations, she advised:

> “Never ignore it. If something is bothering you, you might not react immediately, you may need to think about it. You may need mentorship to help you because as an undergraduate co-op student you’re not in the highest position of power, but you can think about it, work on it, and you can make a difference. Maybe not in that work term […] but it is an opportunity for you to think through and engage things. You should never lose that sense that something is wrong and that something needs to be done.” (43:35 – 44:11).

Dr. Chun’s example provides an important reminder about power asymmetries in engineering and the workplace, affirming the experiences of students as described throughout Chapter 1. Dr. Chun’s example also aligns with what Kim et al. have described as the “displacement of responsibility” in that a student may be able to recognize the situational pressures and conflicts within a workplace but they have limited firsthand experience dealing with it (Kim et al., 2022).

Notably, Dr. Chun received her undergraduate degree from the University of Waterloo with a double major in Systems Design Engineering and English Language and Literature. By engaging with the humanities, Dr. Chun notes that she was able to better identify and explain the power asymmetries and patterns of systemic discrimination in the engineering field.

In spite of the obstacles described throughout Chapter 1, one of the primary objectives of this project is to explore multiple innovative, creative, and generative methods to prepare students with critical and ethical thinking skills that will enable them to navigate their careers and contribute to more equitable and inclusive communities. In the next chapters of this dissertation, I demonstrate ways that disciplines and perspectives in HSS are well-equipped to support this objective through multiple cross-disciplinary pedagogical interventions I conducted at the CML during my doctoral degree.

Chapter 2: Towards Interdisciplinary Ethics Pedagogy and Research

> "I used to think the top environmental problems were biodiversity loss, ecosystem collapse, and climate change. I thought that with 30 years of good science we could address these problems. I was wrong. The top environmental problems are selfishness, greed, and apathy, and to deal with these we need a spiritual and cultural transformation. And we lawyers and scientists don't know how to do that."
>
> – Gus Speth, Former Administrator – UN Development Programme, Author, Environmentalist, Advisor (Earth Charter, 2021)[19]

In December 2022, I attended the Faculty of Environment's TD Walter Bean Public Lecture featuring Dr. Shari Fox Gearheard. Dr. Gearheard is a Senior Research Scientist with the National Snow and Ice Data Center at the University of Colorado Boulder, has lived in Kangiqtugaapik (Clyde River), Nunavut for most of her career, and began working with Inuit hunters and Elders in the late 1990s. Her lecture, based on her book *The Meaning of Ice,* pointed out the lasting impacts that colonialism, Western science, and research have had on Indigenous communities. The work of Western researchers who have visited northern communities has led to the perpetuation of stereotypes about the Arctic and informed "creeping policies that intruded into every aspect of [their] lives, legitimated by research informed […] by ideology" (42:55 – 43:07). Therefore, it was a dedicated process for Dr.

[19] Gus Speth discussed this quote on an Earth Charter podcast in November 2021. He clarified that the original quote was part of a statement he made at a conference years earlier.

Gearheard to build trust and relationships in the Clyde River community, where she learned from Inuit methods of observing how rising annual temperatures and the loss of sea ice impacted the animals and fish they depended on (Gearheard, 2013; Waterloo's Faculty of Environment, 2022). Her lecture also highlighted the artwork, illustrations, and photographs of dozens of Inuit collaborators to express that there should be more links between arts and science, stating that "art can help us enhance science, do science, [and] express science in so many ways…in technical and scientific [ways] but also creatively and with heart" (44:30 - 44:48). The underlying thesis of Dr. Gearheard's work advocates the need for and significance of the co-production of knowledge and interdisciplinary research. In this way, Dr. Gearhead highlighted the importance of bringing art and science together in methods for studying and communicating climate change and its impacts (Waterloo's Faculty of Environment, 2022).

Another significant takeaway from this lecture for me was Dr. Gearheard sharing the quote from Gus Speth on the world's top environmental problems and the need for a spiritual and cultural transformation. Speth acknowledges that "30 years of good science" is not, as he expected, the only necessary ingredient for addressing environmental crises. Rather, there is a need for spiritual and cultural transformation that, as illustrated by Dr. Gearheard's research, is conceivable when researchers engage more than so-called "good science" through multiple ways of knowing.

The need for a cultural transformation – propelled by notions of interdisciplinarity, ethics, sustainability, and community – also resonates with my dissertation project. In

Chapter 1, I illustrated how curriculum and culture are two necessary proponents for enhancing EEE and overcoming the obstacles facing educators and students at Waterloo and beyond. Chapter 2 contains the fourth published manuscript in this dissertation, Paper 4: *Fostering Responsible Innovation with Critical Design Methods*, in which I argue for more integration of HSS perspectives into EEE, specifically with critical design – a research-creation approach that prompts reflection and communication about the downstream impacts of technology. The implementation of critical design in engineering education is a unique opportunity for students and educators to practice and enhance their critical thinking, communication, and reflection on the impacts of engineering work. Inspired by Dr. Gearheard's work and my own attempts at interdisciplinary research, I suggest that a degree of humility and a culture of openness is required to foster conversations about how engineering education and practice can be enhanced by HSS perspectives and expertise.

According to the Mirriam-Webster Dictionary, the definition of humility is "freedom from pride or arrogance; the quality or state of being humble." In the *Ritual of the Calling of an Engineer*, the nearly 100-year-old "Iron Ring" ceremony (established in 1925) during which Canadian engineering graduates are incorporated into engineering culture and reminded of their professional responsibilities, humility is mentioned frequently in terms of the engineer's obligation to acknowledge their partial perspective. Though humility is perceived as something worth cultivating, Paul et al. argues that this framing of humility can limit engineers if they do not acknowledge the goals or consequences outside of their expertise as part of their responsibilities (Paul et al., 2023). Similar to what Gus Speth suggests about lawyers' and scientists' limitations (i.e., that they don't know how to [participate in 'a spiritual and cultural transformation']), aspects of engineering culture do not always prepare engineers for a multistakeholder research and collaboration process in which they yield their expertise for another's. For instance, Parthasarathy (2023) and Arshad-Ayaz et al. (2020) have observed in humanitarian engineering conducted in the Global South, even the most well-intended projects can fail to meet their objectives because of a lack of social context and community engagement on part of non-local engineers and researchers.

In teaching RI, van Grunsven et al. advocate for developing engineering students' epistemic humility, that is, "what we recognize as morally relevant in our anticipatory endeavours about emerging technologies reflects how we have framed the problems that those technologies purportedly generate or help solve" (van Grunsven et al., 2023, p. 287). In other words, engineering students must be able to critically reflect on their own positionality and knowledge (and lack thereof) in framing problems and be willing to accommodate knowledge from alternative sources who have different, though not inferior, perspectives and expertise. But it is not always easy to do this. As evidenced by the Iron Ring ceremony, engineers have a great sense of pride in their specialty. Embracing more inclusive and collaborative knowledge-making across disciplines is unsettling and contradictive to the antiquated values set out in the Iron Ring ceremony, which reinforces the intellectual superiority and elitism of engineering culture (Paul et al., 2023). Opportunities for interdisciplinarity collaboration can be stifled by feelings of superiority within one's discipline (Klein, 2008) and a lack of communication about different meanings, methods, and expectations in research (Roper, 2021). These are significant barriers to working across disciplines.

It is understandable why there may be discomfort with or hesitance to working with someone who has a different background; with that said, being able to communicate with multiple stakeholders who have different needs and values is an essential skill for engineering. Therefore, one of my primary objectives through this dissertation is to demonstrate the power of interdisciplinary collaboration and, in doing so, help students to be more humble, open-minded, inclusive, and thereby, more effective, and successful engineers.

One way that our interventions seek to accomplish this objective is by cultivating a safe and "brave" space (Arao & Clemens, 2013) where participants can develop a shared language across disciplines and be comfortable with failure in the design process, while also being exposed to ideas and concepts that are outside their own expertise. A key strength of our critical design interventions is the low barrier to participation that allows participants to bring their knowledge, experience, and creativity to asking questions and mapping alternative contexts for engineering work. For instance, this is demonstrated through our use of the *Tarot Cards of Tech* as discussed in Papers 4 and 5. Through our critical design interventions, we aim to enable engineers to leverage their existing expertise, gain insights from alternative perspectives, and learn to make space for critical reflection on the practices and cultures in engineering that uplift or hinder their ability to design with ethical and equitable outcomes in practice.

Paper 4 will provide a detailed overview of critical design, including its history and inspirations, specific applications in engineering curriculum, and broader potential for informing responsible innovation and design in tech contexts. A unique contribution of critical design that sets it apart from other EEE interventions is its attention to "problem *finding*" (Malpass, 2017, emphasis added) – the process of uncovering assumptions and power asymmetries in the social, ethical, environmental, and political contexts surrounding a technology. This presents a compelling contrast to how technical problem solving is typically emphasized in engineering fields. Further, critical design does not prioritize what engineering ethics scholars Bucciarelli (2008) and McGinn have condemned of some EEE approaches in that they are "seeking tidy solutions to ethical problems" (McGinn, 2018, p. 365). In fact, it is the opposite: critical design aims to engage participants in discursive activities that allow them to practice critical thinking in problems and scenarios that are unlikely to have one clear answer.

Paper 4 describes workshops and interventions conducted between September 2020 and February 2023 and was published in the Journal of Responsible Innovation in March 2024. I helped to design, facilitate, and evaluate this work as part of the Critical by Design research group with faculty members Marcel O'Gorman and Heather Love and Research Assistant Rebecca Sherlock. These interventions represent a sample of the ongoing projects that have been conducted in the Critical Media Lab for several years.

2.1 Paper 4: Fostering Responsible Innovation with Critical Design Methods[20]

2.1.1 Introduction

In 2018, the *Globe and Mail* reported on the growth of what some reporters called 'techlash,' a backlash against globally toxic outcomes of technological innovation (O'Gorman, 2018). At the time, the Cambridge Analytica Scandal had revealed how social media platforms can capitalize on the psychological profiles and vulnerabilities of users to sway voters and even incite genocide, as was the case in Myanmar (Whitten-Woodring et al., 2020). The scandal drew attention to other toxic tech consequences: conflict minerals mined by child laborers in Congo were being exported for use in iPhone production (Sarfaty, 2015); cryptocurrency had almost the same carbon footprint as the entire country of New Zealand (Kumar, 2022); data sets for algorithms that power everything from search engines to facial recognition platforms were biased toward white males (Lohr, 2022). More recently, the COVID-19 pandemic has underlined the need for more ethical deliberation in technology development, as we've witnessed the exacerbation of socioeconomic and racial inequality (Zheng & Walsham, 2021), the online spread of misinformation (Vraga et al., 2020), and concerns about privacy and surveillance (Vitak & Zimmer, 2020).

The project outlined in this paper responds to these problems by focusing on the education of future tech developers. There is a significant need for Engineering and

[20] Orchard, A., & O'Gorman, M. (2024). Fostering responsible innovation with critical design methods. *Journal of Responsible Innovation*, *11*(1), 2318823. https://doi.org/10.1080/23299460.2024.2318823

Computer Science graduates to learn and practice ethics more rigorously in their design workflow. Many programs in these areas do offer separate courses on ethics, but: a) the content is often disconnected from design practice; and b) 'ethics' target primarily the general safety of the public and not the many contexts of what has come to be known as responsible innovation (RI) (Hipp, 2007).

Stilgoe, Owen, and Macnaghten (2013) identified four main dimensions of RI: anticipation, reflexivity in governance and design, inclusion, and responsiveness. Broadly speaking, RI means 'taking care of the future through collective stewardship of science and innovation in the present' (Stilgoe et al., 2013, p. 1570). The RI community at large investigates new forms of governance in the development and application of innovation. In light of rapidly advancing technology with increasingly disproportionate impacts on marginalized groups and the environment, RI principles provide a critical framework for educators to discuss complex, and sometimes controversial, innovations with future engineers and technologists (Richter et al., 2019).

In our research with undergraduate and graduate students, we describe RI in terms of the 'ethical design and development practices that account for social, psychological, and environmental impacts of technology.' We observe that current methods of teaching ethics to tech developers are not enough to establish a strong ethos – beliefs and practices that inform ethical design – of RI. As one engineering educator put it, the integration of ethics into the curricula of tech developers is 'in need of rescue' (Kalichman, 2014, p. 69). The strategy of including supplemental classes in ethics is often met with resistance by students and faculty alike, who struggle to see the relevance of these class (Cech, 2014). Furthermore, as Chivukula et al. (2021, 4) have demonstrated, although various values-based approaches to design have been developed in the fields of Human-Computer Interaction (HCI) and Science and Technology Studies (STS), such efforts have been criticized for their ‘lack of resonance in authentic work settings, or due to the lack of translation of these practices from academia to practice.’ We acknowledge the potential disconnect students may experience between learning responsible design in the classroom and attempting to actualize these lessons in a fast-paced tech workplace; to this end, we introduce methods that can be injected into the design process to help students think more critically about the downstream impacts of technology.

This project takes an integrative approach rooted in the theory and practice of critical design. Critical design, the key methodology behind this project, is a research practice that has been described as a mode of ‘problem finding’ rather than ‘problem solving’ (Malpass 2017). More specifically, ‘critical design practice challenges hegemonies and dominant ideologies in contexts of science and technology, social inequality, and unchallenged disciplinary norms’ (Malpass 2017, 4). Anthony Dunne and Fiona Raby (2013), the design team that coined the term ‘critical design,’ note that it emerged from their ‘concerns with the uncritical drive behind technological progress, when technology is always assumed to be good and capable of solving any problem.’ Notably, critical design emerges from traditions of critical thinking and culture criticism that are native to the arts and humanities, especially the Frankfurt School of critical theory, which applied Marxist philosophy to the critique of capitalist consumption practices. These traditions are not commonly taught in engineering curricula.

In this article we ask: Can critical design methods, which are generally the domain of arts practitioners, be taught to future tech developers to advance the development of a widespread ethos of responsible innovation?

To address this question, we present two main methods of teaching and making with critical design tools and concepts: instructor-led workshops and cross-disciplinary project-based exercises. We note there are few references of critical design methods in RI literature (Conley et al., 2022; Fuenfschilling et al., 2022); in this article, we seek to make more connections to the RI field with this arts-based approach. Combining critical design, RI, and collaborative cross-disciplinary pedagogy is a highly interdisciplinary project and, to our knowledge, does not align with any individual methodological framework for assessing its impacts. Methods for quantitative data collection are often outside the domain of critical design practitioners, who come from qualitative fields and may even be resistant to a culture of 'dataism' (Brooks, 2013); with that said, one of the significant contributions of this work is its innovative integration of these fields and methods. To illustrate the impact and potential for this approach, we will discuss student projects and outputs from these two interventions and reflect on our implementation of the pedagogical tools developed thus far.

Following the Introduction (section 2.1.1), there are four main sections in this article:[21]

- Section 2.1.2 provides an overview of RI discourse and a detailed description of critical design and examples of its use in previous pedagogical interventions.
- Section 2.1.3 defines critical design and provides background on its theoretical and methodological origins and examples of pedagogical applications.
- Section 2.1.4 describes the specific methods we used in our interventions, the student project results, and our pedagogical outputs.
- Section 2.1.5 discusses the strengths, obstacles, and limitations of our interventions and posits areas for future research.

To advance RI practices in the tech industry, future developers must learn how to critically consider the broad context of their innovations, finding and addressing social, psychological, and ecological problems before they arise. Critical design may be a creative way to facilitate this process. This ongoing work hopes to demonstrate that RI can be fostered and championed through a more thorough collaboration between the tech community and disciplines in the arts and humanities – disciplines that excel in the critical contextualization of technological innovation but rarely have the opportunity to intervene directly in the processes that are the subject of that critique.

[21] The section numbers have been modified from the original version of this paper to align with dissertation formatting.

2.1.2 Theoretical Embedding in RI Discourses

Responsible innovation and responsible research and innovation (RRI) emerged in the last 15 years with the common intent of challenging the 'epistemological norms and practices concerning the production and valorisation of scientific knowledge' (Owen & Pansera, 2019, p. 26). Both discourses are invested in fostering innovation that enables a sustainable, just, and flourishing future, but can be differentiated from each other based on their origins: RRI is policy-driven, with a focus on inclusive and sustainable research that is co-created with society, whereas RI is tied to academia and its critical stance on the 'relationships and dynamics between science, innovation, politics, and society' (Owen & Pansera, 2019, p. 42). While our research resonates with this conceptualization of RI, we acknowledge that the context of our research study is heavily influenced by a corporatized vision of RI that prioritizes the idea of gaining competitive market advantage at the expense of ongoing social and environmental problems.

Industry, governmental, and non-profit entities have all contributed to conversations about how engineering and technology sectors need to think and act more ethically and responsibly. In the last decade, there has been an influx of RI declarations, manifestos, and principles produced by the Mozilla Foundation, Future of Life Institute, and Canadian Information and Communications Technology Council (ICTC), to name only a few (*AI Principles*, n.d.; *The Mozilla Manifesto*, n.d.; ICTC-CTIC, 2021). These documents are akin to Corporate Social Responsibility (CSR) policies and statements, and typically aim to articulate shared values for the company and external stakeholders (van de Poel et al., 2020).

Some of these documents advocate for broadly defined values including justice, fairness, trust, respect, inclusion, diversity, and interdisciplinarity (Communitech et al., 2018; ICTC-CTIC, 2021), while others are more specific to outcomes including privacy, security, governance, accountability, and transparency (*IEEE 7000-2021 for Systems Design Ethical Concerns*, n.d.; *Responsible AI Principles from Microsoft*, n.d.).

For businesses, it can be difficult to actualize these values given current political and socio-economic systems (Lubberink, 2018). Lajoie and O'Gorman also came to this conclusion in a study with Deloitte that questioned whether C-suite executives actually implemented the tenets of the *Tech for Good Declaration* adopted by their companies (Lajoie, 2019). Businesses have financial pressures that compete with the tenets of RI and must find a balance their profit- and morally-driven motives (Garst et al., 2017; Lubberink, 2018).

Still, Felt, Fochler, and Sigl (2018, 202) argue that RI work could play the role of a 'moral glue' that holds 'contradictory promises of economic, societal, and scientific benefits together,' while others suggest that RI initiatives tend to focus on improving the alignment of innovation with societal values and are often treated as add-ons to the innovation process rather than integrated holistically (Fuenfschilling et al., 2022; Stahl et al., 2021). Moreover, and this is a key concern, such declarations and manifestoes may be used for corporate 'ethics-', 'green-', or 'responsibility-washing,' in which hollow symbolic gestures are made rather than actively addressing real issues in innovation (Garst et al., 2017; Green, 2021; Owen & Pansera, 2019).

Many of the students at our institution take co-op terms at MAANG (Meta, Amazon, Apple, Netflix, Google)[22] companies, and become entrenched in the overtly capitalist culture of these firms. Though some of these companies published their own responsible innovation principles (mentioned earlier), we are critical of big tech's tendency to 'frame innovation as emphatically socio-ethically motivated' through their public-facing manifestos, principles, or declarations (van Grunsven et al., 2023, p. 12). One of our mandates as instructors of future tech developers is to help students critically assess the rhetoric of ethics promoted by large tech corporations and help them develop their own design values and practices rooted in responsible innovation.

For the last two decades, Engineering educators have emphasized the need for ethics and responsibility to be (1) more broadly defined and (2) more rigorously integrated across the curriculum (Cruz & Frey, 2003; Li & Fu, 2012; van den Hoven, 2019). Engineering curricula are largely characterized by their emphasis on technical subject matter and are not likely to yield space for accommodating contemporary changes in the social contexts of technology (Walczak et al., 2010). RI research acknowledges the need to make ethics integral to Engineering programs; one challenge is that students usually perceive ethics as rules or codes, rather than an opportunity to address open-ended approaches and source more innovative research questions (Sunderland et al., 2014). Problem-based learning is one

[22] In Paper 1, we refer to this group of companies as FANNG. This change in Paper 4 is because Facebook updated its holding company name to Meta in late 2021.

approach used in RI pedagogy (Bardone et al., 2023; Conley et al., 2022) that allows reflexivity between diverse disciplinary backgrounds.

Survey studies have found that students recognize the importance of ethics to their profession, but seldom have the opportunity to integrate or feel confident with integrating ethical decision-making into contexts outside the classroom (Orchard & Radke, 2023b; Truax et al., 2021). Students also embrace the idea that new technologies can and should be used to address society's most urgent ethical challenges (van Grunsven et al., 2023). However, due to their limited exposure to ethics and responsible innovation in the Engineering curriculum at large, many students are not intellectually prepared to think critically about the social, environmental, and political implications of the work they will do during their internships and future careers. Through our critical design interventions, we aim to provide students with tools to critically contextualize their work and situate themselves within a RI discourse that questions the dominant narratives of big tech.

2.1.3 Methods of Critical Design

Critical Design is a research practice focused on challenging audience perspectives on the status quo, and it was inspired primarily by the impacts of consumer technologies on human wellbeing. As Malpass puts it, 'A common approach in the techno-centric domain of product design is for the designer and technologist to focus on what technology can do and too often ignore the contextual issues that can turn a technology into a product, and in turn modify the human experience of that technology' (Malpass 2017, 56). Critical design objects aim to expand the context of design by communicating a provocative viewpoint on the complex social, environmental, economic, and ethical implications of science and technology. These objects attempt to problematize existing discourses and overcome pre-configured assumptions of users, products, and practices (Fuenfschilling et al., 2022).

Unlike other methods of design, which focus on the development of a final product or solution, critical design is process-oriented, rhetorical, and discursive, which explains why it is often conflated with 'speculative design' (Dunne & Raby, 2013) or 'discursive design' (Tharp & Tharp, 2019). What Dunne and Raby (2013) have described as the 'methodological playground' of critical design allows designers 'to explore what might be and to establish alternatives that offer an experience similar to the quality of poetic language' (Malpass 2017, 47). Sample critical design methods include the creation of speculative fictions, 'what if?' statements, alternative histories, and objects-to-think-with (O'Gorman, 2015, 2020). A mainstream example of speculative fiction, for example, is the TV show *Black Mirror*, which often narrativizes subjects related to responsible innovation such as privacy and transparency, often using humor or satire to convey their message. Objects-to-think-with, on the other hand, which are developed through practices of critical making (Hertz, 2015; Ratto, 2011) and applied media theory (O'Gorman, 2015, 2020), are physical products like the DIY cellphone (Mellis & Buechley, 2014) or Resistor Case ("Resistor Case," 2021) (see fig. 1), which promote critical reflection about technology. Rather than narrativizing issues related to responsible innovation, these methods take a hands-on approach that promote reflection on innovation as part of a design process.

Figure 3: ***The Resistor Case***

Note. Image property of Marcel O'Gorman.

In recent years, novel research has been conducted on the use of critical design in a tech development context (i.e., workshops and curricula). Since 2011, Torkildsby and Vaes (2019) have led multiple critical design workshops to approach the topic of 'product-related stigma.' In one of their week-long workshops, graduate students from architecture, product design, heritage studies, and urbanism explored how public stigma, stereotypes, and discrimination influence the design of products, services, and environments. Torkildsby and Vaes used a set of cards, the Product Intervention Model for Stigma (PIMS), to help students brainstorm their topics (Vaes, 2014). Workshop participants reportedly found the exercise to be methodologically liberating, playful, and helpful for identifying root causes of the stigma-related problems at hand (Torkildsby and Vaes 2019).

McMillan (2020) constructed a workshop series around the fictional premise of a brain-computer interface called *Aura:maton* that detects the wearer's physiological states and emits a scent according to their brain activity. After the speculative design case, participants used *The Envisioning Cards* (Friedman & Hendry, 2012) to unpack more social, economic, and ecological issues. McMillan reported that the participants, six professionals from a range of industries, imagined both favorable and unfavorable scenarios with *Aura:maton*, such as a way to entice a lover or to release a chemical attack for crowd control. While this project did not engage participants in the creation of a critical design project, it drew on the methods of critical design to create the centerpiece for the workshop.

Like Torkildsby and Vaes (2019) and McMillan (2020), the Critical Media Lab has run critical design workshops and used design card decks that prompt participants to challenge assumptions and investigate the potential uses and consequences of technology. For more examples of workshops and design cards, see works by Antle et al. (2022) and Urquhart and Craigon (2021). In Section 4, we will discuss our specific interventions and contributions to the expanding research community at the intersections of critical design, tech development, and responsible innovation.

2.1.4 Critical Design Interventions by the Critical Media Lab

As members of the Critical Media Lab at the University of Waterloo, we are engaged in multiple curricular, research, and community-oriented initiatives rooted in responsible innovation. The Critical Media Lab is located in Communitech, a start-up incubator and innovation hub in Kitchener, Ontario. In 2018, author O'Gorman worked with Communitech and other partners to develop the Tech for Good Declaration (Communitech, Deloitte, and Rideau Hall Foundation 2018), already mentioned. Over the last 15 years, faculty, researchers, and students in the Critical Media Lab have contributed to dozens of critical design projects and have led numerous events related to responsible innovation.

Learning labs and maker spaces have grown in popularity in the last two decades. However, these spaces more often emphasize innovation and creativity without any explicit attention to responsibility or ethics (Conley et al., 2022). The Futures Lab, a maker space grounded in RI thinking and models at James Madison University, is an exception to this trend and offers a close comparison with the Critical Media Lab.

This section will discuss two examples of past and ongoing critical design initiatives led by our team. First, we discuss a graduate-level Critical Design Methods course from Fall 2021 wherein students from English and Systems Design Engineering participated in a cross-disciplinary critical design assignment. We provide examples of student work that came from this exercise and posit avenues for future research. Secondly, we provide an overview of the Responsible Innovation workshops that we have been conducting with students from multiple disciplines since 2019.

2.1.4.1 Cross Disciplinary Curricular Interventions

In the fall semester of 2020, author O’Gorman taught the graduate course English 701: Critical Design Methods. The following is an outline taken from the syllabus:

> This course introduces students to both the theory and practice of Critical Design, broadly construed. Critical Design is not a field of its own, but a mode of design thinking that is informed by critical theories and research methods from the arts and humanities. Critical Design can intersect with and draw on established fields of design from graphic and UX design to industrial and urban design. The course begins with an overview of the history of design as critique, before examining the recent emergence of research-creation practices such as speculative design, critical making, discursive design, and applied media theory. The positionality of designers and audiences will be considered in readings and assignments that focus on gender, disability, race, class, keeping in mind the concept of intersectionality. Special attention will be paid to the design of media technologies and the infrastructures that support them, which involves methods in UX design, sustainable hardware design, and digital urban design. Students will demonstrate their knowledge of course materials through writing, design, and light fabrication. (O’Gorman 2020)

The course contained an assignment wherein English students received the Capstone Project descriptions from student projects in the concurrent Systems Design Engineering Capstone course. The ‘Engineering Critical Design’ assignment prompted English students to create a critical context for one of the Engineering project descriptions using critical design methods and present and discuss the projects with the Engineering students. The assignment for English students involved following instructions:

1. Forecast the potential social, cultural, and environmental impacts of each proposed Engineering project.

2. Apply critical design methods to propose alternative speculative design projects that respond to one or more of the forecasted impacts identified in step 1.
3. Present the work in a brief video that also explains the critical design methods employed.

Other instructions on the syllabus included: 'Keep in mind that the point of this project is not to create useful or efficient engineering design solutions. Your goal is to provide a critical context for the projects being created by the Engineering students.' From the instructors' and researchers' perspectives, the main objectives of this assignment were to:

1. Facilitate a cross-disciplinary discussion between students on engineering projects and their impacts.
2. Observe and measure student project results, interactions between the two courses, and student knowledge and perceptions of critical design.

The English critical design iterations utilized a variety of methods and media to position Engineering projects within broader critical contexts. We will describe two group projects, *Parcel and Package* and *Envirocene*, to provide context as to the students' work and the conversations conducted between the two courses.

In order to mitigate package theft from 'porch pirates,' one Engineering capstone project proposed a software solution to set delivery times during the evening and night, from 6pm to 8am, so that the customer can be home to receive their package and it is not left unattended. In response to the capstone project, English student Christopher Rogers designed a satirical, futuristic trade magazine titled *Parcel and Package* wherein he illustrated implications that could arise from an emphasis on reducing cost and eliminating inefficiencies, such the marginalization of couriers, violence, surveillance, and deregulation (see Fig. 4 and 5). As a speculative design fiction, the magazine invites readers to consider the consequences of heightening the expectations of human couriers to an unreasonable standard. It responds to the project in a way that would allow the Engineering students to think about the potential downstream effects of their project that might not be readily apparent.

A second Engineering capstone group presented a smartphone application that logs perishable food items, provides metrics, predicts future food waste, and nudges users to adopt environmentally conscious behaviors. Although the Engineering project presents an opportunity for users to reduce food waste and environmental impact, the Engineering team acknowledged in their proposal that similar solutions had not been readily adopted in the past, partially due to individual lack of concern for and knowledge about food waste. Through the format of satirical commercial, English students Olivia Roth and Lisa Brackenridge presented a fictional household appliance called the *Envirocene* which reduces any amount of food waste to the size of a pea, thereby making more room in the fridge (to buy more food) while sending a smaller quantity of food to a landfill (see Fig. 6 and 7).

Although the *Envirocene* eliminated the food waste, the commercial revealed that in the process, the appliance costs more, takes more energy, and emits more harmful emissions than before. The project is therefore a reflection on luxury environmentalism.

Figure 4: ***Parcel and Package Speculative Fiction Magazine Cover.***

Note. Reproduced with permission from student Christopher Rogers.

Figure 5: ***Advertisement from speculative fiction magazine, Parcel and Package.***

Note. Reproduced with permission from student Christopher Rogers.

Using reductio ad absurdum, a form of argument that pushes the logic of an argument to an absurd conclusion, the English students took the goal of the Engineering project to an extreme in which food waste is eliminated, solving one problem, but the elimination contributes to a variety of other problems in the process. The critical iteration prompted the Engineering project to consider the motivations of consumers and the potential impacts of integrating financial incentives into their application.

Figure 6: ***Screenshot of actress holding spoiled food in commercial.***

Note. Reproduced with permission from students Olivia Roth and Lisa Brackenridge.

Figure 7: ***Screenshot of actress using the Envirocene in commercial.***

Note: Reproduced with permission from students Olivia Roth and Lisa Brackenridge.

The English students said that the Engineering group initially thought the *Envirocene* was a genuinely good idea. The satirical commercial was so well executed that it convinced the Engineering group of the product idea, despite the physical impossibility of a science-fictional device that drastically reduces the mass of food. As a result, the Engineering and English students conducted a critically-informed, reflective conversation about issues of socioeconomic privilege related to food waste – thereby accomplishing the intended outcome of critical design: to enable a creative space for reflection and critical discourse around a problem area. In addition, the critical design project served as a vehicle that allowed students from very different disciplines to share a common problem-solving language related to responsible innovation.

It is important to note that while the critical design artifacts (e.g., the *Parcel and Package* magazine, *Envirocene* commercial) are not intended to be taken seriously, the underlying critique of the design should be the take-home message for Engineering students. For example, the *Envirocene* commercial argues that although the food waste problem might be fixed through a complex new technology, the solution comes at the cost of other kinds of significant environmental damage. Moreover, the solution ignores underlying problems related to food waste, such as asymmetrical economic systems that lead to food insecurity. This prompted a practical discussion on critically and socially informed alternative approaches to addressing food waste. These and other discussions facilitated by the collaboration encouraged self-reflexive thinking on the part of Engineering students. The critical design objects required the Engineering students to face their own biases and positionality while reconsidering their design approach, which often focused on the execution of a fairly rapid "techno-fix," rather than engaging in careful consideration of the broader context of the problem as part of the design process. Our belief is that the primary purpose of critical design practices is not to solve practical problems but to engage students in discursive activities that allow them to practice the use of critical thinking and develop critical communication skills. To this end, critical design is deliberately opposed to solutionism. That said, critical design should not be isolated entirely from the practical ends of design; in our configuration, it is meant to be part of the design flow, as a hands-on, creative space for critical reflection, one that O'Gorman calls 'making attention' (O'Gorman 2020).

In the Engineering Critical Design assignment instructions, it was advised that English students should not try to produce an efficient or useful product for Engineering, but rather to create a critical context for the design process. For the critical designs to be effective in highlighting issues that the Engineering projects could actually consider and respond to, we suggest there would need to be an earlier introduction and more prolonged engagement with the ideas. In this case, that would mean bringing English and Engineering students together in week 2 of a semester, rather than weeks 8-10, and having ongoing conversations about ethical questions arising during the design process.

A significant limitation to this study is the lack of student feedback. Time constraints placed on Engineering students due to a tightly packed curriculum is an obstacle not only to critical reflection but also to gathering feedback about interventions designed to promote critical reflection. Our research in progress involves improving methods for gathering empirical feedback from Science, Technology, Engineering and Math (STEM) students (and their non-STEM collaborators), including feedback about the obstacles to integrating ethical thinking into their workflow and the potential for critical design to support that process.

2.1.4.2 Responsible Innovation Workshops

The second example of a critical design intervention we have implemented in recent years is a series of Responsible Innovation workshops. O'Gorman has led multiple iterations of these workshops in different venues and contexts including undergraduate engineering courses, research centers for responsible innovation, a national hackathon, a tech conference with over 2,500 attendees, and a sustainable electronics training program.

The responsible innovation workshops typically begin with a facilitator introducing some of the main issues in responsible innovation, such as algorithmic bias, conflict minerals, e-waste, automation, data privacy, and ‘deceptive design’ (also known as dark patterns) (Brignull, 2011). As an incentive for adopting responsible innovation measures, the facilitator notes that Environmental, Social and Governance indicators (ESG’s) are gaining popularity among investors. The facilitator then introduces critical design to investigate how issues in responsible innovation might be identified in the participants’ own tech products and services. The following workshop exercises are adapted for each audience: in some cases, the participants bring their own works-in-progress, and we apply critical design to them, whereas in others we provide examples for participants to work on in groups.

In January 2022, we led a day-long workshop for the Collaborative Research and Training Experience in Sustainable Electronics Design (CREATE-SEED) program headquartered at Polytechnique Montréal. The 12 participants, all PhD students from Canadian universities, were from mixed disciplinary backgrounds, ranging from chemistry to mining engineering. During this workshop, participants completed three main assignments:

1. *Tarot Cards of Tech*: Apply up to three cards to a current or past research project. Discuss the results as a group.

2. Speculative Future: Respond to the following speculative scenario: An asteroid has collided with Earth and the results were catastrophic. Fortunately, you were invited to escape on a SpaceX rocket, and you are heading to a research station on a secret planet called Musktopia. Your mission is to help colonize this new home, and all technologies must be reinvented. You are in charge of designing something to take the place of the smartphone. How would your design differ from current technologies? What features would you include or exclude?
3. The Utopian Smartphone: A top-secret company funded by a team of billionaire environmentalists is developing a new smartphone. This is a chance to reinvent smartphones from the ground up, based on principles of a circular economy. Each team will be tasked with designing a separate device component. At the end of the design session, we will put the pieces together and evaluate the results.

The *Tarot Cards of Tech* are a speculative design card deck produced by Artefact, a Seattle-based design firm working with companies in financial, automotive, healthcare, and fashion sectors. There are 12 cards in the deck, each with a handful of prompts for the designer to consider opportunities and consequences of a given technology or scenario. Though Artefact did not explicitly intend for their cards to be used in the context of critical design, we find they are an accessible discussion starter for students in our workshops (see Fig. 8 and 9). Some of the card prompts include:

- How might a community change if 80% of the population used your product?

- If the environment was your client, how would your product change?
- Does your product respect people's boundaries and the other parts of their lives?

Figure 8: ***The 'Smash Hit' card from the Tarot Cards of Tech designed by Artefact (2018).***

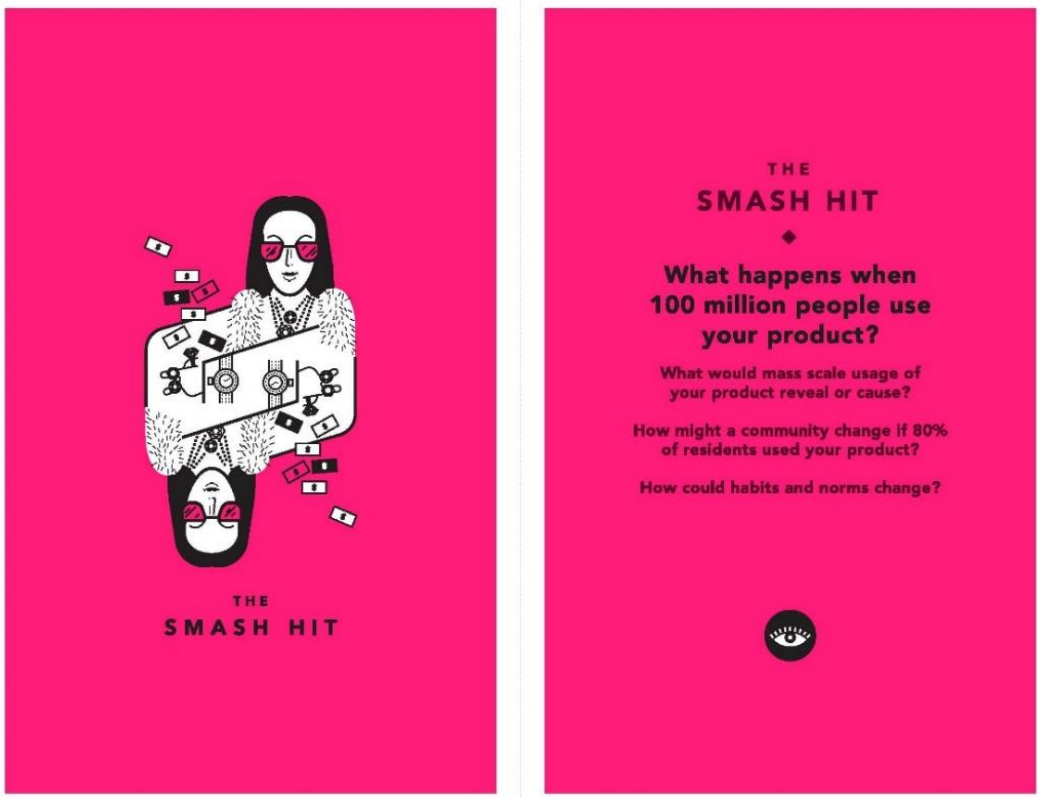

Figure 9: ***The 'Scandal' card from the Tarot Cards of Tech designed by Artefact (2018).***

One reason we often employ the *Tarot Cards of Tech,* in this workshop and across many others, is because the card prompts are imaginative and engaging regardless of a participant's background; therefore, it is easy for us to reuse and adapt the card prompts while accommodating the appropriate complexity for different audiences, whether that be undergraduates or PhD students.

In the second and third assignments, the CREATE-SEED students were prompted to consider sustainability, accessibility, and social impact into their designs for a new smartphone. Through this speculative scenario, students asked critical questions about the existing technologies we use and how they could be modified to better fulfil principles of a circular economy. In a debrief at the end of the workshop, students commented that they found the methods useful and were eager for us to provide additional resources to learn more about critical design and responsible innovation.

2.1.5 Discussion and Outlook

We have conducted critical design interventions with undergraduate and graduate participant groups, each with their own contexts for responsible innovation and design. In the English and Engineering student project collaboration, we provide two examples of critical design projects made by students: the *Parcel and Package* magazine is a form of speculative fiction and the *Envirocene* uses reductio ad absurdum in a satirical infomercial medium. Both examples involve the design of a prototype or 'prop' that generates critical discussion around potential downstream impacts of the Engineering projects. In our RI workshop, PhD students examined their own research with the *Tarot Cards of Tech* and then worked together on a speculative scenario wherein they reimagined the design of smartphones using sustainable materials. In this iteration of our RI workshop, students did not create physical prototypes but rather conceived of alternatives to the extractive materials presently used in smartphone production in the context of a speculative thought experiment. We highlight these examples to demonstrate multiple critical design methods and their potential application in various contexts from entire courses to visiting workshops. These and other methods, including critical making and applied media theory, represent what Dunne and Raby have described as the 'methodological playground' of critical design (2013).

One of the strengths of using critical design for exploring RI is its accessibility and adaptability for audiences of different disciplinary and professional backgrounds. In the *Envirocene* project, students were able to critique the food waste problem through humour and satire. In the RI workshop, students from multiple engineering backgrounds were able to draw upon their technical expertise in a thought experiment for designing a sustainable smartphone.

A significant aspect of the work outlined here is the producing and sharing of critical spaces for and with students, particularly when activities engage with such topics as equity, diversity, and inclusion (EDI), environmental sustainability, and social and psychological impacts. Some of the key takeaways from this work, particularly when participants are engaged in cross-disciplinary collaboration, is the importance of developing shared language across disciplines, which helps foster a safe and 'brave' (Arao & Clemens, 2013) collaboration environment that allows for failure as part of the design process. Critical design is an engaging entry point for ethical discussions and a promising avenue for considering responsible anticipation (van Grunsven et al., 2023). Our research demonstrates how critical design can inspire creativity and reveal the value tensions inherent to technological development. It is vital for future technologists to develop the critical thinking and communication skills needed for designing responsibly.

A large part of our ongoing work involves intervening in undergraduate Engineering curricula, a project that presents several obstacles for non-Engineering researchers. Like Walczak et al. (2010) and others, we observe that undergraduate Engineering curriculum is very full with little room for additional content. Opportunities to inject critical design and responsible innovation initiatives into engineering coursework is only possible when the instructor is receptive to the ideas and willing to make space in their courses to do so. One promising area for intervention is in Engineering communication courses, where instructors trained in the arts, social sciences and humanities have an opportunity to introduce concepts and methods related to responsible innovation and critical design. This opportunity is a major focus of our future research.

We also note that at University of Waterloo, undergraduate students are highly motivated by their co-op obligations, which includes applying to hundreds of potential positions and taking dozens of interviews while balancing their coursework. In a case study of the undergraduate Engineering communication courses at the University of Waterloo, Truax, Orchard, and Love (2021) found that students receive infrequent and fragmented exposure to ethics over the course of their degrees and often experience intense social pressures to attain Silicon Valley-based co-op placements. These curricular and cultural factors combine to create an academic environment wherein notions of RI struggle to take hold.

Despite a lack of immediate incentives for Engineering students to adopt responsible design principles, we note that they are receptive to the idea of RI, and they engage enthusiastically with the ideas and activities embedded in our interventions. We speculate that current undergraduates may be morally sympathetic to RI concepts for the same reasons they identify with Greta Thunberg's environmental efforts; that is, for the sake of 'intergenerational justice' (Sabherwal et al., 2021). This is yet another hypothesis to test in our ongoing surveys of engineering students. We have also begun integrating information about Environmental, Social, and Governance (ESG) rating systems in our workshops so that students might be encouraged to consider how 'tech for good' can be 'good for business.'

As indicated by our anecdotal reports on the success of our interventions, a key limitation to our work is the lack of participant feedback. There is a need for more measurement of and evidence for the implementation of critical design. However, the qualitative nature of critical design does not lend itself to quantitative results. Moreover, methods for the collection of data are often outside of the domain of critical design practitioners, who come from non-STEM fields in which data collection is not common and in which researchers may even be skeptical of a culture of 'dataism' (Brooks, 2013). We argue, given the rhetorical and discursive nature of critical design, that it is conceptually and methodologically appropriate for these interventions to be examined through qualitative feedback and observations gleaned from individual experiences. For instance, during the *Envirocene* project, the initial confusion between collaborators was a necessary precursor to them developing a 'shared language' (Arao & Clemens, 2013) on the problem of food waste. Though quantitative feedback may be preferable by some research audiences, we maintain the importance of providing deep context in illustrating the RI issues that we are investigating.

Another limitation of our work is that, while it provides a space for reflection about responsible innovation and an opportunity to develop new design skills, the return on investment is not immediately evident for participants. The incentive to implement critical design, for some participants, hinges on its economic or empirically demonstrated contribution to their work. Based on informal participant feedback and our observations, we find that our workshops, for example, provide an introduction to critical design and responsible innovation – which accomplishes what it is meant to, namely *introduce* a novel way of problem finding and thinking critically in the design process. But for a technologist to implement critical design in their workflow, it would mean assigning valuable time to tasks that could be seen as delaying product delivery. In the cross-disciplinary curricular interventions, for instance, there were a few weeks for deliberation as English students produced iterations on the Systems Design Engineering projects. Doing research on and producing a creative response to projects is naturally more time consuming than applying the *Tarot Cards of Tech* during a short workshop. We recognize the intuitive conclusion that more time will likely result in a deeper understanding and more robust responses to ethical issues; however, we also acknowledge that participants are not always prepared to prioritize critical design – whether because of their inexperience, lack of contextual knowledge, or entrenched disciplinary practices and behaviours.

Furthermore, it is important for us to monitor the tone of these interventions so that they serve as opportunities for discussion, rather than the application of critique; we want to avoid what Malpass has described as 'design for design's sake,' in that the intellectual stance of these interventions do not come across as elitist (2013, 335). Design ‘toolkits,’ for instance, are popular in academic and corporate settings; however, they tend to distill the self-reflexivity and rigor of designers into a formulaic package of tools to be employed by anyone, thereby assuming that their claims to knowledge and ways of doing things are universal (Ansari, 2019). When toolkits or workshops do not ‘attempt to include or engage with the knowledge of other regions, cultures, and communities,’ they are at risk of engaging in a ‘strategy of erasure or exclusion’ (Ansari, 2019, p. 6). We are cognizant of these issues particularly as our future work analyzes existing toolkits for RI and explores the development of new accessible resources for creative RI pedagogy that implement critical design methods while focusing on inclusivity and an openness to epistemological diversity.

2.2 Interdisciplinary Research and Collaboration

In the introduction to Chapter 2, I prefaced our article on critical design for RI by talking about Dr. Shari Fox Gearheard’s lecture on her climate research conducted with Inuit hunters and Elders in Nunavut. Dr. Gearheard’s experience highlights the power of interdisciplinary research to accommodate and reconfigure multiple epistemological frameworks and ways of knowing.

Although interdisciplinary collaboration is a valuable and rewarding experience that can uncover novel insights impossible to explore without a diversity of perspectives, there can be challenging aspects of collaborating with other disciplines. In Paper 4, although the emphasis was on the *successes* that come from integrating critical design into engineering classroom/workshop contexts, we also discussed some of the obstacles to engaging with engineering students and educators in cross-disciplinary pedagogical spaces using critical design. Some of the main challenges stem from curricular constraints, students' incentives to participate, time and resources of collaborating instructors, and perceptions of the relevance of ethics and related topics to technical domains. These findings corroborate a long standing set of conclusions that appear across many EEE publications (Cech, 2013; Herkert, 2000; Kirkscey et al., 2023; Lee et al., 2019; Leydens & Lucena, 2017; Walczak et al., 2010).

In the writing and review process for Paper 4, we also learned a great deal about how RI is studied in social science disciplines, as well as in a European context where the *Journal of Responsible Innovation* (JRI) is largely situated. From our North American perspective, we largely understood the term "responsible innovation" in connection with corporate, non-profit, and governmental entities that advocated for a socially conscious approach to business that, for example, resonated with Corporate Social Responsibility. Perhaps due to the Critical Media Lab's involvement with Communitech, Deloitte, and Rideau Hall Foundation in the creation of the Tech for Good Declaration, this is how our corporate-biased vision of RI was formed. From JRI, we learned that RI and RRI tend to have more policy-driven outcomes that are less motivated by corporate decision-making and stakeholder engagement and more focused on participatory governance and public-facing RI mechanisms (Stilgoe et al., 2013; van de Poel et al., 2020). Research articles and commentary pieces in JRI typically involve introducing and assessing programming and frameworks from theoretical or empirical perspectives.

Given the interest in RI at governmental and industry levels, educators and institutions have started integrating RI into curricula over the last decade (Van Grunsven et al., 2024). The pedagogy category of JRI (where our article was accepted) is focused on studies of teaching, training, and learning related to RI (*Journal of Responsible Innovation Aims and Scope*, n.d.). Van den Hoven and van Grunsven et al. note that RI pedagogy attempts to reconfigure the role of ethics from being considered “an external constraint on or limitation to engineering” to instead be viewed as “design requirements that foster creative solutions throughout the innovation and design processes” (van den Hoven, 2013; van Grunsven et al., 2023, p. 2). This social science and policy-oriented research was adjacent (but not central) to our original conceptions of RI which guided the design of our intervention and workshops through 2023. However, this research area has since had a more direct influence on my ideas about the responsible *anticipation* of technology development and social impacts, which I will discuss in detail in the next section.

Our literature review found that problem-based learning, active learning, value sensitive design, and interdisciplinary ethics pedagogy are current approaches in RI curricula (Sunderland et al., 2014; van den Hoven, 2013; Van Grunsven et al., 2024); however, we also found limited examples of how arts and humanities perspectives (namely, in terms of qualitative methodologies) contributed to these pedagogical outcomes. Notably, Conley and York proposed an experimental ethics framework using design fiction in an undergraduate STEM course (York & Conley, 2020) but there is otherwise limited precedent for the design and evaluation of cross-disciplinary approaches in RI like what we have been working on.

Therefore, the reviewers challenged us to articulate the contribution of our qualitative methodology in a journal that has historically favored empirical evidence for measuring the effectiveness of RI pedagogy. Though we have surveyed multiple participant groups from critical design workshops and related curricular activities, we have largely found it methodologically counter-intuitive to apply quantitative assessments to critical design since this method is inherently contextual, discursive, and process-oriented. Further, our workshop participants, in addition to the CREATE-SEED students discussed in Paper 4, have been from a wide range of disciplinary and professional contexts, making it more challenging to generalize our survey findings. For instance, we have conducted versions of our critical design workshops with engineering educators and professionals at an IEEE conference, Master of Business Administration (MBA) students and start-up founders at Communitech[23], and undergraduate STEM students at a national hackathon, to name a few. The survey feedback ranges considerably based on these audiences; for example, start-up founders at Communitech considered critical design in the context of their product and service development and how they could use it to support their clients, whereas STEM students were interested in exploring any ethical concerns related to their sprint projects being conducted as part of the hackathon. Therefore, we pushed back on the reviewers' desires for more quantitative accounts on the effectiveness of our interventions. Nonetheless, our argument in Paper 4 – that our interventions provide a good introduction to critical design, yet more time

[23] Communitech Hub (or "Communitech") is a start-up incubator in Kitchener, Ontario. The Critical Media Lab has been located there since 2018.

and practice is needed to fully instill a heightened level of critical thinking – is an appropriate description of all first-time users of critical design. In future research, it would be interesting to incorporate a longitudinal measure that allows participants to capture their reflections and thinking process over the length of a course that engages with different critical design methods. This could also potentially be accomplished within a series of workshops with repeating participants. In this case, it would be appropriate to use journal writing or blogging in combination with a focus group format, as opposed to survey studies.

2.3 Responsible Anticipation

During my research into RI, I encountered a concept within the area, *responsible anticipation*, that appeared complementary to our goals in using critical and speculative design to enhance approaches for teaching ethical technology design and development. Responsible anticipation, one of the four dimensions of the RI framework posed by Stilgoe et al., is “the forward-looking activity of asking ‘what if…’ questions…to consider contingency, what is known, what is likely, what is plausible and what is possible” within the context of the innovation process (Stilgoe et al., 2013, p. 1570). Through science and public communication, it is crucial for experts to strike a balance between excessively optimistic and pessimistic anticipation (Vallor, 2016) and avoid a narrow focus on dramatic or sensationalist future scenarios (van de Poel, 2016). Forecasts that are overly speculative, informed by hype or ideology, or detached from reality can distract from genuine societal implications in the current time (Brey, 2012; van Grunsven et al., 2023). Scholars argue that acts of anticipation should “have at least the potential of contributing to the actualisation of a certain sociotechnical future" (Van Grunsven et al., 2024, p. 5); therefore, anticipation in practice tends to be guided by evidence-based or precautionary approaches (van de Poel, 2016).

Critical and speculative design (Dunne & Raby, 2013; Malpass, 2017) (e.g., speculative fiction, critical making, and alternative histories) aim to expand the context of, problematize existing discourses around, and overcome pre-configured assumptions of users and behaviors related to science and technology (Fuenfschilling et al., 2022). To this end, critical design anticipates the potential impacts of technology; however, it is typically more provocative and speculative than frameworks used in the RI field.

Though I recognize the concerns with overhyped predictions about a technology, the aim of critical and speculative design is to lead the user to consider new beliefs and values, question the status quo, expose assumptions, and provoke action (Malpass 2013). The CML's research does not "focus on morally thrilling scenarios…that overlook important, if more mundane and obscured, societal impacts" for the purpose of entertainment or to fuel ideologies spread through profit-seeking agendas in Big Tech, which is one area of concern in RI scholarship (van de Poel, 2016; Van Grunsven et al., 2024, p. 3). We also do not practice "design for design's sake" in a way that invokes elitist or academic-exclusive commentary on social issues (Malpass, 2013, p. 334). Our critical design research is genuinely interested in analyzing and anticipating the ethical implications of technology, particularly in the context of EEE. Furthermore, critical design can be engaged in a hands-on, creative space that promotes critical reflection (O'Gorman, 2020).

Despite the tension between critical and speculative design and the framework for responsible anticipation, both perspectives agree that we must be attentive to how anticipation is framed. Moreover, I argue it is in this tension between reality and potentially (un)desirable sociotechnical outcomes that critical and speculative design can support the goals of responsible anticipation. In the following paragraphs, I aim to articulate how responsible anticipation frameworks could benefit from critical and speculative design approaches.

It is difficult to predict the exact impact of technology on society. Van de Poel argues that the current appraisal of emerging technologies is based on science or evidence-based approaches (what we know and can scientifically prove) or precautionary approaches (scenarios that might occur but the probability of which is unknown) (van de Poel, 2016, p. 667). As these approaches are naturally limited and we cannot overcome a certain degree of uncertainty, van Grunsven (2022) asks what does *good* anticipation of an emerging technology and its real world consequences encompass?

According to Van Grunsven, there are two criteria to consider in a responsible anticipation framework. The first is *reflective anticipation*: "anticipations should reflect an awareness of how acts of anticipation can themselves actively frame how we, as a society, see, think and talk about an emerging technology in terms of its social acceptability" (Van Grunsven, 2022, p. 65). The second is *technological groundedness:* "anticipation should be grounded in a serious engagement with the technological functionalities used, developed, and implemented" (Van Grunsven, 2022, pp. 65–66).

Van Grunsven applies these criteria in their case study of the future of human-robot relationships and sex robots. Sex robots are a fringe technology that hasn't yet been fully realized from a technical standpoint but there are plenty of popular culture and speculative science fiction references (e.g., Spike Jonze's *Her,* Jeannette Winterson's *Frankkissstein,* Alex Garland's *Ex Machina*) that have contributed to both optimistic and pessimistic views on what a sexual human-robot relationship would entail. With these examples in mind, I interpret *reflective anticipation* as a reminder that the stories told about future technologies will undoubtedly influence the discourses and behaviors deemed appropriate should the technology come to fruition. I am also reminded of Donna Haraway's meditation on speculative thinking, "it matters what stories we tell to tell other stories with…it matters what stories make worlds, what worlds make stories" (Haraway, 2016, p. 12). For instance, stories that portray human-robot relationships as unhealthy will negatively bias society's attitudes about them; conversely, is it possible to imagine positive or healthy stories about human-robot relationships? How might modeling this social acceptability be beneficial for certain groups of people in the future? Critical and speculative designers can surely bring unique perspectives to address these questions.

These criteria are a useful starting point for establishing what good anticipation of emerging technology could look like – "good" anticipation being responsible, and "bad" being irresponsible (Van Grunsven et al., 2024). They also posit three stages for engineering ethics educators who want to foster responsible anticipation (Van Grunsven et al., 2024,)[24]:

1. Provide anticipatory exercises of reflective problem framing: Introduce images, metaphors, or arguments that influence our thinking about the (un)desirability of an emerging innovation.
2. Encourage reflexivity: Prompt students to reflect on how their own intuitions, beliefs, and values disrupt the innovation or problem being examined.
3. Support processes of inclusion: Prompt students to seek out alternative stakeholders who have a stake in how the emerging innovation is being anticipated.

Note that the authors do not provide specifics of their teaching interventions related to these stages in their recent work. Still, these three stages resonate with the workshops done in the CML, as detailed in Paper 4. To further explore how critical design methods align with van Grunsven's conceptualization of responsible anticipation, I will describe a speculative design workshop I attended in January 2024 and reflect on the Critical Media Lab's interventions as described in Paper 4. More specifically, I will argue that the *Parcel and Package* magazine and the CREATE-SEED students responses to the "Utopian Smartphone" speculative fiction assignment from Paper 4 are two good examples of how critical and speculative design can put participants in a mode of creative thinking about sociotechnical problems.

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[24] The descriptions of each item in this list are summarized from a longer description in Van Grunsven et al., 2024.

But before going any further, I will clarify the rationale for drawing these connections. I would argue that the CML workshops I helped to design and facilitate (detailed in Paper 4) were insufficient on their own, in terms of guiding participants toward action-oriented RI. Participant feedback and observations indicated that our workshops provided a good *introduction* to critical design; however, more time and commitment is needed for technologists to enhance their critical thinking abilities and develop a deeper understanding of ethical issues. Moving forward, I would suggest that integrating the two criteria of responsible anticipation, *reflective anticipation* and *technological groundedness*, into longer versions of the workshops, entire workshops, or a curriculum in which these concepts are reinforced regularly would provide another foothold for participants to take critical design into their own contexts. This suggestion for making RI more actionable is not intended to make the process of ethical thinking and reflection easier or more efficient; rather, this suggestion is to make more explicit the aims of RI generally. The notion of responsible anticipation is implicit in our interventions, but it could be developed further. In the following examples, I will explain how critical and speculative design is well-situated to stimulate *reflective anticipation,* and in doing so, generate valuable insights to complement, challenge, and contextualize expert analyses of *technological groundedness*.

2.3.1 Speculative F(r)iction in Generative AI Workshop

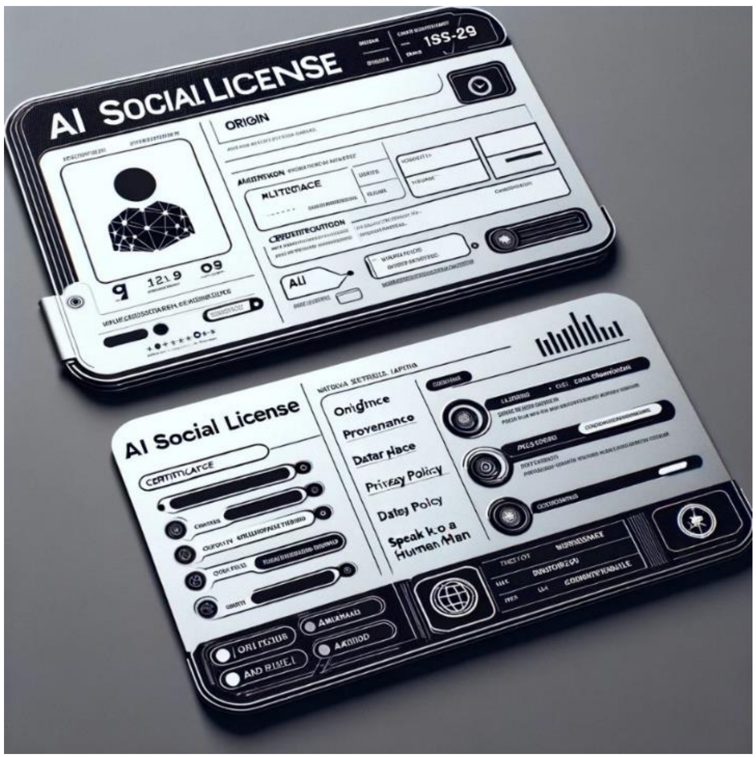
In January 2024, I attended a virtual workshop using speculative fiction to envision downstream impacts of a fictional technology/object-to-think-with. The workshop, “Speculative F(r)iction in Generative AI,” was led by Bogdana Rakova, a Senior Trustworthy AI Fellow at Mozilla. At this workshop, participants were given a primer on speculative fiction and how introducing friction into the design of generative AI systems could contribute to improved transparency, evaluation, and human agency. Rakova argues that friction can be perceived negatively because it slows down the innovation process. Through her ongoing research and this workshop, she hopes to open “new discursive spaces grounded in a speculative everything[25] approach to the blurry boundaries between fact, fiction, and friction in AI” (Rakova, 2023). To explore ways of making AI systems more transparent, the workshop was a thought experiment for participants to envision safety-enabling frictions in the context of designing, building, and regulating generative AI. The workshop was framed around a speculative science fiction, “The AI Social License” (see Fig. 10) with the following premise:

> “The year is 2028. You’ve just been awakened from a time chamber you entered four years ago. At the time that you entered the chamber, you found it very difficult to make sense of the world around you: a collapsing global economy, climate disasters, conflicts, and personal mental health breakdowns. Eventually, you signed a contract with a hibernation service that would keep you alive in a capsule and would only wake you up when the world was safe for you and your community.
>
> As part of your reentry into the world, you are given a medical checkup. As you walk into the clinician’s office, you realize that the doctor has an AI assistant they are talking to. You are immediately concerned about the AI agent and ask the clinician to explain. They present you with the card below titled “*AI Social License*.” It has a QR code, which you’re instructed to scan with your phone.

[25] In reference to Speculative Everything by Anthony Dunne and Fiona Raby.

The AI Social License (ASL) is a digital document and a conversational interface that anyone can interact with. You can ask questions, decide if you can trust it, and report issues or concerns. Specifically the ASL is designed to enable a more meaningful form of consent and contestability with regards to data and its use." (Rakova, 2024)[26]

Figure 10: ***AI Social License***



Note. Generated with OpenAI's GPT 4 and DALL-E by Bogdana Rakova (2024)

Put simply, an ASL is a contract allowing an AI agent to provide medical consultation. The companies who build the AI agent must register it in a public database and provide information about its training data, algorithms, uses, and evaluation testing. In the context of

[26] The full description can be viewed at https://bobi-rakova.medium.com/the-ai-social-license-9d5ed4dc1815.

this narrative, the licensing of an AI agent represents a mechanism of friction in the consent process to enhance transparency of AI systems.

As part of the workshop, participants were separated into groups and invited to discuss three main prompts on how they envision interactions and areas of concern with regard to consent with the ASL:

1. How does the ASL ask for and register consent? What does consent mean?
2. What would you ask the ASL? What answers do you imagine the ASL providing?
3. How does that impact meaningful consent? Is there something that could exist for you to trust the ASL?

As a participant, I asked how this consent mechanism could overcome the weaknesses of Terms of Service agreements seen today, many of which contain convoluted jargon and default opt-out settings designed to mislead users (Brignull, 2023). My group's conversation touched on topics including user accessibility, medical confidentiality and security, the robustness and reliability of ASL training data, and patient rights in the case of misdiagnosis or malpractice on the part of the ASL.

In the context of using speculative f(r)iction to investigate the governance of AI systems, I observed two important characteristics of Rakova's workshop approach that link with responsible anticipation. Firstly, by situating the narrative in the near-future of 2028, Rakova found balance between a relatable and uncanny future scenario. The scenario's motivation for participants to have entered a "time chamber" to avoid global disasters is inspired by current conditions in the real world. The accompanying questions are flexible enough to leave space for participants to envision both optimistic and pessimistic outcomes of an ASL, a balance which Shannon Vallor (2016) and Ibo van de Poel (2016) have deemed important to prevent anticipation from being too far-fetched. Hilgartner notes that novel visions can be inspirational but if they depart too far from collective experience, they may not be taken seriously (Hilgartner, 2015). This resonates with the effectiveness of *Black Mirror* episodes: the most impactful episodes are arguably the ones not so far out of imagination's reach that they still disturb the status quo as we know it.[27] The ASL narrative achieves the same effect. Additionally, given the rapid improvements of Natural Language Processing capabilities as of 2024, furnishing an AI agent with the ability to interface with a human patient by 2028 is not an unrealistic technological projection. The timeline and details of the speculative narrative's context help to reinforce the workshop's connection to *technological groundedness*.

Secondly, Rakova emphasizes that design fiction is not to predict the future but "to open up all sorts of possibilities that can be discussed, debated, and used to collectively define a preferable future for a given group of people" (Rakova, 2023). Given recent debates about whether AI, specifically chatbots like ChatGPT and others, can reliably provide medical advice and augment or replace the work of physicians (Shmerling, 2024), Rakova does a good job of narrativizing this emerging technology while also guiding participants to

---

[27] Science fiction author William Gibson has said that he aims to foster a sense of "contemporary weirdness" in his famously prescient speculative fiction writing about the near future (Ward, 2010).

consider how they might encounter it in their own lives. Matt Malpass notes that speculative design “makes visible what is emerging” in science and technology development and aims to “broaden the contexts and applications of work carried out in laboratories and show them in everyday contexts” (Malpass, 2013, p. 337). For instance, as a participant I envisioned a potential conflict with the ASL if a patient doesn’t know they are pregnant – this could have political implications if they live in a place with conservative views of abortion. Again, similar to how digital redlining has impacted marginalized communities access to education, healthcare, and community resources (Köseoğlu et al., 2023; McCall et al., 2022), there are multitudes of situations where someone could be at a disadvantage in giving consent to an ASL because of their gender, race, socioeconomic status, disability, or other personal characteristic or circumstance.

My main critique of this workshop is that the current questions prompt participants to think about their own reaction to the ASL but stop short of prompting them to imagine others’ perspectives. To this end, I think that the *reflective anticipation* element could be fleshed out more. If I were to add to the workshop, I would include questions that ask participants to reflect on societal values and expectations related to the ASL; perhaps this would stimulate a more holistic awareness of how anticipation frames the social acceptability of the ASL as a new technology, as van Grunsven is advocating for.

One reason that I chose to examine Rakova’s workshop is that my own ratio of facilitated workshops to attended workshops is unbalanced toward the former. As a research assistant in the Critical Media Lab, I have grown accustomed to our content and style of workshops. Therefore, it is useful to see a different workshop that is centered around one very detailed object/narrative rather than having multiple case studies or being individualized to the participants' own work. Having said that, it is one of our research objectives to demonstrate how critical and speculative design can be used as a tool in the engineering design workflow and our audience's work specifically. Still, a strength of Rakova's approach is that a story with this level of detail allows participants to uncover multiple layers in the way it connects to theirs and others' experience. In future work, I would be interested in having participants use the *Tarot Cards of Tech* to create their own narratives that they could use as the basis for a workshop like Rakova's.

2.3.2 Critical Media Lab Interventions

The two interventions discussed in Paper 4, the cross-disciplinary curricular intervention between English and Engineering students and the RI workshops, were not designed with a responsible anticipation framework in mind. Still, there are consistent characteristics of these critical and speculative design interventions and results that demonstrate *reflective anticipation* and *technological groundedness*.

One compelling example is Christopher Rogers's *Parcel and Package* speculative fiction magazine. This project acutely observes public discourse around the risk of porch pirates and aggressive demands for fast shipping; these concerns were highly visible around the time this project was completed (2021), still during a period of increased online shopping related to the COVID-19 pandemic. The magazine's editorial, "It's Time to Arm Human

Couriers" (see fig. 4) and full-page advertisement for the "all new 2025 SecuriShop Fourth Generative Logistics Vehicle" equipped with "caffeine tablet dispensers and auto fatigue sensors" (see fig. 5) illustrate dangerous working conditions for couriers in a world with ultra-high levels of consumption. This vision of the future prompts the audience to consider the social acceptability of armed delivery workers who are subjected to surveillance, biometric monitoring, and other productivity enhancing tools for the sake of receiving packages at an accelerated rate. It can also lead the audience to consider, if they do think aspects of this vision are reasonable, the boundaries they would draw around the use of this technology for people in other contexts. It is key to engage with other perspectives to recognize that what is desirable for me, may not be desirable for others. We can also ask about the political and social infrastructure that could enable a future like this to occur. Though this is a dark vision of consumerism, it is a sobering one that can be used to provoke reflection on the values and design of a technology, its potential uses, and downstream consequences. Rogers's magazine is a great example of *reflective anticipation*, in its appeals to the elevated expectations of delivery workers during the COVID-19 pandemic, and *technological groundedness*, in recontextualizing the use of existing technologies (firearms, biometric sensors, etc..) to illustrate a plausible, though not particularly enticing, vision of the future.

Another example is the collaborative project completed by the CREATE-SEED students in response to the Utopian Smartphone scenario:

> “A top-secret company funded by a team of billionaire environmentalists is developing a new smartphone. This is a chance to reinvent smartphones from the ground up, based on principles of a circular economy. Each team will be tasked with designing a separate device component. At the end of the design session, we will put the pieces together and evaluate the results.” (see Paper 4)

To help make the case for this workshop’s alignment with responsible anticipation, I will provide some additional information that is not in Paper 4. The five teams, comprised of PhD students in Chemical, Electrical, Biological, and Mining Engineering (among other related domains), were each tasked with designing one part of the smartphone: the enclosure, screen/touch-based input, power source/battery, integrated circuitry, and network connectivity. The teams populated a virtual Mural board with their brainstorming and prototyping ideas; shown below is the power source/battery team, with whom I was able to listen in during their workshop time. To fulfill the brief of a smartphone redesign based on the principles of a circular economy, the power source/battery team focused on renewable energy sources, including organic materials, oxygen, and solar energy (see fig. 11). They also mentioned how a biomolecule or protein-based battery would allow them to avoid mining and processing metal substances. This led them to settle on an approach that would allow them to leverage the properties of algae species to develop their battery (see fig. 12).

Figure 11: ***Team 3's Mural Brainstorming Section***

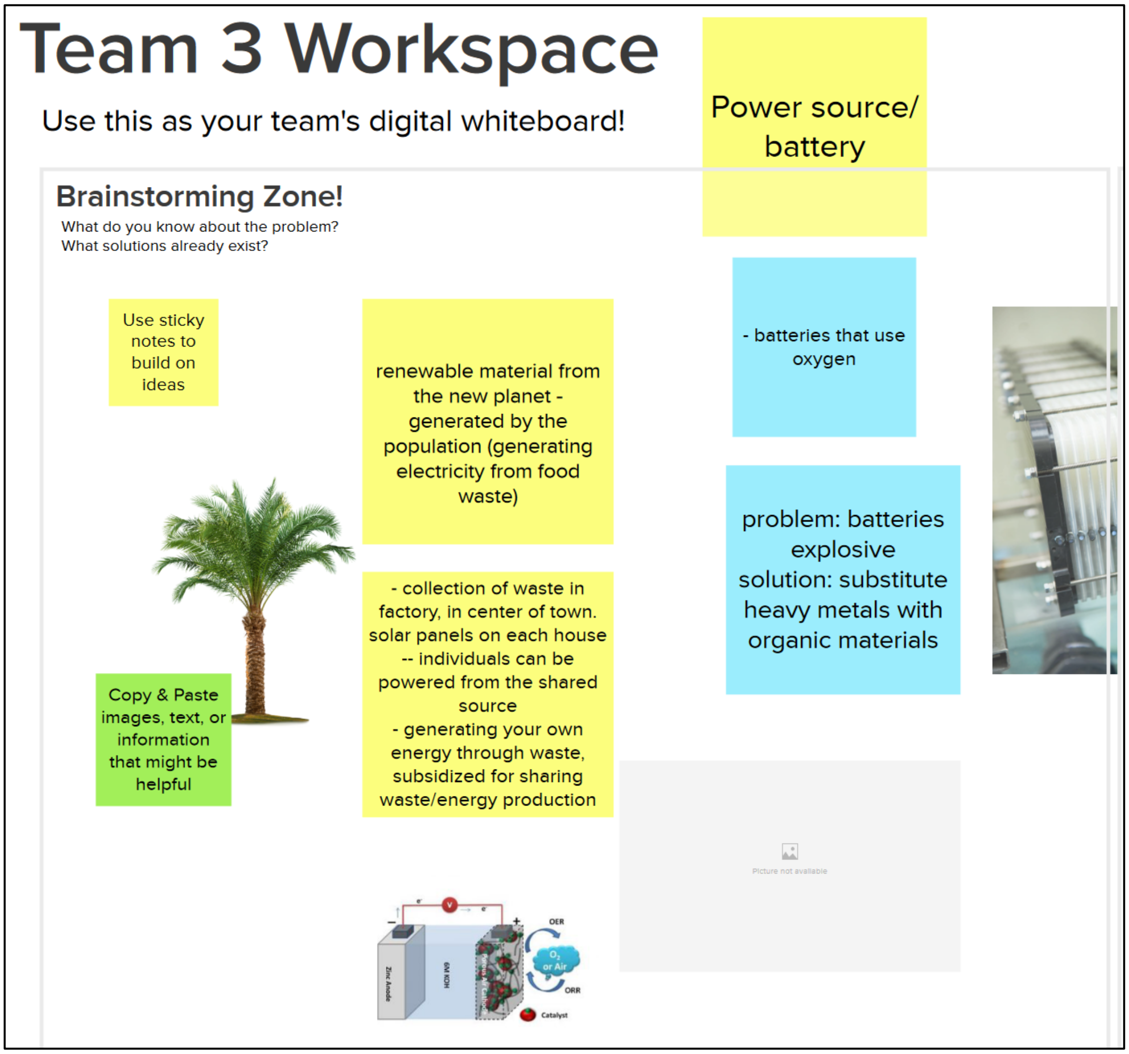
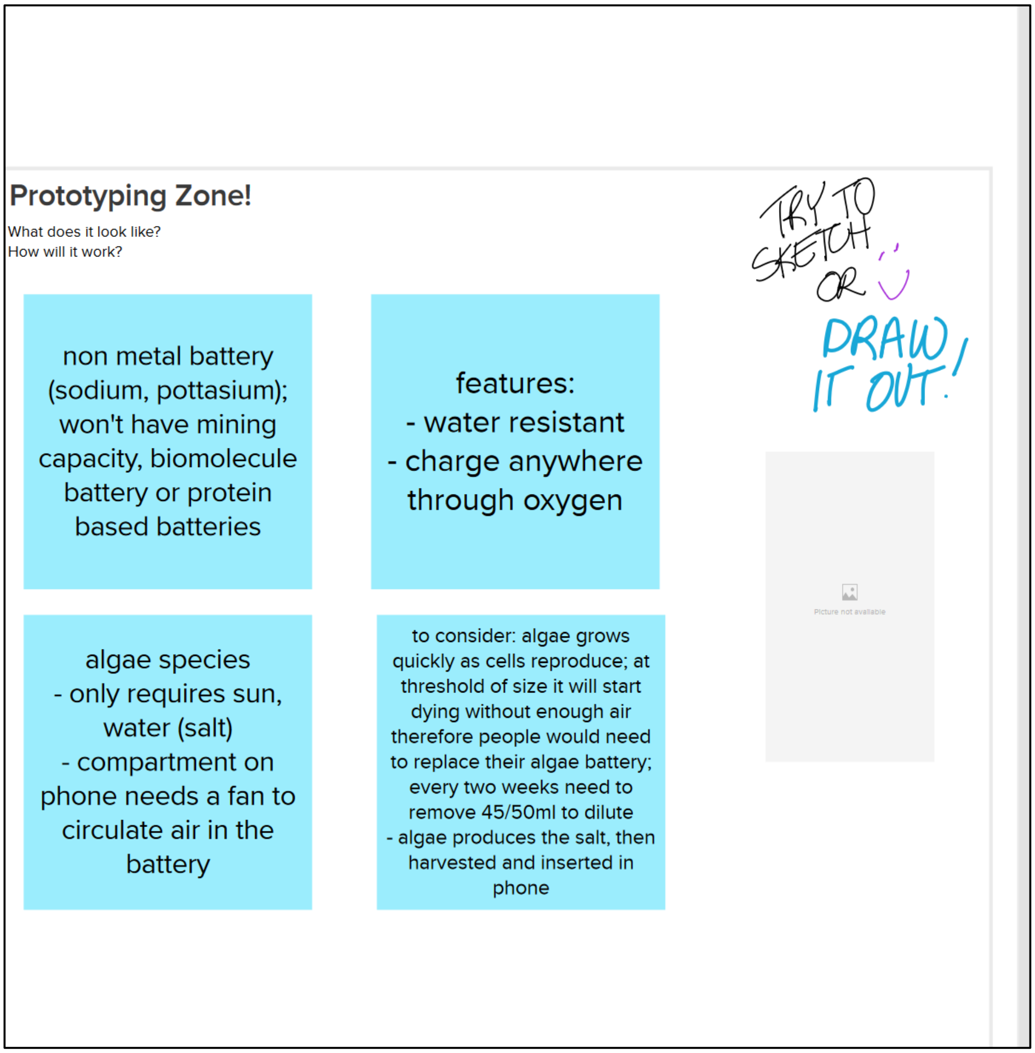


Figure 12: ***Team 3's Mural Prototyping Section***



It is unlikely that the CREATE-SEED students would have envisioned this new design without the constrains and framing of the speculative fiction scenario. The participants did not actually prototype an algae-powered battery; however, I would suggest this is a plausible idea developed with the scientific expertise of these PhD students.

I argued at the beginning of this section that *reflective anticipation* can complement, challenge, and contextualize *technological groundedness*. The Utopian Smartphone scenario is one example of how *technological groundedness* can be inspired by the creative framing of a speculative future. This is important because we want to be able to develop critical design activities that engage the expertise of our STEM participants – which encourages their participation and buy-in to the activity – while infusing opportunities for critical and ethical reflection.

With that said, I do not see these two criteria situated in opposition to one another or at two ends of a spectrum. I also do not want to frame *reflective anticipation* in service of *technological groundedness*, much the way that humanities and social science disciplines are sometimes framed as ‘supplementary’ to technical expertise (Cech, 2014). As Chapter 1 discussed, engineering education approaches that prioritize technical knowledge over ethics and related topics can leave graduates unprepared to grapple with the complex sociotechnical contexts they will face in their careers (Goldenkoff & Cech, 2024). Therefore, skills that are necessary to participate in *reflective anticipation,* including ethical thinking, critical analysis and reflection, and communication, should not be framed in a hierarchical relationship below technical knowledge. In the same vein, the practice of *reflective anticipation* requires epistemic humility (Van Grunsven et al., 2024) and should not be positioned as an intellectually or morally superior endeavor. Ideally, employing these two criteria should be an iterative exercise.

The Speculative F(r)iction workshop, *Parcel and Package* magazine, and Utopian Smartphone scenario all connect with the two criteria for responsible anticipation at different levels. When developing interventions, scenarios, or workshops that prompt participants to think, design, and reflect, both criteria can be emphasized. The workshop designer has flexibility to focus on either or both criteria as desired and appropriate to their audience.

2.4 Chapter 2 Conclusion

By examining multiple cross-disciplinary interventions and projects done by and through the Critical Media Lab, Chapter 2 highlighted the opportunities and challenges for integrating HSS perspectives into engineering and tech curriculum through critical design methods. Since 2021, we have conducted 14 workshops with 364 participants across multiple disciplinary backgrounds (see Table 5); we have honed our workshop activities, aided significantly by the *Tarot Cards of Tech*, to facilitate inclusive and accessible conversations about the ethical and social considerations of technology, engineering, and design. I have been a facilitator for seven of the fourteen workshops in Table 5. I also note there were many iterations of these workshops which preceded 2021 and were designed and led by Marcel O'Gorman.

In 2023, we started integrating Value Sensitive Design into our workshops. This is an area of work I will elaborate on in Chapter 3. We hope that these activities and examples provide inspiration for other educators who want to integrate more critical thinking and reflection about technology through a creative avenue such as critical and speculative design.

Table 5: ***Workshops Completed by Critical by Design Research Team since 2021.***

Audience/Venue	Participant (N)	Tool/Method	Session Time	Facilitators
uXperience Design Conference	20	CD, RI	90 min	RS
Students at Hackathon	25	CD, RI	2 hours	MO, AO
CREATE-SEED PhD Students	15	CD, RI	4 hours	MO, AO
Communitech Founders	10	CD, RI	90 min	MO, RS
MBA Students	20	CD, RI	90 min	AO, RS, HL
Year 1 Engineering Students	125*	VSD, RI	80 min	AO, RS, HL
Year 3 Engineering Students	50	VSD, RI	60 min	AO
IEEE Ethics Conference	25	CD, RI, VSD	90 min	AO, RS, HL
Year 4 English Students	4	CD, RI, VSD	90 min	RS
Graduate English Students	10	VSD, RI	90 min	RS
Diversity in Engineering Conference	60	CD, RI, VSD	90 min	AO, RS, HL
	Total: 364			

Tool/Method: Critical Design (CD), Responsible Innovation (RI), Value Sensitive Design (VSD)

Facilitators: Rebecca Sherlock (RS), Marcel O'Gorman (MO), Alexi Orchard (AO), Heather Love (HL)

*This is the total participants across four of the same workshops conducted with different Year 1 Engineering students. AO and RS conducted one together, RS conducted one independently, HL conducted two.

This chapter has also shown the RI field can provide frameworks and criteria for developing and assessing speculative thought experiments. The notion of responsible anticipation helps to identify elements of a critical and speculative object or narrative that elicit both reflective and technologically grounded responses. Further, the practice of responsible anticipation requires interdisciplinary thinking and collaboration. This was demonstrated through my analyses of the Speculative F(r)iction workshop and Critical Media Lab interventions.

Designing and facilitating the interventions presented in Chapter 2 has been a great team effort with members of the Critical Media Lab and collaborators from across the university. To elaborate on my individual contributions to this field of work, in Chapter 3 I will introduce a novel pedagogical tool and workshop that I designed and facilitated as an independent instructor and facilitator in the last two years of my doctoral studies.

Chapter 3: Critical Collaborations

> "Data is a thing, a process, and a relationship we make and put to use. We can make it and use it differently."
>
> - Feminist Data Manifest-No, 2019

In 2019, Drs. Marika Cifor and Patricia Garcia organized the Feminist Data Studies Workshop at the Institute for Research on Women and Gender at the University of Michigan. Participants were gathered based on their complementary expertise in feminist data studies across multiple disciplines. As part of the workshop, these scholars and practitioners drafted the Feminist Data Manifest-No, a set of declarations and commitments that refuse harmful data regimes and aim to create new data futures (Cifor et al., 2019). The Manifest-No advocates for justice, fairness, and transparency, much like other manifestos previously mentioned in Chapter 2, such as the Tech for Good Declaration or Microsoft Responsible AI Principles (Communitech et al., 2018; *Responsible AI Principles from Microsoft*, n.d.); however, the Manifest-No is an explicit call to action that vehemently refuses "any code of phony 'ethics' and false proclamations of transparency that are wielded as cover, as tools of power, as forms of escape that let the people who create systems off the hook from accountability or responsibility," such as those developed by corporations or organizations motivated by their own interests (Cifor et al., 2019). In this way, the 32 refusals and commitments of the Manifest-No charts a path for scholars and practitioners to make and use data differently.

The Feminist Data Manifest-No is one resource dedicated to envisioning and building fair and safe data practices for everyone; other frameworks in this same conversation, which I will explain more in this chapter, include *Data Feminism* (D'Ignazio & Klein, 2020), *Design Justice* (Costanza-Chock, 2020), and Value Sensitive Design (VSD) (Friedman & Hendry, 2019). *Data Feminism* and *Design Justice* are informed by intersectional feminist theory, an area based on Kimberle Crenshaw's critique of the conception of discrimination as existing along a single categorical axis where race and gender are considered independently of one another (Crenshaw, 1998). Crenshaw argues that individuals who are "multiply-burdened" (i.e., they belong to more than one non-dominant race or gender identity) are *intersectionally* disadvantaged under white supremacy, heteropatriarchy, capitalism, and settler colonialism (Costanza-Chock, 2020; Crenshaw, 1998, p. 315). *Data Feminism* and *Design Justice* use this framing to highlight the multiple facets of inequities that exist in technology design.

Now, it is possible that some engineers would not be able to imagine why or how intersectional feminist theory is relevant to engineering. At first glance, some engineers might even reject this notion altogether. But some of the individuals who have researched and proposed these approaches and declarations, such as the Feminist Data Manifest-No, are engineers, computer scientists, and data scientists who have recognized the inequities, biases, and structural problems within their fields. This work does not exist separately from these technical fields; it exists to be embedded in and to transform our understanding, methods, and uses of design and engineering.

In recent years, more educators have integrated *Data Feminism* and *Design Justice* frameworks into their data science and engineering courses (Baynes & Norris, 2021; Ostrowski et al., 2023; Ozkan & Hira, 2021). The purpose of bringing feminist data studies and value sensitive design[28] into my dissertation is to demonstrate how these frameworks and approaches can be put into practice and used to highlight the Graduate Attributes "Ethics and equity" and the "Impact of engineering on society and the environment" in the context of technical design decision-making. To do this, Chapter 3 will first describe three workshops that have embedded aspects of VSD, *Data Feminism*, and *Design Justice* to varying degrees:

1. Value Sensitive Design – Rebecca Sherlock and I conducted this workshop with first year Management Sciences Engineering students in March 2023.
2. Leading Equitable Data Practices – I was a participant in this three-week workshop, conducted by the non-profit organization LA Tech4Good in November 2022.
3. Designing for Equity in Public Spaces – I conducted this workshop with third year Systems Design Engineering students in March 2023.

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[28] Value sensitive design can certainly be used alongside intersectional feminist studies frameworks, as this section of the dissertation will demonstrate, but Friedman and Hendry do not explicitly attend to that audience in their original work.

The first two workshops and the concepts therein inspired the third workshop. I will give an overview of each and then provide a detailed explanation of and reflection on my process of designing and conducting *Designing for Equity in Public Spaces.*[29]

The ethos of these feminist data studies frameworks aligns with the Critical Media Lab's work toward ethical and responsible innovation through our approaches and workshops. Our study and implementation of critical design (Dunne & Raby, 2013), design-based card tools, and value sensitive design (Friedman & Hendry, 2019) is motivated by a desire for critical thinking and reflection on the power asymmetries and structural and societal hierarchies that influence the design and use of technology.

The second part of Chapter 3 will introduce a critical design-inspired pedagogical tool, *The Innovation Problem Finder Dartboard*, that I invented and integrated into my first year Communication for the Engineering Profession course (ENGL 192) in 2023. In my course, this tool was used to help students generate and investigate their project topics through the lens of EDI and social and environmental justice. Paper 4: "The Innovation Problem Finder Dartboard: Embedding Critical Design in the Engineering Workflow" was published and presented at the Canadian Engineering Education Association Annual Conference in June 2024.

[29] After participating in Workshop 2 and leading Workshop 3, I wrote a blog post on my experience for the LA Tech4Good webpage, which can be found here: https://www.latech4good.org/news/waterloopark. Parts of the blog are rewritten and expanded in the following sections on these two workshops.

3.1 Three Workshops

In Chapter 2, I introduced the *Tarot Cards of Tech* (see fig. 8 and 9). This is the card-based design tool that we use most often in our workshops and interventions but there are many other card decks and similar resources used for similar purposes. Two examples found in responsible innovation literature include the *IMAGINE RRI* cards (Felt et al., 2018) and the *Moral-IT Deck* (D. Urquhart & J. Craigon, 2021). There have been multiple studies of ethics and RI-focused card-based tools. Some strengths of these card decks include summarized information presentation and portable and accessible physical design (Carneiro et al., 2012; Mugge & Desmet, 2016; R. Roy & Warren, 2019).

Another values-based card collection that has inspired work in the CML is *The Envisioning Cards*, which is part of Value Sensitive Design (Friedman & Hendry, 2019). *The Envisioning Cards* focus on four criteria – stakeholders, time, values, and pervasiveness – to guide designers in thinking about the impacts of their work. A more recent expansion pack for the cards encourages a 'multi-lifespan' (Yoo et al., 2022) approach that extends the temporal dimension of design. These cards have been implemented, researched, and adapted in medicine, security and privacy, AI, robotics, and post-secondary engineering classrooms around the world (Dexe et al., 2020; Lopez et al., 2019; Lupetti & Cila, 2019; Silin & Bystrova, 2020).

There are 17 "methods" of VSD that work to investigate values in technology. Some methods are novel (e.g., value dams and flows, the Envisioning Cards), and others represent methods from social scientific and design research that have been adapted within a VSD framework (e.g., value-oriented interviews) (Friedman & Hendry, 2019, p. 60).

Since the CML workshops are typically 1-2 hours in length (see Table 5) and we cannot possibly cover the entire library of VSD methods, we typically focus on early-stage, conceptual investigations[30] in the VSD process, which includes stakeholder analysis and value source analysis. To illustrate our approach, I will describe the VSD workshop that I conducted with Rebecca Sherlock, another CML Research Assistant, in March 2023.

3.1.1 Workshop 1: Value Sensitive Design

In March 2023, Rebecca Sherlock and I conducted an 80-minute VSD workshop with first year Management Engineering students. Our learning objectives for this workshop were for students to:

1. Practice identifying stakeholders, values, and value tensions based on the VSD framework in the context of a Management Engineering-related case study, such as the Tim Horton's coffee shop drive-thru.
2. Practice and enhance their analytical and critical thinking skills by applying these concepts (stakeholders, values, and value tensions) to their own project topics.

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[30] Though there are multiple VSD methods to draw from, we have found only a few that are suitable for student projects or one-off interventions/workshops because some VSD methods assume interaction with the stakeholders, which is typically less feasible in the classroom context. This is why we focus on the conceptual investigations, which come first in the tripartite VSD methodology. Hypothetically, if an entire design course was structured around VSD methods and students were able to choose projects with stakeholders that they could personally engage with, it would achieve a more comprehensive implementation of VSD in the classroom context.

The workshop began with an overview describing the uses and motivations of VSD, and then introduced three types of stakeholders (direct, indirect, and excluded) and the concept of values, as illustrated by Shalom Schwartz's Spectrum of Basic Human Values (Schwartz, 2012). Direct stakeholders are those who interact directly with a technology or problem; indirect are those who Friedman and Hendry describe direct stakeholders as "those who interact directly with a technology" and indirect stakeholders as "those who do not interact directly with a technology but may nonetheless be affected" (Friedman & Hendry, 2019, p. 65). Excluded stakeholders are those who are not permitted or choose not to interact with the technology or problem space. For example, a stakeholder may be excluded on the basis of public policy, the law, or sociocultural or community factors (Yoo, 2018).

To apply the concepts of stakeholders and values, we presented a case study of a Tim Horton's coffee shop drive-thru parking lot that is close to Waterloo's campus. We chose this case study for two reasons: it resembles a project scenario that would be suitable to a Management Engineering context and the students were familiar enough with the nearby location that they could more easily envision stakeholders and values.

In the first section of the workshop, students completed the first and third steps of the VSD methods framework, Stakeholder Analysis and Value Source Analysis, based on the drive-thru parking lot. For example, direct stakeholders included customers, employees, drivers, and pedestrians. We mapped the values of these stakeholders on the large whiteboard (see Fig. 13); for instance, some of the values for drivers included safety, convenience, and vehicle accessibility. The class easily identified direct and indirect stakeholders but initially struggled to unpack what constitutes an excluded stakeholder and who would be one for this case.

Eventually, the group identified Canada geese, who nest and roam in the area close to the parking lot, to be excluded stakeholders.[31] The students speculated that the geese value freedom, safety, and care for their goslings – values which can conflict with other stakeholders in the scenario. This example prompted a longer discussion on the assumptions and bias that designers can have from an external perspective on a problem space.

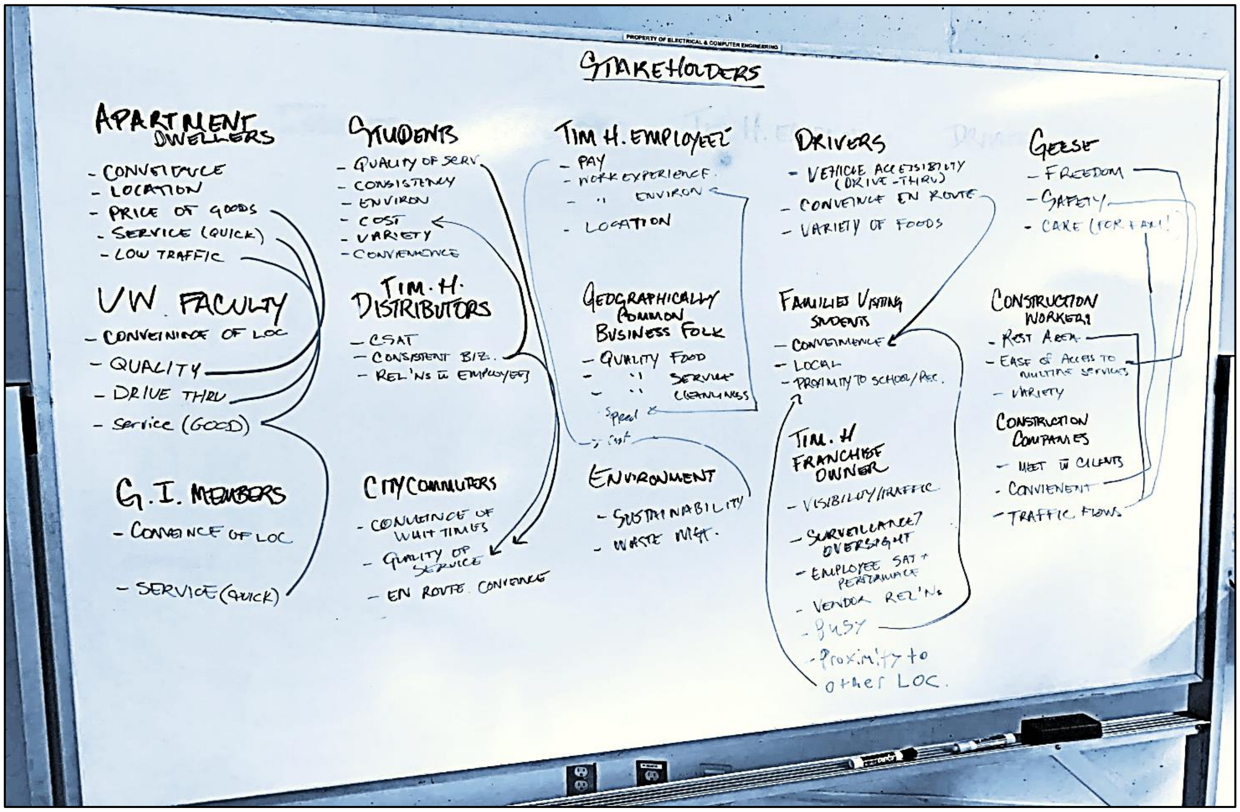
In the second section of the workshop, the student groups applied Stakeholder Identification and Value Source Analysis to their own projects in the course. They used large poster boards, sticky notes, and permanent markers to list the stakeholders, identify their values, and draw value tensions between them. We concluded the workshop with a class discussion about the value tensions they found within their individual projects and next steps for integrating this analysis into their ongoing work.

One of the key takeaways for this and other workshops done with VSD is the benefit to using a case study that connects with the discipline or domain of our audience. The Tim Horton's example was distant enough from their own project topics that although it helped

[31] In multiple workshops, students have asked us how to categorize excluded stakeholders. Based on the summary of conceptual investigation process in the VSD methodology (Friedman & Hendry, 2019, p. 32), non-humans can be direct, indirect, or excluded stakeholders but there is limited guidance as to how to categorize excluded stakeholders that I have found so far. Daisy Yoo, a former PhD student of Batya Friedman, identified four categories of excluded stakeholders in their thesis (Yoo, 2018) based on the specific case study of VSD in a healthcare setting but in this case, the categories presented were specific to their thesis topic. Further, Friedman and Hendry offer no clarification around whether stakeholders can be both direct and excluded (or indirect and excluded), as the geese arguably are in Workshop 1, and how that influences the Value Source Analysis and following steps in the VSD methodology.

them learn the VSD process, it still required them to translate these steps into the more targeted context of their projects. Thus, they were not simply duplicating work when they applied VSD to their own projects. This approach connects with my discussion in Chapter 1 regarding the use of case studies: they should be situated in relatable contexts with details that are appropriate to the audience's experience.

Figure 13: ***The Stakeholder Analysis and Value Source Analysis process.***



Note. Image property of Critical by Design research team.

We have also found that it is more engaging for students to work together while using paper and markers to create visual representations, rather than typing ideas on their computer, to communicate their ideas in these activities.

During the Winter 2023 term in which the VSD workshop with Management Engineering students took place, I was also considering my main takeaways from a three-week data equity workshop I took with a non-profit organization, LA Tech4Good, in November 2022. The VSD workshop and this data equity workshop influenced the design of my own workshop, *Designing for Equity in Public Spaces*, also conducted in March 2023. I will first give a brief overview of the data equity workshop and its key concepts, and then introduce my solo workshop that integrates VSD and data equity.

3.1.2 Workshop 2: Data Equity

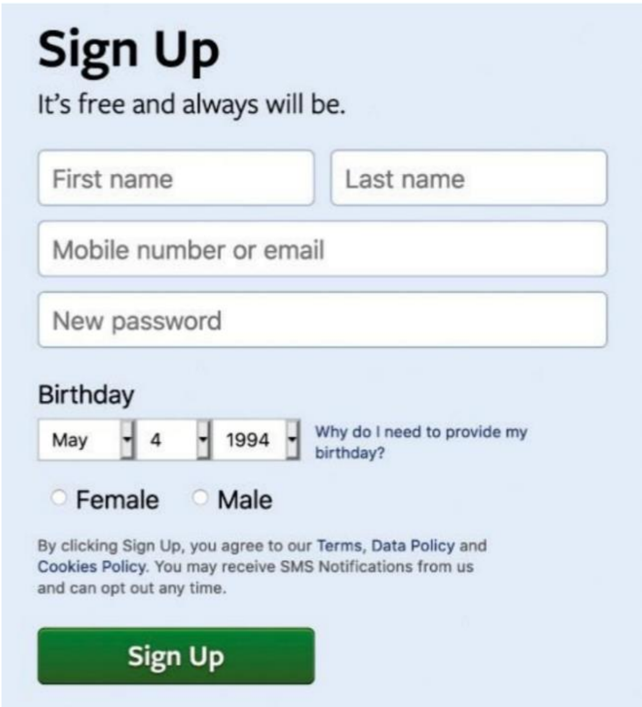
The second workshop is not one that we designed or facilitated but rather is one that I participated in separately from the CML's research projects. I am including a description of it here to explain where I see value sensitive design (Workshop 1) and data equity (Workshop 2) being a useful combination for scaffolding learning outcomes and deliverables that connect the Graduate Attribute "Ethics and equity" to the engineering design process more explicitly (Workshop 3).

In November 2022, I participated in a three-week workshop, *Leading Equitable Data Practices*, led by the American non-profit organization LA Tech4Good. Their mandate is to establish principles and practices that guide the end-to-end process of a data project through the lens of justice, equity, and inclusivity. Their work champions the Data Feminism tenet of data work being "both an outcome and a process" which situates equity at every stage of a data project (D'Ignazio & Klein, 2023). The workshop provided resources and tools to design a documentation framework, propose guidelines and policies for your organization's data projects, and identify structural issues that can arise during data science projects (LA Tech4Good, n.d.). One of the unique aspects of this workshop series that sets it apart from other "how to" data management workshops, courses, and offerings that can be found online is its emphasis on equity and intersectionality. Some of the weekly readings and resources included research from AI and data ethics experts and scholars such as Sasha Costanza-Chock, Catherine D'Ignazio and Lauren Klein, Virginia Eubanks, and Timnit Gebru.

Of these authors, the data equity workshop emphasized Sasha Costanza-Chock (author of *Design Justice*) and Catherine D'Ignazio and Lauren Klein (authors of *Data Feminism*). When designing equity-based outcomes, these authors provide inspiration for any data practitioner. Data Feminism, a set of design principles informed by intersectional feminist theory, challenges power asymmetries and hierarchical classification systems that make different identities and types of human labor obscured or invisible. In the fourth chapter, "What Gets Counted Counts," D'Ignazio and Klein call out the classic Facebook sign-up feature from prior to 2014, where female and male are the only gender options (see Fig. 14) (D'Ignazio & Klein, 2020). As of 2023, Facebook updated these options to improve their inclusivity (see Fig. 15).

LA Tech4Good's workshop also discussed the Gates Foundation's "Reinvent the Toilet Challenge," a $200 million project for worldwide teams to design affordable sanitation solutions in developing countries. A key obstacle in this initiative was that the community faced issues of "access, social mobilization, and ongoing maintenance" that were not solvable by an innovative toilet design; rather, they needed the expertise of those who are familiar with the community and infrastructure of those countries (Costanza-Chock, 2020). Costanza-Chock observed that innovative designs are not effective solutions without accounting for the context and community who they're meant to serve.

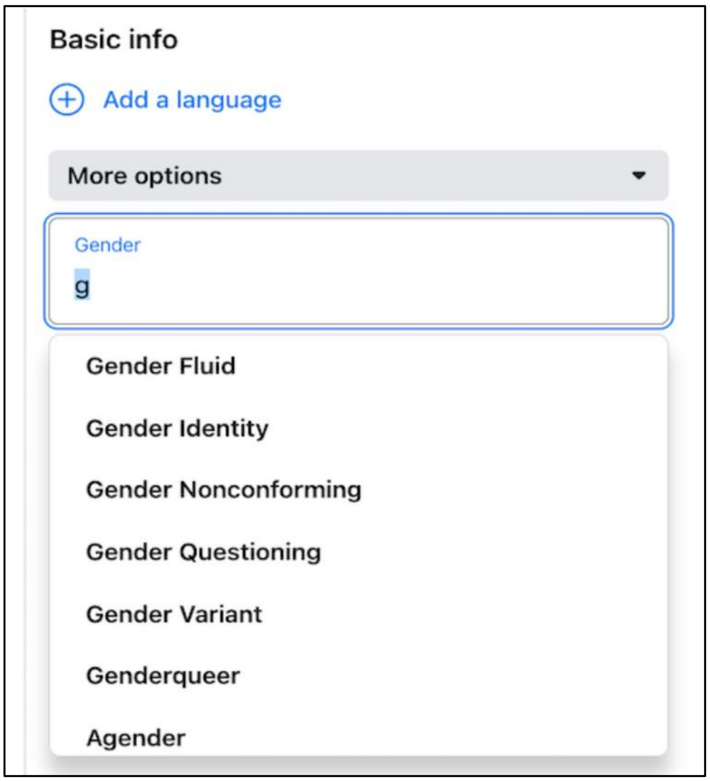
Figure 14: ***Facebook female and male options until 2014.***



The Facebook gender options and Reinvent the Toilet Challenge examples aptly framed the outcomes of this workshop in terms of emphasizing how data work is about understanding groups of people and structural challenges, including colonialism, classism, and ableism (among many others), that they face in their daily lives and interactions with technology, public services, and resources.

Another useful resource included in the data equity workshop was a scaffolded approach to implementing Gebru et al.'s "Datasheets for Datasets" framework (Gebru et al., 2021). "Datasheets for Datasets" is a framework for documenting the motivation, composition, collection process, uses, distribution, and maintenance of datasets that aids dataset creators and consumers in increasing transparency and accountability (Gebru et al., 2021).

Figure 15: ***Some of the Facebook Gender Options in 2023***



The framework is tailored to machine learning data management, but multiple questions are applicable to other types of projects. For instance, questions in the Collection Process section (Gebru et al., 2021, pp. 6–7) prompt users to consider "Does the dataset contain data that, if viewed directly, might be offensive, insulting, threatening, or might otherwise cause anxiety? If so, please describe why." The LA Tech4Good facilitators guided participants through an abbreviated application of these questions to our own projects, which helped us generate ideas about metrics for considering equity. There was no outcome or deliverable from this workshop other than them providing and explaining these frameworks in a handful of case studies so that we could understand them for our own use in the future.

And I did happen to use them soon after! It so happened that the examples and resources used in Workshop 2 complemented the VSD framework the CML was coincidentally exploring around the same period. In the next section, I will explain the development and implementation of my own workshop that combines aspects of Workshops 1 and 2 with the goal of scaffolding a hybrid approach to demonstrate how to design for ethics and equity in an engineering project.

3.1.3 Workshop 3: Designing for Equity in Public Spaces

In March 2023, I conducted a 60-minute *Designing for Equity in Public Spaces* workshop with third year Systems Design Engineering students in the Systems Design Methods 2: Testing, Verification, and Validation (SYDE 362) course. SYDE 362 is an introduction to design verification, validation, and performance measurement and analysis using engineering tools. Aligning with their ongoing course assignments and projects, my workshop focused on how to identify and implement equity-based metrics and methods in a case study on the use and maintenance of Waterloo Park, a large park located near Uptown Waterloo. The learning outcomes for this workshop were for students to:

1. Explain the concept of data equity and identify different types of stakeholders.
2. Select metrics and methods for how they would collect and assess information needed for an engineering report.
3. Identify what structural issues could influence the research process in the context of the Waterloo Park case study and reassess their metrics and methods with data equity in mind.

I took aspects from VSD (Workshop 1) and data equity (Workshop 2) and organized this 3rd workshop into three breakout activities with interstitial lecture content and discussion time. I will review the content of each of these sections in more detail:

- Lecture 1: What is Data Equity?; Introduce Case Study: Waterloo Park
    - Breakout 1: Identifying Stakeholders, Metrics, and Methods
- Lecture 2: Background on Parks
    - Breakout 2: Datasheets for Datasets
- Lecture 3: What are Structural Problems?
    - Breakout 3: Identifying Structural Problems with Datasheets for Datasets

Lecture 1: What is Data Equity?

A common misconception to clarify when introducing the concept of data equity is that data is objective. People who work with data collection, organization, and management are constantly making decisions about what information to collect, include or exclude, and implement at multiple stages throughout a project. These decisions are inherently subject to the biases of the data practitioner and others working on a project. Rachel Whaley, the Data Equity Program Lead at LA Tech4Good, notes that incorporating equity as part of this decision making process involves identifying contexts where people could be harmed and working to prevent or reduce harm, especially when it is disproportionately impacting a specific group who may or may not be represented in the data (Data Con LA, 2021). I used the Facebook gender options from *Data Feminism* (D'Ignazio & Klein, 2020) (see fig. 14 and 15) to exemplify this point.

However, simply including a group of people in a dataset is not necessarily the answer to making a dataset more equitable. D'Ignazio and Klein argue that being counted can result in the *paradox of exposure*: people who stand to significantly gain from being counted are potentially in the most danger from that same counting act (D'Ignazio & Klein, 2020). For example, being included in a government census report increases visibility and indicates the need for political representation; however, providing information to a political entity without knowing its motivation and potential future use purposes could also be risky for marginalized groups. D'Ignazio and Klein argue that we must be cognizant of who is doing the counting, and whose interests are being served by it. To help illustrate this point further, we watched "Not Your Average Average," a YouTube video on perspective taking in data science (We All Count, 2019).

Case Study: Waterloo Park

With the concept of data equity introduced, I moved students into their breakout groups and introduced the case study: "The Region of Waterloo has requested a report on the public's use of Waterloo Park.[32] Write a report through an equity lens that will inform park service, maintenance, and future development."

Breakout 1: Identifying Stakeholders, Metrics, and Methods

Breakout 1 incorporates the first step of VSD, Stakeholder Identification. I prompted students to identify the direct (e.g., cyclists, walkers, students, children), indirect (e.g., maintenance workers, construction workers, investors), and excluded (e.g., unhoused people, intoxicated patrons) stakeholders. In groups, the students discussed what metrics and methods of data collection would best fulfill the case study. Some of the metrics were related to the traffic through the park (e.g., number of cars, number of Ion trains per hour), and others were related to the status of park maintenance (e.g., electricity usage, maintenance budget, water quality). Lastly, the students identified both qualitative and quantitative methods for collecting information (e.g., observation, satisfaction kiosk, water samples, equipment testing). This step came relatively easily to the students: they were able to envision the high-level functions of a public park, describe the activities and experiences of participants in this space, and identify suitable metrics and methods that would derive data from these functions and activities to inform their report (see Table 6).

[32] Waterloo Park is 119 acres and located between the two local universities (Waterloo and Wilfred Laurier) and uptown Waterloo. It has a lake, animal farm, picnic areas, splash pad, sports fields, and playgrounds (City of Waterloo, 2024).

Table 6: ***Exercise from Breakout 1***

Stakeholders	**Metrics**	**Methods**
Direct • Residents • Cyclists • Sports Teams • Walkers • University students • Children Indirect • Workers (maintenance or construction) • Urban planners • Investors Excluded • Unhoused people • Intoxicated people	• Density map • Number of cars • Park enjoyment/satisfaction • Electricity usage • Parks maintenance and development budget • Water quality • Health of wildlife • Safety and accessibility standards of park benches, steps, playground equipment, etc. • Ions per hour	• Observation • Survey of patrons • Secondary data (e.g., incident reports) • Satisfaction kiosk • Meter/bills from city • Equipment testing • Water samples • Environmental analysis

Note. The class populated this table to start developing a report on Waterloo Park.

Lecture 2: Background on Parks

After Breakout 1, I circled back to talk more about the function, maintenance, and coordination of parks. I provided this additional context to supplement the students' ideas from the first breakout activity.

As Cohen discusses, parks provide many kinds of community assets, facilities, and programs (D. Cohen, 2018). The information that parks collect about their usage will influence financial and labor resources, inform public and elected official on return on investment of tax dollars, be used to mitigate problems related to litter and graffiti, and monitor park patronage that may include intimidating groups of people, such as protest groups, intoxicated individuals, and unsheltered or homeless individuals (D. Cohen, 2018).

Cohen notes that parks may conduct population-based surveys and ask people about their use of park facilities. However, these methods may not be representative, may capture only a fraction of the local residents, and may not yield precise information about the specific facilities that are being used (D. Cohen, 2018). Surveys also rely on the memory and ability of individuals to accurately report their park use. These are some of the considerations that I highlighted for the SYDE 362 class to help them flesh out their ideas in Table 6.

Breakout 2: Apply Datasheets for Datasets Questions

Prior to Breakout 2, I introduced Gebru et al.'s "Datasheets for Datasets," a framework for thinking about equity in the context of data projects by looking at the dataset documentation. This framework contains 52 questions that help to document the lifecycle of a data project. I provided examples from two of the sections, Composition (e.g., "What data does each instance consist of? Raw data, such as unprocessed text or images, or features?") and Collection (e.g., "Over what time frame was the data collected?"), to demonstrate how their report could utilize the framework.

In Breakout 2, the students were tasked with reviewing the questions in "Datasheets for Datasets" and noting which of them would be applicable to the metrics and methods they had identified for their investigation of Waterloo Park. As I noted previously, "Datasheets for

Datasets" is aimed at ML projects but can be used more broadly. In the breakout discussion, most students found questions in the first three sections, Motivation, Composition, and Collection Process, that applied to them. The last three sections, Preprocessing, Distribution, and Maintenance were more specific to developing a ML project and not necessarily applicable at this point.

Breakout 2 introduced concrete questions and steps during the pre-research stages that allowed students to identify additional considerations for their metrics and methods for assessing Waterloo Park. For instance, one group noted that they planned to seek out existing datasets on incidents reported in the park – collected by park employees or local authorities, such as the police – but that the Motivation questions, "Who created the dataset?" and "Who funded the creation of the dataset?" prompted them to be mindful of any bias that could have influenced the collection and documentation of that information.

Lecture 3: What are Structural Problems?

Once students developed a list of stakeholders, metrics, and methods for their analysis of Waterloo Park, the next section of the workshop is intended to broaden their perspective on how their analytic approach could be implicated by structural problems. Structural problems refer to problems that are caused by or related to biases that are embedded in societal infrastructure through the perpetuation of dominant cultural, political, or social values and norms. Some examples include colonialism, racism, or classism (among many others). To illustrate an example of structural problems influencing a design project, I introduced the

Reinvent the Toilet Challenge example (Costanza-Chock, 2020; *Reinvent the Toilet Challenge*, n.d.):

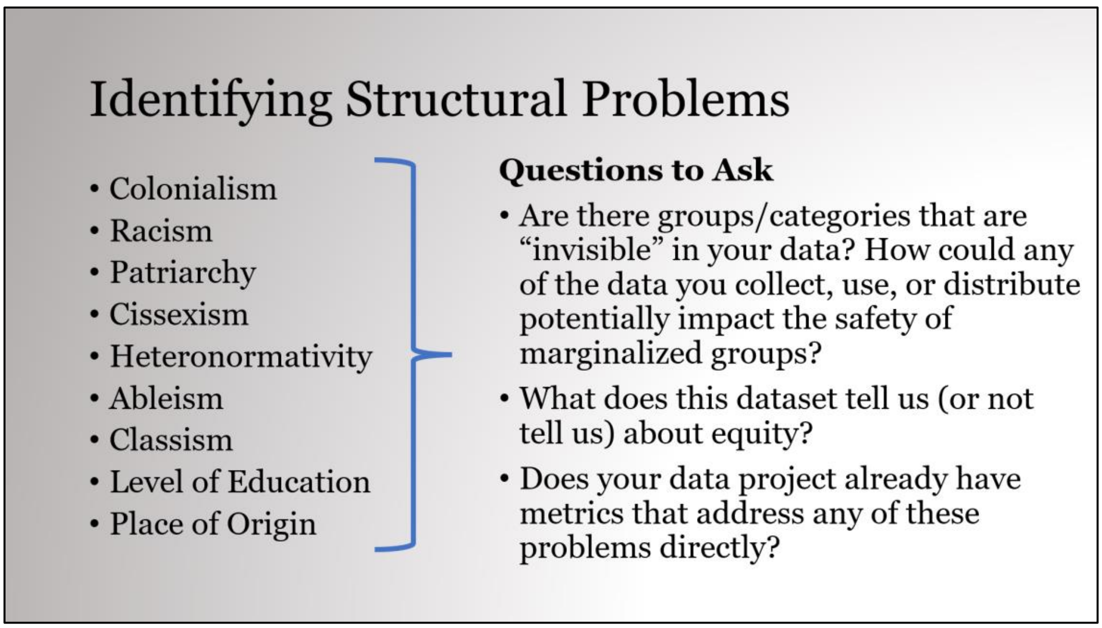
> Upon initiating the Reinvent the Toilet challenge, involved researchers were given a predefined set of metrics: create a toilet that "removes germs from human waste and recovers valuable resources such as energy, clean water, and nutrients; Operates 'off the grid' without connections to water, sewer, or electrical lines; Costs less than US$.05 cents per user per day; Promotes sustainable and financially profitable sanitation services and businesses that operate in poor, urban settings; [and] Is a truly aspirational next-generation product that everyone will want to use—in developed as well as developing nations" (Costanza-Chock, 2020, p. 126). These design constraints resulted in innovative sanitation solutions, but they were incompatible with the existing sewage infrastructure, unaffordable to maintain, and did not account for the patriarchal and misogynistic norms that constituted the structural problems (i.e., women being at risk to be attacked by men in public spaces) facing the community (Costanza-Chock, 2020).

This example demonstrated that the metrics we decide to include (or exclude) and our proximity to the design, problem spaces, and communities have a tremendous impact on what can be accomplished. The next step was to look for these considerations in the Waterloo Park case study.

Breakout 3: Identifying Structural Problems with Datasheets for Datasets

In Breakout 3, the student groups ideated potential structural problems that their metrics or methods might intersect with. On the slides, I showed a list of structural problems alongside some of the "Datasheets for Datasets" questions to help spur discussion (see Fig. 16). After a few minutes of in-group discussion, students shared their ideas with the class. Some of the potential structural issues they foresaw included ableism, colonialism, classism, sexism, transphobia, and classism. For example, one group wanted to survey the park patrons by asking them to scan a QR code when they visit but some of the park patrons are children, cyclists, or unhoused people, and therefore QR codes are inaccessible. The group acknowledged that they would be unable to gather information that way or potentially exclude some groups from the data collection. In this case, the group realized that children can be both a Direct and Excluded stakeholder group.

Figure 16: ***Slide from Designing for Equity in Public Spaces Workshop.***



Note. The "Questions to Ask" are taken from Datasheets for Datasets (Gebru et al., 2021).

The student group noted that the QR code presents issues of accessibility and privacy, and suggested that decisions about the survey design and data collection process could raise questions related to classism and ableism. Further, this final breakout section was a valuable opportunity for them to (1) think critically about the initial metrics and methods they had envisioned using and (2) re-evaluate those approaches based on contextual factors and structural problems. In this way, the combination of the VSD Stakeholder Identification process with the Data Equity exercises and "Datasheets for Datasets" questions allowed students to generate and assess equity-informed approaches to the Waterloo Park case study. Ideally, the final takeaway of this workshop for students is that you can consider ethics and equity while ideating on and developing a data project by looking at direct, indirect, and excluded stakeholders in the context of the metrics and methods that account for their visibility (or lack thereof) in your dataset.

3.1.4 Reflection on Workshop 3

I reflected on the design objectives and decisions that I made during the process of designing and implementing this workshop. Some of these objectives strengthened the workshop, while others leave room for future work.

At a high level, the breakouts and lecture sections were scaffolded so as to clarify that there are multiple steps to integrating equity into a data project, as well as to emphasize the importance of community and context in identifying obstacles and structural problems. The inclusion of VSD's Stakeholder Identification process and separating them into Direct, Indirect, and Excluded categories was valuable for recognizing a breadth of park patrons. With that said, the results of this step are biased by the students' experience. However, it is important for students to recognize that every dataset has bias, and it cannot be removed. Through this workshop, I aimed to make students more aware of potential sources of bias and guide them to acknowledge multiple perspectives on a problem.

This workshop did not include VSD's Value Source Analysis because of time constraints. Also, the Waterloo Park case study was not detailed enough to facilitate conversations about values; instead, the case study was tailored more to data equity rather than VSD. In a longer workshop, a section on values could be included as part of the design process. One of the limitations for investigating values in a short workshop is that the participants must have a medium to high level of familiarity with the topic and stakeholders without the facilitator spending too much time on background information. For example, in the VSD Workshops, we conducted the Value Source Analysis with the Tim Horton's drive thru scenario because it was a nearby location for students; therefore, it was easier for them to practice envisioning those stakeholders and values in the context of our short workshop, as it was based on their personal experience. In practice, engineers will design and build things to be used by people and in places that they are not familiar with. In conversations with other CML researchers, we have grappled with how to introduce value identification in a way that encourages students to think about alternative perspectives while also reminding them that engineers and designers should not project values onto stakeholders based on superficial identity traits. While identifying values, needs, and goals are important aspects of persona creation and audience analysis in engineering and design (Dym et al., 2014), students must be aware of the strengths and weaknesses of personas and value identification methods so as not to perpetuate existing biases and stereotypes (Guan et al., 2023; Jansen et al., 2021). In a longer intervention, I would discuss values and personas more thoroughly with an emphasis on how to conduct and evaluate qualitative, quantitative, and mixed methods for user research studies.

One of the objectives that I had while designing this workshop was to give students vocabulary for talking about equity and ethics in their engineering work. Though students are likely to know terms including “stakeholders,” “bias,” “equity,” or “disproportionate harms,” putting them into context with the “paradox of exposure” and examples from *Data Feminism* and *Design Justice* helps to concretize where issues can arise and potentially be mitigated in a data project. In my workshop and teaching experience, I have observed that engineering students are eager to engage with ethical or social issues, but they have often had a narrow conception of what kinds of issues that might entail. For instance, privacy is often one of the first topics that comes up in relation to ethical concerns – privacy is highly subjective and difficult to define (Solove, 2010), but if we consider high-level privacy implications for a stakeholder who is excluded on the basis of their age, income, or gender, there are slightly clearer lines to draw about when, why, and how decision-making in building datasets is impactful. Giving students the vocabulary to describe the issues that can arise in their data and engineering work is a crucial first step to helping them address problems of ethics and equity in practice.

A second objective I had while designing this workshop was to let students bring their technical knowledge and skills (which they are developing through the learning outcomes of SYDE 362) to bear on a project that is equity focused. Too often in the engineering curriculum, ethics and equity outcomes are separated from technical content, as demonstrated in Chapter 1 of this dissertation. By gesturing to technical components in an equity workshop, even though the workshop did not explicitly get into using the methods that students proposed, I hope students will see that these competencies are not isolated from one another. By providing opportunities for students to learn vocabulary for equity in design and to incorporate their technical knowledge, my goal was that students would leave the workshop feeling empowered to engage with questions of equity in design, rather than alienated by the uncertainty of what ethics and equity can contribute to engineering work.

Through this workshop and others like it in Table 5, I have demonstrated the potential for HSS methods and approaches – including VSD, design justice, data feminism, and data equity – to infuse engineering ethics pedagogy with more cross-disciplinary perspectives on ethics and related topics.

In the next section, I introduce my own critical design-inspired pedagogical tool, The Innovation Problem Finder Dartboard (IPFD). The IPFD provides further evidence for the utility of HSS perspectives in bringing ethics and related topics to bear on EEE, particularly for teaching ethics, communication, critical thinking, and problem definition. Paper 5, *The Innovation Problem Finder Dartboard: Embedding Critical Design in the Engineering Workflow*, was published in the Conference Proceedings of the Canadian Engineering Education Association in 2024. The IPFD was conceptualized and designed in early 2022, showcased as part of a poster presentation at the Annual Cybersecurity and Privacy Institute Conference at Waterloo in October 2022, and first applied as a pedagogical exercise in my Communication in the Engineering Profession course in Fall 2023.

3.2 Paper 5: The Innovation Problem Finder Dartboard: Embedding Critical Design in the Engineering Workflow[33]

3.2.1 Introduction

Given the complex socio-technical issues that Engineering graduates will face in their careers, it is crucial that they are prepared to think critically, engage with multiple stakeholders and perspectives, and approach the engineering design process with a lens for ethics, equity, and social and environmental justice. To address these outcomes, many educators have drawn on knowledge and methods from humanities and social science (HSS) disciplines, such as philosophy, media studies, and science and technology studies (STS) (Christensen et al., 2022; J. Leydens & Lucena, 2017; Wylie et al., 2017).

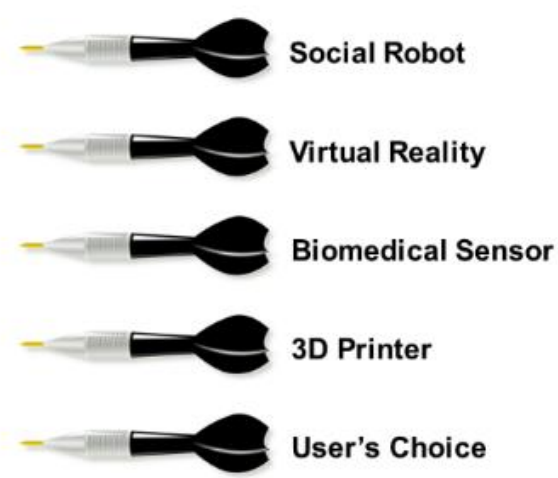
This paper proposes using critical design – a humanities-based research-creation method (Dunne & Raby, 2013; Malpass, 2017) – as another approach to critically thinking about the opportunities and consequences of design and technology. Specifically, the paper introduces a novel pedagogical tool, the *Innovation Problem Finder Dartboard* (IPFD), for embedding a layer of critical-design-inspired thinking and perspective-taking in the engineering design process.

The IPFD is a tool for ideating on the potential uses, misuses, and alternative contexts of a given technology. The 'dart' stands in for the technology the user is interested in

[33] Orchard, A. (2024). The Innovation Problem Finder Dartboard: Embedding Critical Design in the Engineering Workflow. *Proceedings of the Canadian Engineering Education Association (CEEA)*. Paper 78.

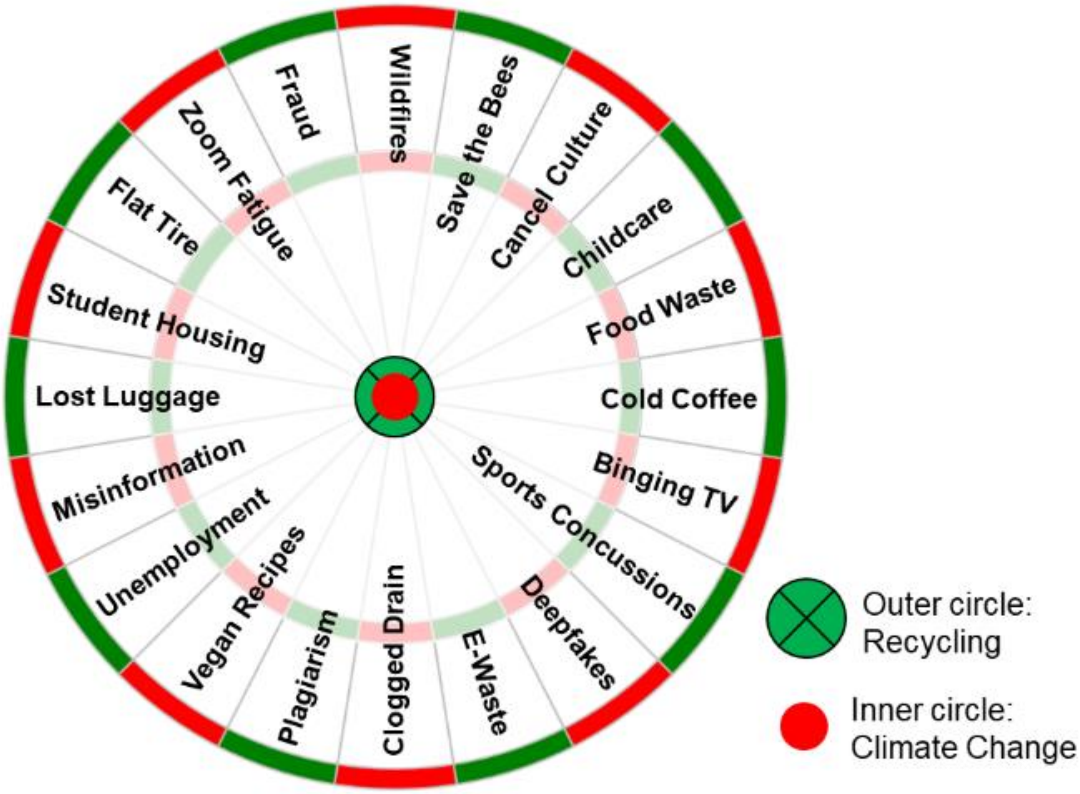
exploring (e.g., virtual reality, wearable technology, artificial intelligence (AI)) that they would like to examine (see fig. 17). Upon landing on one of the board's sections, which is populated by a specific issue or topic (e.g., recycling, childcare, food security), the user speculates as to how the technology could improve, worsen, or recontextualize the topic on that section (see fig. 18). For example, a user might be prompted to consider, "How could virtual reality be used for childcare settings?" This question activates a deeper exploration of socio-technical dimensions related to the intersection of a technology and its potential impact on the world.

Figure 17: ***An example of the technologies that a user might choose for their dart.***



Note. Adapted from unattributed, CC0 1.0.

Figure 18: ***A mockup of the Innovation Problem Finder Dartboard.***



Note. Image property of Alexi Orchard.

Though the primary purpose of the IPFD is to serve as a generative tool for creative and critical thinking, its design also offers a more subtle critique of the way that some large technology companies and leaders haphazardly approach the design and problem-solving process – without consulting the communities who are impacted most (e.g., Gates Foundation Reinvent the Toilet Challenge (*Reinvent the Toilet Challenge*, n.d.)), without considering social and ethical issues that could result (e.g., Google Glass backlash (Honan, n.d.)), without the expertise needed to meaningfully contribute (e.g., Elon Musk's Thailand cave rescue incident (Tufekci, 2018)), and/or for increasing profit and status (e.g., *Titan* submersible implosion (Regalado, 2023)). The IPFD is a problem 'finding,' rather than 'solving' (Malpass, 2017), tool and is designed to provoke student reflections on the limitations of an innovation-at-all-costs mindset and the importance of engaging in a thorough investigation of all stakeholders and contexts.

This paper engages with the engineering education literature that seeks to reorient the cultural image of the engineer as "problem solver" to one who also *defines* problems by engaging with context and critical thinking in and about engineering (section 3.2.2). The IPFD activity offers a novel approach to achieving these objectives by guiding students to think about how EDI and social and environmental justice fit into their research projects (section 3.2.3). This paper describes the design, implementation, and outcomes of the IPFD and complementary materials (e.g., worksheet, case studies) for educators interested in this activity (sections 3.2.4-5).

3.2.2 Background

3.2.2.1 Engineers as Problem Solvers

One of the dominant identities associated with engineers and engineering culture is that of the "problem solver" (Downey, 2008; Flemming & Johnston, 2019). From the beginning of their education, students identify with this image and are trained to approach engineering as a problem solving exercise through the simplification and abstraction of real world problems to develop solutions that fit within the capabilities of engineering tools (Bucciarelli, 1994;

Nieusma, 2018). This process involves reconceptualizing complex situations to facilitate analysis (Schmidt, 2014). For completing well-defined textbook exercises, this process is reasonably clear-cut for the problem solver (Flemming & Johnston, 2020). However, in the real world, problems are “not conveniently confined to engineers’ field of expertise and do not obediently stay within their control;” rather, they are ill-structured, involving multiple stakeholders and influenced by societal challenges (Foley & Gibbs, 2019, p. 13). Technical expertise alone cannot address the wide set of needs and values within complex socio-technical systems, which may also change and evolve across interdisciplinary domains (Foley & Gibbs, 2019). Flemming and Johnston have argued that the “problem solver” ideal is also problematic in that it reflects some of the issues with engineering culture – a culture that has been found to “lack in promoting of self-awareness, political awareness, understanding perspectives of others, and hearing marginal voices” (Flemming & Johnston, 2019).

To be successful engineers, students must not only learn to be problem solvers but also problem *definers* (Downey, 2008; Flemming & Johnston, 2019; Schmidt, 2014). Scholars emphasize the importance of the problem definition stage of the engineering workflow, especially given that a faulty, biased, or incomplete problem definition can lead to an inadequate solution or cause more problems, damage, or harm (Flemming & Johnston, 2019; J. C. Lucena et al., 2010).

On a fundamental level, a strong problem definition must identify the context in which the problem lies, the stakeholders, and why the problem is indeed a problem for the stakeholders (Flemming & Johnston, 2019). It must identify the objectives, constraints, and functions that the design must account for (Dym et al., 2014). The problem definition process must also extend beyond technical, legal, and financial dimensions of a problem, and also account for user experiences, broader social impacts, and ethical implications (Nieusma, 2018).

3.2.2.2 Contextualization and Critical Thinking

Being effective at defining problems requires not only understanding the context of an engineering project and its stakeholders but also being aware of one's positionality in relation to a project's outputs and impact. This contextualization involves thinking critically in regards to both the impact of engineering solutions in social and environmental contexts and engineers' ability to serve their communities (Claris & Riley, 2012; Kleine et al., n.d.). Claris and Riley argue that many engineers have "no practice of thinking critically about problem framing, power relations within the profession, hegemonic epistemologies of the discipline, or reproductive practices of engineering education" (Claris & Riley, 2012, p. 102). In the absence of these critical thinking and reflection skills, problem definition can be derailed by an engineer's implicit values and unconscious bias, poor awareness of the full range of stakeholders (leading to their exclusion from the outset), or inability to observe a wider or historical system that leads to some design elements being left out (Foley & Gibbs, 2019). This leaves the public with technologies that replicate an inequitable status quo and the engineering profession with a lack of diversity and few tools for understanding, talking about, or acting on these problems (Claris & Riley, 2012).

For engineering students, their immediate contexts are their education and early career experience. The institutional context plays a significant role in influencing what type of careers and goals students will aspire to achieve. Some educational institutions demonstrate a strong commitment to humanitarian engineering and engineering for social good; at others, it has been found that the competitive internship culture makes for an environment where notions of responsibility struggle to take hold (Truax et al., 2021). Particularly in Western countries, future engineers are surrounded by a rhetoric of excitement and appeals to the wealth, power, and global corporate influence of working in an engineering field (Foley & Gibbs, 2019). As such, it is important for educators (and for educators to help students) to acknowledge how that context shapes the learning experience.

3.2.2.3 Motivating Examples: Design Pitfalls and Failures

Despite the entrepreneurial and commercial hype around success in engineering and tech industries, there are multiple high-profile examples of failed innovations that were related to a poor understanding of the problem space, an inflated sense of expertise and authority, and/or inadequate engagement with stakeholders. Scholars have argued that discussing concrete stories and current events helps students connect with ethical issues and become more aware of their role as decision makers that may directly or indirectly impact other humans or non-humans (Hitt et al., 2020; Lind & Swenson-Lepper, 2013). The following cases are contemporary real-world examples, spanning multiple areas within engineering, that can help students reflect on the broader context of engineering and potential pitfalls in the design process. As I will discuss in more detail in Section 3, I constructed these case studies to set the stage for the IPFD activity and the process of problem definition more generally.

Case Study 1: In 2011, the Gates Foundation launched the ‘Reinvent the Toilet Challenge,’ a $200 million project for worldwide project teams to design affordable sanitation solutions in developing countries (*Reinvent the Toilet Challenge*, n.d.). The defined objectives were primarily technical: to create a toilet that “removes germs from human waste […]; Operates ‘off the grid’ without connections to water, sewer, or electrical lines; costs less than US $0.05 per user per day; Promotes sustainable and financially profitable santitation services […] that operate in poor, urban settings; [and] is a truly aspirational next-generation product that everyone will want to use – in developed as well as developing nations” (Costanza-Chock, 2020). Despite the multiple impressive prototypes generated, the project teams did not account for the whole context: it turned out that sanitation experts from the developing countries concluded that their communities faced issues of “access, social mobilization, and ongoing maintenance” that would make the project’s innovations unfeasible (Costanza-Chock, 2020). Some of these issues included a lack of sewage infrastructure and women’s fears of using public toilets in contexts where they could be attacked by men. This failure exemplifies how “technical expertise does not equal social wisdom” (Parthasarathy, 2023) and even the most well-intended projects, especially when designed for the Global South by people unfamiliar with local needs, can fail to achieve their objectives (Arshad-Ayaz et al., 2020).

Case Study 2: In 2013, Google was widely criticized following the release of its augmented reality smart glasses (ARSGs), Google Glass, in part due to the privacy concerns of those who interacted with users of the product. The product sparked backlash for its camera that allowed users, also known as ‘glassholes,’ to record others around them without their consent (Honan, n.d.). In the last decade, other companies including Snapchat, North, and RayBan have introduced their own ARSGs. A 2022 user study on North’s Focals echoes social and ethical concerns also found with other headsets (Adapa et al., 2018; Due, 2014; Fallert, 2024; Hofmann et al., 2017): despite the minor conveniences of having a heads-up display for communication, gaming, or way-finding, the glasses were distracting and disorienting in public and non-users were disturbed by and/or had impaired social interactions with the device-wearers (Orchard et al., 2022). In this case, some of the design features inhibit users from fulfilling their needs and values. With the renewed interest in technologies such as the Meta Quest 3 and Apple Vision Pro (two mixed reality headsets debuted in 2023-2024), the impact of consumer wearables is an evolving case study with multiple complex socio-technical dimensions (e.g., privacy, accessibility, mental and physical wellbeing) that are almost surely relatable for students as engineers and in their everyday lives.

Case Study 3: In 2018, 12 boys and their soccer coach disappeared for nine days while visiting Thailand, and were eventually found trapped in a cave (*Thailand Cave Rescue*, n.d.). This accident drew the attention of tech billionaire Elon Musk, who instructed his engineers to build a miniature submarine to aid in their rescue. After Musk received widespread media coverage for his efforts, the leader of the rescue mission reported that the mini submarine was impractical; Musk irritably responded by accusing the rescue leader of not being a "subject matter expert" (Tufekci, 2018). As Tufekci notes, the rescue mission needed to be a careful, methodical approach that kept the 13 individuals safe, rather than a quick fix that wasn't backed by deep expertise, appropriate testing, and contextual experience (Tufekci, 2018). This incident demonstrates the importance of humility in innovation – being able to acknowledge that ours is not the only knowledge system with the ability to identify and address issues (Arshad-Ayaz et al., 2020).

Case Study 4: Musk's belligerent attitude toward the cave rescue incident is emblematic of the uncritical, techno-centric "move fast and break things" mentality that pervades Silicon Valley (Cardinal, 2023). In 2023, the same ethos of disruptive innovation ultimately led to the deaths of aerospace engineer Stockton Rush and four passengers in their deep-sea dive in an unapproved submersible, OceanGate's *Titan* (Regalado, 2023). Despite warnings that the vessel hadn't been proved to withstand the appropriate level of atmospheric pressure, Rush was determined to pursue the dive, telling a YouTuber, "You're remembered for the rules you break" (John Holowesko [@jholowesko], 2023). Four days after losing contact with the *Titan*, experts concluded that the submersible had likely been destroyed in a catastrophic implosion (Regalado, 2023).

The first two examples (Gates and Google Glass) offer lessons about community and stakeholder engagement. In these cases, it is not that the technology was flawed, it is that their social contexts were misaligned with human needs and values. The latter two examples

(Musk and Rush) demonstrate how ego, wealth, and prioritizing status over safety can bias a project and, in worst case scenarios, have fatal consequences. I have used these case studies to spur conversation and reflection about the importance of context, expertise, and safety; having said that, they are by no means exhaustive. They are provided for educators to reuse at their discretion and, in the context of this paper, to illustrate some of the motivation for the IPFD activity.

3.2.2.4 Engineering Ethics Curriculum

Early in their education, students become familiar with the Engineers Canada Code of Ethics, which states they shall "hold paramount the safety, health, and welfare of the public and protection of the environment" (Engineers Canada, n.d.). "Ethics and equity" (#10) and "the impact of engineering on society and the environment" (#9) are two of the 12 Graduate Attributes included in the Canadian Engineering Accreditation Board (CEAB) requirements (Engineers Canada, 2016). Depending on an institution's resources, these outcomes are typically embedded in dedicated courses, technical courses with ethics content embedded, or a combination of these methods (Hess & Fore, 2018). Given the densely-packed engineering curriculum and other cultural or institutional obstacles (Walczak et al., 2010), it can be difficult for instructors to facilitate meaningful interactions with ethics and responsibility topics when it is not explicitly stated in the course description.

Some scholars have been moving away from professional codes, case studies, and ethical theories in favour of discussing current events, open-ended questions, and multi-disciplinary readings (Hitt et al., 2020; Zhu & Jesiek, 2017). Hitt et al. suggest that the dominant approaches (codes and case studies) tend to decontextualize ethics and presuppose that there are clear, universal solutions to ethical problems (Hitt et al., 2020). Educators have shown that 'ethics across the curriculum' or curricula with more repeated exposure to ethics (rather than one-off modules) provide promising opportunities for students to practice critical reflection in and about engineering and technology throughout their degree (Cruz & Frey, 2003; Grosz et al., 2019).

Multiple scholars have also argued that cross-disciplinary engagement and collaboration with humanities and social science perspectives are beneficial to engineering education (Kleine et al., n.d.; J. Leydens & Lucena, 2017; Wylie et al., 2017). Communication and writing courses, often taught by an interdepartmental unit or cross-disciplinary instructors, are one avenue for teaching additional dimensions of engineering, such as the impact of technology on society and professional skills more broadly (Marshall et al., 2019).

At my institution, the mandatory first year communication courses for engineering students in several programs are taught by instructors from the English and Communication Arts departments, facilitated through an initiative focused on undergraduate communication outcomes that is also designed to fulfill the CEAB Graduate Attribute for communication skills (#7). Some instructors, including myself and a few colleagues, integrate ethics-related content into our Engineering Communication courses. While ethics, equity, diversity, and inclusion (EDI), and social and environmental justice topics are relevant to the engineering profession at large, they also lend themselves to generative communication-focused outcomes (e.g., independent research, discussion and debate, report-writing, and presentations) taught in these courses (Truax et al., 2021). The work of English and Communication Arts instructors has supported engineering ethics education through cross-disciplinary perspectives and expertise. The case studies provided in section 3.2.2.3 are one example of this. Furthermore, the remainder of this paper attempts to situate critical design and my pedagogical intervention, the *Innovation Problem Finder Dartboard*, as a cross-disciplinary approach to facilitating more critical reflection during the problem definition stage of the engineering design process.

3.2.2.5 Critical Design: 'Problem Finding'

Critical design is an arts- and humanities-based research practice that has been described as a mode of 'problem finding' rather than 'problem solving' (Malpass, 2017). Coined by designers Anthony Dunne and Fiona Raby, critical design is a response to their concerns about the "uncritical drive behind technological progress, when technology is always assumed to be good and capable of solving any problem" (Dunne & Raby, 2013, p. 34). Critical design aims to make visible underlying assumptions, power asymmetries, and political and social issues (Hansson et al., 2018; Malpass, 2013). Given that critical design is process-oriented, rhetorical, and discursive, it typically places symbolic and semiotic properties of designed objects above their "functional" properties (Malazita, 2018). Put simply, critical design is more interested in suggesting alternative perspectives and encouraging discussion than in designing something functional or pragmatic (Hansson et al., 2018). In fact, critical design is opposed to solutionism and instead seeks to foster a creative space for critical reflection, one that media theorist Marcel O'Gorman calls "making attention" (O'Gorman, 2020). Common modes of critical design include speculative fiction, alternative histories, critical making, and objects-to-think-with (Hertz, 2015; O'Gorman, 2020; Ratto, 2011). A mainstream example is the television show *Black Mirror*.

Educators have used critical design for facilitating exploration of more ethical and inclusive contexts for tech development. For example, the interdisciplinary engineering design program at Rensselaer Polytechnique Institute (RPI) has incorporated speculative and critical design into their Capstone course (Malazita, 2018). Students were tasked with creating a critical design object based on a concept or topic they researched in STS literature. One of the student projects was an anti-ableist Velcro meets Rubik's Cube game, called *Velcube*, that investigated and celebrated neurodiversity. In this case, the objective of the project was to generate discussion and engagement with social theory through material exploration.

It is important to note that critical design participants can but do not necessarily need to be the designers of an object; they can also react to an existing object. For instance, artist Caroline McMillan led a critical design workshop series based around the fictional premise of a brain-computer interface called *Aura:maton* that led participants to envision more sustainable approaches to designing wearable technology (McMillan, 2019, 2020). In McMillan's workshop, participants did not create a critical design object. Rather, the critical design object was the interface that prompted participants to reflect on social, economic, and ecological issues that could arise from an futuristic imaginary where that same interface was a consumer object.

From these two examples, it is evident that the aims of critical design, fostering discussion and reflection, can be accomplished through different forms of participation (other examples of critical design interventions using workshops, speculative fiction, and design cards can be found in (Antle et al., 2022; D. Urquhart & J. Craigon, 2021; Rakova, 2024; Torkildsby & Vaes, 2019)). In this vein, the IPFD is a critical design object inspired by design historian Matt Malpass's 'problem finding' (Malpass, 2017), intended to aid students in exploring the multiple contexts of their work.

While I am not trying to conflate problem finding (in the critical design sense) and problem definition (in the engineering sense), I am advancing the argument that critical design practices can be valuable and generative tools for fostering engineers' problem-definition abilities. Problem finding, in the context of the IPFD activity, is a process of envisioning cultural, political, or ethical implications of potential socio-technical imaginaries. For the purposes of developing a problem definition in engineering, I argue that the IPFD puts students in a "mode" of problem finding for thinking both creatively and critically about potential socio-technical factors at the outset of a new project or research endeavor.

3.2.3 Intervention Design

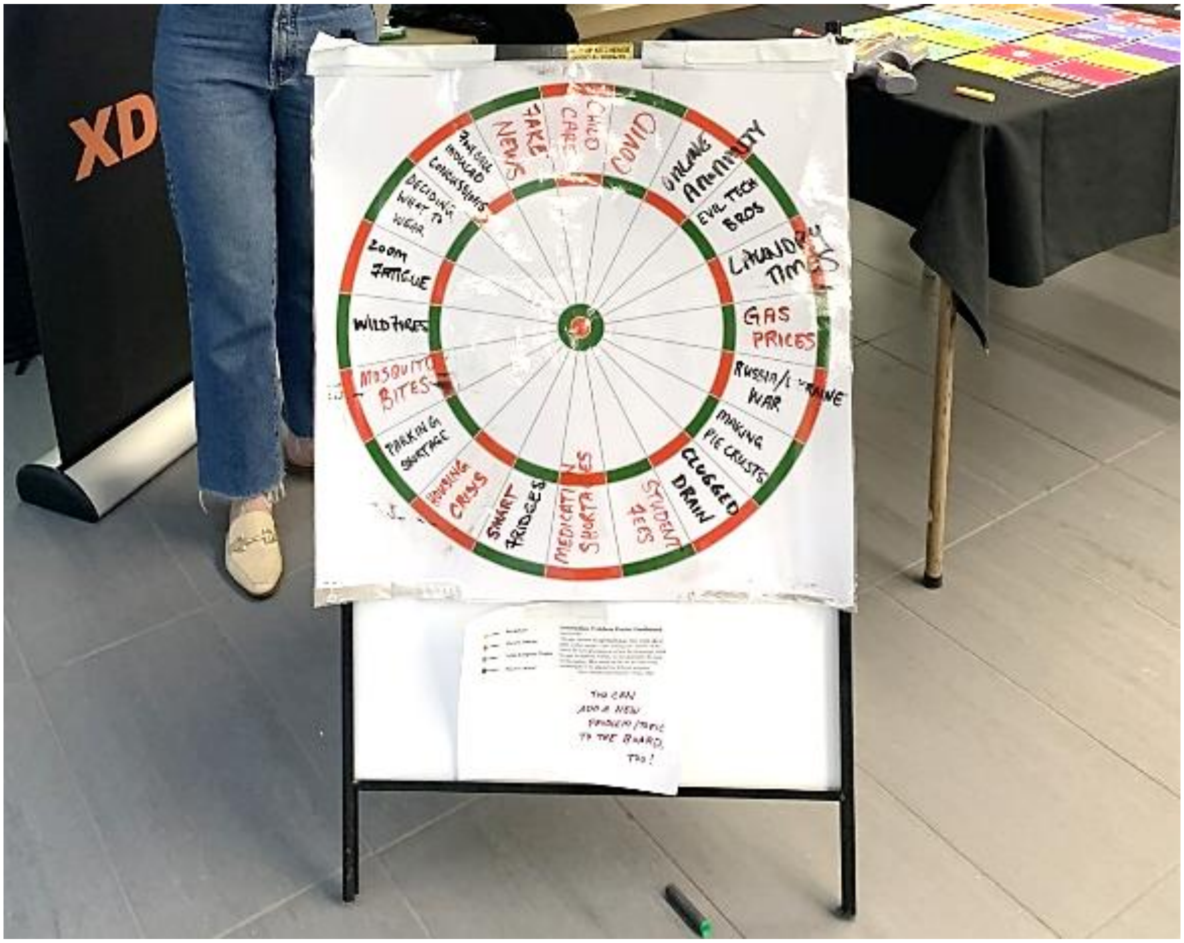
3.2.3.1 The Innovation Problem Finder Dartboard

The *Innovation Problem Finder Dartboard* is printed on a laminated poster board, approximately two feet in diameter, with open dartboard sections where the numbered sections on a regular dartboard would be. The lamination allows for the board to be written on and erased like a white board (see Fig. 19). The darts are foam with a suction cup tip that adheres to the board when shot through a toy nerf gun. Each section of the IPFD contains a different social, political, or ethical topic, such as childcare, food waste, or misinformation, as shown in Figure 18.

The instructions for using the IPFD are as follows: 1) The user identifies their dart as the kind of technology that they would like to consider; for instance, the technology could be social robotics, virtual reality (VR), or wearable tech, as shown in Figure 17; 2) Upon shooting their dart and landing on a section of the board, the user must speculate on how their technology could improve, worsen, or recontextualize the topic at hand.

The topics on the original version of the board have a broad range in the communities that they are most relevant to and the kind of social, political, or ethical impact they can have. Due to the range of topics and the user's freedom to choose the technology their dart represents, the results can be quite random and potentially absurd. Nonetheless, even generating silly, random, or absurd pairings fulfils the IPFD's purpose, as its "critical design object" status is meant to encourage discussion and reflection.

Figure 19: ***The Innovation Problem Finder Dartboard***



Note. v.1. Showcased at the MINDS Conference at the University of Waterloo in 2023. Image property of Marcel O’Gorman.

Users should be willing to entertain an unexpected result for the purpose of thinking creatively and critically about what that problem-technology context could be. Sometimes a problem-technology pairing will be a dead end – i.e., if it is too straightforward or obvious and not needing further exploration; or the pairing can possess many layers of context that a user can unfold. It is up to the user how far they wish to conduct their speculative investigation.

3.2.3.2 The IPFD as Critique

Drawing from the material and social representation of Darts (the traditional bar game) is meant to reflect the metaphor of a techno-solutionist attitude that, for instance, throws AI at every problem on the wall just to see if it will stick, so to speak. This metaphor resonates with the current trend of generative AI models drawing significant attention, resources, and financial investment from large corporations, start-ups, and governments (Armano, 2023; Sawers, 2024).

The only static topics on the IPFD that are intentionally related to the traditional scoring criteria in Darts are Recycling and Climate Change, the green (25 points) and red (50 points) bullseyes respectively. These topics signify the myth that recycling has a significant impact on climate change, a narrative that nearly 6 in 10 Americans were found to believe in a poll by the University of Maryland (Selig & Guskin, 2023). Recycling does contribute to a small reduction in carbon emissions; however, the public messaging tends to de-emphasize the magnitude of structural factors that perpetuate highly-consumptive behaviors (Annie Stoeth, 2020). Hence, if you aim for the red bullseye (climate change) but land in the green (recycling), you are sentenced to work on recycling, a topic that is not as directly impactful as it might be perceived. This example illustrates the aims of the IPFD in considering broader contexts and discourses in and about a topic. It also gestures to the importance of recognizing how political, economic, and cultural values and ideologies can influence the dissemination of science and engineering research.

To summarize, the purpose of the IPFD as a critical design object is to: 1) provoke conversation and reflection about ethical issues and 2) serve as a metaphor of and critique the techno-solutionist attitude that approaches problem solving without the necessary context to make a meaningful impact.

3.2.3.3 Implementation in a First Year Engineering Communication Course

In Fall 2023, the theme of my first year Engineering Communication course was Technology for Equity, inspired by the AI4Equity conference theme at the 2021 IEEE International Symposium on Technology and Society (proceedings of this conference can be found in *IEEE Technology and Society Magazine* (Pitt & Tzanou, 2022)). The students in this section were all from the Computer Engineering major, so this theme was appropriate. This course fulfills the CEAB Graduate Attribute for communication skills (#7). The course content also speaks to the impact of engineering on society and the environment (#9) and ethics and equity (#10). To this end, the readings and deliverables encouraged students to consider topics including ethics, social and environmental justice, and EDI. These topics are explored in a design context, through the composition of academic, professional, and public communications, and in the broader context of the impacts of technology on society. These outcomes, topics, and deliverables culminated in the final project, a conference-style research paper and presentation. In the classes leading up to the IPFD activity, we had read and discussed some of the motivating examples provided in section 2.3.

In the context of this course, the IPFD activity is intended as a collaborative brainstorming session to help students generate their final project topics. The learning outcomes (LO) specific to this class activity are for students to:

LO1. Generate a potential problem-technology pairing for use with the larger class project.

LO2. Identify EDI, social, and environmental justice issues that are relevant to specific problem-technology contexts.

LO3. Enhance and practice their critical thinking skills through collaboration and discussion.

At the start of class, I explained the exercise and worksheet. I populated most of the IPFD sections with various topics myself (see fig. 18) but left a handful of spaces open for the students to volunteer their ideas. By leaving some of the spaces open, I hoped that they would embrace adding their own fun or thought-provoking topics to the board. Some of the topics they chose included international student housing, plagiarism, and misinformation.

Part 1 of the worksheet has four columns: Technology (Dart), Problem (Space on Board), Potential Opportunities, and Foreseeable Challenges (see Appendix B). In small groups, students devised a short list (3-4 items) of technologies they wanted to speculate on. They then took turns shooting at the IPFD and keeping track of what problems they landed on in the first two columns of the worksheet. After exhausting their turn at the IPFD, they worked together on filling the opportunities and challenges sections on the worksheet. Some of the results were fruitful in terms of inspiring project ideas, whereas other pairings merely garnered laughter due to their absurdity. In the class discussion, I asked the groups to summarize their conversation and give an example of one problem-technology pairing that led them to discuss EDI or social and environmental justice.

We then transitioned to Part 2 of the worksheet, which was completed individually and focused on helping students tease out details of only one problem-technology intersection that they were interested in pursuing for their project. Part 2 contains seven questions to guide students through a contextual exploration of their chosen topic:

1. Describe one problem-technology pairing found in Part 1 of the worksheet.
2. Describe the specific technology: its main function, key properties/attributes, and how it is used in the context of your problem.
3. What populations are related to or impacted by your topic? (e.g., types of occupations – medical doctors, school teachers, bus drivers; demographics – age, gender, race, education, economic status; types of non-humans – plants, birds, environments)
4. What places are related to your topic? (e.g., physical – city, hospital, classroom, bedroom; digital – platforms, forums, online spaces)
5. Review the Tarot Cards of Tech and find two cards that you are interested in. Copy their questions into this box and then answer them in the right column.

The Tarot Cards of Tech are a deck of design cards made by the Artefact Group that aim to help creators foresee unintended consequences and reveal opportunities for creating positive change (Artefact, 2018). Some of the questions include: “What could a bad actor do with your product?”; “How does your product change or create new ways for people to interact?”; “If your product was dedicated to empowering the lives of an underserved population, what kind of impact could you make?” The students were instructed to answer these questions in terms of the technology (rather than “product”) they were focused on.

3.2.4 Outcomes

3.2.4.1 Learning Outcomes

In this first year communication course, the IPFD activity was a low-stakes, collaborative intervention that introduced students to a creative method of ‘problem finding’ for their term research projects (LO1). Accompanied by the worksheet, the IPFD helped students consider a diverse range of problems and stakeholders (LO2). The randomness of the IPFD makes this a fun activity that provides the opportunity for students to investigate topics outside their lived experience.

Though it can be fun and empowering for students to consider topics that are novel to them, at this point it is most essential for students to practice critical thinking (LO3). It is useful to recall the motivating examples – the Gates Foundation Reinvent the Toilet Challenge, Google Glass, the Thailand cave rescue, and the *Titan* submersible incident – and their lessons about stakeholder engagement, expertise, and contextualization. Reflecting on these cases as they relate to their own topic introduces an element of humility, in that students learn to recognize their knowledge system as not the only one capable of identifying and addressing issues (Arshad-Ayaz et al., 2020). In fact, it is productive for students to acknowledge that applying ethics in the engineering design process is “subject to multiple constraints not all of which may be met, thus creating the possibility of multiple, imperfect approaches to resolving a situation” (Claris & Riley, 2012, p. 114; Whitbeck, 2011). Thus, if a student happens not to find many problem-technology pairings with 1) a low barrier to exploration based on their engineering knowledge or 2) rich intersections for exploring new contexts, it can prompt a discussion *about* engineering, humility, and boundaries of expertise (Claris & Riley, 2012). In the case that a student lands on a problem-technology pairing that isn’t within their ability to assess, they should be able to think critically and articulate how and why they have come to that conclusion.

In Part 2 of the worksheet, the Tarot of Tech questions in particular can really help students start to scope out more EDI-related considerations in their project. For instance, one student started working with the idea that an AI tutor could be beneficial for providing personalized education and assessment but after they were prompted to think about how an AI tutor could empower underserved populations specifically, their initial problem research steered them to consider factors such as accessibility, bias, and privacy.

The IPFD activity is a creative brainstorming approach that draws attention to EDI, social, and environmental justice issues while planning the term research project. Once completed, this worksheet informs their proposal and the thesis statement of their term project. In their proposals, they must describe the technology, the impacted population(s), and the social, ethical, and/or environmental factors that will scope their research topic. This pre-research phase has multiple parallels to the process of crafting a problem statement, such as asking questions, establishing objectives and constraints, and communicating ideas to other designers and stakeholders (Dym et al., 2014). Because this is a communication course, the next steps in the class focus on learning how to conduct a literature review and build an annotated bibliography around their topic. At a higher level, though, this activity achieves multiple goals as it prepares students for the course learning outcomes that are aligned with CEAB Graduate Attributes: communication skills, ethics and equity, and the impact of engineering on society and the environment.

3.2.4.2 The IPFD at Conferences

The IPFD has also been exhibited at conferences and workshops held at my university, during which it received mixed reactions from a multi-disciplinary audience. At the 2022 Cybersecurity and Privacy Institute Annual Conference at the University of Waterloo, I presented the IPFD as part of a poster presentation. I was approached by individuals working for start-ups and other local tech companies. One individual said that it would be a “great tool for their research and development team” and that I should “make it into an app,” a suggestion to which I nodded politely. Perhaps unsurprisingly, this individual focused on how it could be used to generate new product ideas but was not explicitly interested in the critical aspect of the exercise. This kind of response is understandable given that the IPFD is a ‘critical design object’ designed to generate ideas while simultaneously critiquing the superficial approach that tech developers might take to identifying problems and designing solutions. This instance was a full-circle moment in that the audience who I am critiquing with this object engaged with the object earnestly. Perhaps with more time and a proper introduction to the individual, it would have felt more appropriate to re-explain the purpose of my project.

At the 2023 MINDS Conference at the University of Waterloo, the IPFD served as an engaging icebreaker for attendees walking by the Critical Media Lab's booth. We invited students and professionals to pick their own 'dart' and speculate about the problem space they landed on. In this context, the IPFD provoked interesting conversations about how to frame problems with a lens for ethics and equity, engage communities in design, and overcome systemic obstacles within engineering education and the tech industry.

3.2.4.3 Conclusions and Future Work

A significant aspect of the future work on this project is making it accessible to other educators. Transferring this activity to a digitized format will be a considerable undertaking from a conceptual perspective. Inherent to the activity is the user's material engagement, hinging on the user's ability to first, strike the IPFD, and second, generate discussion and ideas from the problem-technology pairings. Transferring this experience to a digital format may cause it to lose some of its novelty and be less connected with its metaphorical sentiment.

A high-level consideration for future work is whether this critical design object represents a desirable and feasible approach for engineering educators. As Kleine et al. have noted, engineering educators often agree that contextualizing engineering work and problems is beneficial but they can take multiple different approaches to embedding it in their pedagogy (Kleine et al., n.d.). Critical design has some precedent in engineering education (Malazita, 2018; Orchard & O'Gorman, 2024; Torkildsby & Vaes, 2019) but more research is needed. The IPFD activity is one example of how critical design can prompt users to reflect on their expertise and positionality, envision and respond to alternative contexts, and think critically about how the design and use of a technology can be implicated by ethics, EDI, and social and environmental justice; as noted in Section 2, these are essential skills that engineering educators seek to develop in their students. One of the main obstacles to integrating critical design in engineering education is that it, as a process of contextualization and reflection, can be time consuming. With that said, making space for that process is an important step to crafting a well-developed problem definition.

3.3 Chapter 3 Conclusion

The purpose of Chapter 3 has been to show different pedagogical approaches to integrating the Graduate Attributes "Ethics and equity" and "Impact of engineering on society and the environment" into the engineering design process more explicitly. My objective in conducting and examining these workshops and classroom exercises has been to demonstrate that these Graduate Attributes do not need to be isolated to ethics-specific courses, but they can be addressed in a variety of class-based contexts, including a technical methods course, such as SYDE 362.

A significant takeaway from using VSD, feminist data studies, and critical design approaches is that they can prompt students to think beyond human-centered frameworks and challenge assumptions about who and what “counts” in these systems. For instance, in the VSD workshop, the class decided that the Canada geese are direct stakeholders, yet we still had to deliberate on whether their non-human needs and values (i.e., their habitat and well-being) were relevant to the case study.

Another takeaway is that even choosing which method to collect or organize data with will establish a basis for who will be included or excluded and, in either case, could create negative repercussions. For example, in the Waterloo Park case study, the class was prompted to reflect on the trade-off of (1) what data they were potentially losing from their analysis or (2) whose data they were potentially putting at risk, by choosing methods that were not accessible or privacy-protecting.

These approaches are not exhaustive, and I acknowledge that the general engineering curriculum accounts for stakeholder analysis, though most explicitly in terms of client requirements, objectives, and constraints, rather than equity-based considerations (Dym et al., 2014). As part of the VSD workshop, I noted that the CML researchers are cognizant of the limitations of user personas and have sought to minimize using exercises where students attribute values to stakeholders on a superficial level. One way to mitigate this concern is through facilitating stakeholder interviews with real users, which is an opportunity better suited to a full-length course or longer intervention, as in (Howcroft et al., 2023).

It is worth noting that the workshops and the IPFD activity, at this point in their development, are largely in what Friedman and Hendry would describe as the first stage of VSD, the conceptual investigations: “the analytic, theoretical, or philosophically informed explorations of the central issues and constructs under investigation” (i.e., identifying stakeholders, values, and value tensions) (Friedman & Hendry, 2019, p. 32). The next stages of VSD, the empirical and technical investigations, involve measuring behaviors, attitudes, and practices of the stakeholders, and then assessing how the affordances of a technology support or hinder stakeholder activities (Friedman & Hendry, 2019, p. 34). In future research, I would like to consider how the interventions presented in Chapter 3 can be enhanced by and contribute new insights to empirical and technical investigations, particularly in the context of embedding Graduate Attribute “Ethics and equity” across the engineering curriculum more.

Conclusion

As the epigraph of Chapter 3 stated, “Data is a thing, a process, and a relationship we make and put to use. We can make and use it differently” (Cifor et al., 2019). This dissertation has shown multiple opportunities for teaching EEE differently as well. Though the scope of the dissertation is around EEE, factors of which are largely explored in Chapter 1, this work has demonstrated how students, educators, and researchers can approach teaching, learning, research, and collaboration differently than how single disciplines have modeled it before – by considering alternative perspectives, engaging with interdisciplinary expertise, and reflecting a sense of epistemic humility. While I have advocated for interdisciplinarity and shown examples of this kind of scholarship and pedagogy primarily through Chapters 2 and 3, there are multiple limitations and challenges to bringing perspectives together across multiple disciplines and domains in this work. In this section, I will reflect on these challenges and posit opportunities for future research and pedagogical development.

The obstacles to EEE, as outlined in the Introduction and the three qualitative studies in Chapter 1, including engineering educators and students’ time constraints (stemming from curricular and accreditation requirements), the disparate values and biases between the HSS and STEM, and the lack of institutional support around interdisciplinary ethics programming, all created implications for the contributions of Chapters 2 and 3.

In Chapters 2 and 3 of the dissertation I described the design and implementation of multiple workshops and interventions that I have both facilitated and participated in during my Ph.D. In doing so, I articulated how the strengths and benefits of HSS knowledge and skills can be impactful when embedded in EEE curriculum. It was clear before this project that the longstanding approaches to EEE, such as professional codes and paradigmatic case studies, are not enough to instill the knowledge and skills that engineers need to meaningfully and carefully recognize, analyze, and address complex sociotechnical problems (Conlon & Zandvoort, 2011; Donnelly & Boyle, 2006). This dissertation contributes to ongoing conversations about how the HSS can enhance EEE; my studies specifically illustrate the use of HSS methods and approaches to (1) enable critical conversations about ethics and related topics that challenge the status quo, assumptions, and biases in engineering; and (2) scaffold more in-depth contextual analyses of the stakeholders, values, methods, and impacts that inform and result from engineering design.

However, the evaluation of my interventions is limited by external factors. For instance, Chapter 1 acknowledges the influence of co-op culture on students' motivation to engage with ethics and responsible innovation; these topics do not always register for students as immediately relevant to achieving the normative career success standards perpetuated through the reputation of a tech-industry-focused institution such as the University of Waterloo. Students are also confronted with incentives to stack their resumes by taking on entrepreneurial side projects and enrolling in the maximum number of courses (which at Waterloo Engineering is up to *eight* courses in a single term). This flurry of priorities has multiple outcomes, but most relevant to this dissertation are that this busy schedule and focus on high-paying tech-sector jobs means that students don't have time to care about the ethical issues or to engage in extra-curricular activities that don't advance their resume's desirability for the tech sector. A secondary consequence is that students have low interest in completing the surveys after they participate in our workshops, which makes it difficult to conduct robust research around these topics. As noted in Paper 4, many of our critical design and responsible innovation workshops in engineering classes were facilitated through relationships with individual instructors who were willing to make time and space in the already packed curriculum to integrate HSS perspectives when they are not required to or supported by the institution in doing so. These curricular, cultural, and institutional factors have a significant influence on whether the types of interventions in Chapters 2 and 3 can come to fruition, how well scholars can execute and measure these interventions, and the longer-term payoff that these activities have on student development and growth.

Ideally, there would be multiple touchpoints in the engineering curriculum where students can learn and practice ethical thinking through methods including critical design, responsible innovation, value sensitive design, data feminism, and design justice, among others. Much like having multiple courses for introductory to advanced computer programming, learning ethics, too, requires deliberate, scaffolded, and iterative planning (rather than the "one module" or "one course" approach). This dissertation has shown there is an appetite at Waterloo for curricular development that embeds HSS perspectives more thoroughly across design, ethics, and communication courses. The individual interventions led by CML researchers and other instructors discussed in each chapter are strong evidence of the interest and facility that Waterloo scholars have in ethics and related topics that could be beneficial to the Engineering programs. For instance, the Critical Design Methods course (ENGL 701) in the English Department was cross listed with Systems Design Engineering (SYDE 760) in Fall 2023. More opportunities like this need to be offered and students need to be actively encouraged by the Faculty of Engineering to pursue them. Furthermore, future research needs to take a leap from workshop facilitation to cross-disciplinary curricular development. In Paper 4, we acknowledge that the workshops and collaborative interventions do a good job of *introducing* participants to new concepts such as critical design, but more time and practice are needed to instill this kind of critical thinking as a reflexive practice in engineering contexts. The need for more practice is more reason to strive for cross-curricular ethics programming, like Cohen et al. and Grosz et al. have developed, so that students may build and enhance their critical thinking skills over time rather than settling for mediocre results from one-off, “check box” approaches to ethics and related topics (Cohen et al., 2021; Grosz et al., 2019).

Another challenge for this research is its methodology and how it translates across the disciplines we are trying to reach. As noted in Paper 4, critical design is methodologically and conceptually suited to qualitative evaluation, and the contributions of critical designers are typically outside of the domains of quantitative data collection. While this is true, it does not mean that quantitative methods could not be complementary. Having said that, I would not argue for a solely quantitative assessment of a critical design intervention but, in future research, a mixed-methods approach would be appropriate. For example, future iterations of the studies in Papers 4 and 5 could include comparative pre/post methods (i.e., quantitative, and qualitative surveys, interviews, or focus groups) with control groups, and/or a longitudinal evaluation of the interventions (e.g., within a course-long intervention or throughout a series of workshops).

The inclusion of responsible anticipation into these interventions and their evaluation schemes would also provide more structure – not only for the participants, which I suggested in section 2.3, but also for educators and researchers to assess their intervention design (e.g., How does the framing of this activity provide latitude for participants to connect with *reflective anticipation* and/or *technological groundedness*?). In the same vein, responsible anticipation could also support educators seeking more specificity in their assessment of students' ethical and critical thinking ability. One challenge with embedding HSS-informed ethics pedagogy into EEE has been establishing assessment frameworks (Kisselburgh et al., 2016; Wylie et al., 2017). Engineering students and educators are likely well-equipped to assess the *technological groundedness* of a speculative technology; this first step would be low-hanging fruit for them, so to speak. Their strength, in essence, would be the constraint faced by HSS scholars who perhaps do not have a deep background in technology but can readily facilitate the *reflective anticipation* aspect of an ethics-focused intervention. In future work, I would be interested in team teaching or a research project with more technologically trained collaborators to demonstrate and facilitate the types of sociotechnical, interdisciplinary collaboration that this dissertation has been advocating for.

Although this dissertation is largely addressed to engineering educators –whether they have HSS or STEM backgrounds – there is also potential for HSS-focused scholars to learn from this work and apply it in their own contexts. In fact, I would argue it is beneficial for HSS scholars to be aware of the ways that STEM is teaching and talking about the ethics of technology so that they are able to engage with and support those colleagues and students, if not to also pursue their own parallel interests with a more interdisciplinary lens, such as CML researchers have done in recent work.

CML researchers have contributed to EEE research throughout my graduate studies. Since 2022, our group has been part of a cross-disciplinary, multi-institutional research collaboration with three other Canadian universities. This project is a large-scale focus group study of engineering students completing the Tech Stewardship Practice Program (TSPP), an online micro-credential for teaching the ethical and social impact of technology (Engineering Change Lab, 2022). The study aims to explore engineering students' understandings of ethics, responsibility, and the relationships between technology and society, as well as to examine pedagogical practices related to these topics through the design affordances of the TSPP.[34] As of spring 2024, we have completed our first round of this study with engineering students. Our next steps involve extending these focus groups to include students from HSS and business disciplines to investigate their perceptions on these topics and the impacts of

[34] The preliminary results of the TSPP research project (2023-present) ran parallel to conversations in my dissertation. While the TSPP project is still in progress, as an aside, I will share that our research team on the TSPP project has repetitively discussed a section within the TSPP that focuses on value tensions and polarities (e.g., convenience versus privacy). One such perceived polarity implicit throughout my dissertation, particularly in the Chapter 1 survey studies, is that between ethics, profit, and innovation. I will clarify here that when these concepts are properly framed, they have the potential to complement and accelerate each other. This is a key motivation for Environmental, Social, and Governance (ESG) principles and practices, which we also discussed during workshops in Paper 4. With that said, there is a need for accountability and transparency measures to ensure that these types of efforts are not mere instances of "ethics-washing" (Green, 2021). This is an active discussion in the ongoing TSPP research.

design, ethics, and technology as non-engineering majors. One reason we believe it is relevant to include non-engineering students in this study is because of the multifaceted challenges arising from new technologies. Generative AI is a commanding example of how rapid, unregulated advances of technology can create unpredictable and potentially negative consequences across domains, including but not limited to education, entertainment, and healthcare (Potter, 2024; Reddy, 2024; Wilkes, 2024). Students in HSS, business, and other non-engineering disciplines will more than likely pursue careers in these fields and need to have critical AI literacy to perform their jobs (Ng et al., 2021). A policy brief released by Data & Society in 2024, "AI Governance Needs Sociotechnical Expertise," underlines the importance of HSS to assess the "technical design, social practices, cultural norms…performance, failures, benefits, and harms" of AI systems (Oduro & Kneese, 2024). These are just a few examples of our and others' ongoing and future research that are propelled by and benefit from multiple disciplinary perspectives on ethics and technology.

Lastly, it is my hope that this research will inform institutional initiatives for more interdisciplinary teaching and research opportunities. The research I conducted in this dissertation was enhanced through the individual effort, labor, and care of Waterloo instructors and researchers, not all of whom were supported by interdisciplinary-focused research grants. Though this work and the ongoing research being conducted through the CML is a testament to the successes and lessons to be gained from interdisciplinary collaboration, there is still not enough commitment from institutional leaders to fostering and demonstrating sociotechnical leadership and innovation. More specifically, I advocate for more cross-disciplinary team-taught courses, the development of a cross-curricular ethics program for Engineering departments, and a university-wide, centralized "hub" or institute for interdisciplinary collaborations to be facilitated and promoted. The University of Waterloo, as well as any institution, only stands to gain from more inclusive and diverse knowledge making through championing HSS and interdisciplinary scholarship.

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Appendix

Appendix A

Demographic Results for Chapter 1

Paper 1

Major	Year 1	Year 2	Year 3	Total per Major
Computer Engineering	12	14	2	28 (66.6%)
Electrical Engineering	9	3	0	12 (28.7%)
Engineering (Student did not specify)	1	1	0	2 (4.7%)
TOTAL Participants				42 (100%)

Participation rates for Paper 1

300 students were invited to participate, 59 students began the survey (19.6%), 42 completed survey responses included in the study (14%).

Demographic Results for Paper 2

Note: This table is how it appears in publication. We did not account for the year of students in Mechatronics and Other because they were part of a non-discipline specific course (unlike Systems and Biomedical participants, which sample was directed to specific cohorts based on the courses they had previously completed).

Major	Responses	Year	% Total
Systems	18	3	34.0
Biomedical	16	3	30.1
Mechatronics	10	1-4	18.9
Other	9	1-4	17.0
Total	53	-	100.0

Participation rates for Paper 2

- 82 BME students invited to participate, 43 students began the survey (52.4%), 16 completed survey responses included in the study (19.5%).
- 90 SYDE students invited to participate, 24 students began the survey (26.6%), 18 completed survey responses included in the study (20%).
- 80 STV students invited to participate, 24 students began the survey (30%), 19 completed survey responses included in the study (23.7%).

Demographic Results for Paper 3

Major	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total per Major**
Mechatronics	1	5	3	1	0	10 (23.3%)
Chemical	0	4	2	4	0	10 (23.3%)
Other Engineering	5	3	3	1	1	13 (30%)
Non-Engineering	1	3	2	3	1	10 (23.3%)
Total Participants	7	15	10	9	2	43 (100%)

Note: There is a calculation error in the published version of Paper 3. Mechatronics and Chemical Engineering should have a total of 10 responses respectively, which is 23.3% of the total sample, rather than 18% as it reads in Paper 3.

Other Engineering includes Software, Mechanical, Management Sciences, Civil, Systems Design, Computer, and Nanotechnology.

Non-Engineering includes Health, Science, Math, Global Business and Digital Arts, and Astrophysics.

Participation rates for Paper 3

- A total of 540 students were invited to participate, 132 students began the survey (24.4%), 43 completed survey responses included in this study (7.9%).

Survey Instruments for Chapter 1

Paper 1

ARTS 190 Survey

To be designed with UW Qualtrics

Demographics

1. What is your major/discipline?
2. What year of study/stream/degree program are you in?
3. What format did you take the course? (in-person, online)
4. Which gender do you identify as?
5. Have you taken a co-op placement before? If yes, how many, and in what types of industry?

Understanding and Assessment of the Ethics Component of the Course

Using a scale of one to five:

Prior to the course:

(1) Very low (2) Low (3) Average (4) High (5) Very high

6. What was your level of knowledge about ethics in engineering?
7. What was your level of interest in ethics in engineering?
8. How much exposure did you have to ethical concepts?
9. What level of importance did you think ethical concepts are to engineering?

During the course:

(1) Very Ineffective (2) Ineffective (3) Neutral (4) Effective (5) Very Effective

10. How effective did you find the ethics intervention in your course at:
    a. Exposing you to ethics concerns without your own discipline?
    b. Exposing you to ethics concerns within your own discipline?
    c. Making you more interested in the topic of ethics and how it relates to your discipline?
    d. Exposing you to a disciplinary perspective outside of your faculty [engineering]?

After the course:
(1) Very Unconfident (2) Unconfident (3) Neutral (4) Confident (5) Very Confident

11. How confident do you feel applying the ethical concepts you've learned in your course:
    a. On projects in other courses?
    b. In your future job or co-op placement?

(1) Very Unlikely (2) Unlikely (3) Neutral (4) Likely (5) Very Likely

12. How likely are you to apply the ethical concepts you've learned:
    a. On projects in other courses?
    b. In your future job or co-op placement?

Short Answer

13. How were ethical topics, concerns, issues, principles, incorporated into your course?

14. How effectively was this part of the course integrated and delivered?

15. What was done well, and what made it effective?

16. What was done poorly, and how could it have been improved?

17. How did the instructor's training and discipline influence your engagement with ethical topics? For example, if your instructor is from outside of STEM disciplines, did the class benefit from that perspective or would you have preferred to learn about ethical topics from a STEM instructor?
18. What, if anything, has changed about your perspective on the role of ethics within your profession, thanks to the work you did with ethical topics, concerns, issues, and principles in this class?
19. What are some of the obstacles to incorporating ethics into your projects in other courses and/or on your co-op placements?

20. Have you applied or are you applying principles from this class in other courses and/or co-op placements? If so/not, please explain.

Paper 2 and Paper 3

Note: For Paper 2, SYDE and BME participants received the following version of this survey except for the Post-Test information (as they received only one survey) and the Likert Scale + Short Answer: About STV Course (because they were not in an STV course during this study). STV participants received the entirety of the below survey after the course took place. STV participants received a pre-survey that did not include the Likert Scale + Short Answer: About STV Course but, as noted in Paper 2, we did not receive enough responses to complete the paired analysis.

For Paper 3, STV participants received the entirety of the below post-survey, as well as a pre-survey that did not include the Likert Scale + Short Answer section.

Text at top of first page: This is a post-test and results will be compared to the pre-test conducted at the beginning of this course (STV ###). For the researchers to match your results and allow you to maintain anonymity, please enter your self-generated "username" consisting of the last three letters of your mother's name and the first three letters of your birth city. For example, ESAMIS (Theresa, Mississauga).

Enter username here: __________

Evaluating Scenarios

For REB Reference: There are six scenarios altogether, but students will randomly receive only three of them to respond to. Students will receive the same three scenarios in the pre-test and the post-test, so any change in their responses might be attributed to learned concepts from the course that these scenarios are based on. This is also to shorten the length of the survey for participants but still allow researchers to examine more responses to different scenarios. Sample #1 will receive Scenarios A, B, C. Sample #2 will receive Scenarios D, E, F. Each sample receives one question from each of the three topics for a total of three scenarios. All six scenarios are listed here for ease of access.

- *Scenarios A and D are "General Topics"*

- *Scenarios B and F are "Technologist Topics"*
- *Scenarios C and E are "Engineering Topics"*

This section contains three scenarios about engineering, technology, design, and other topics related to your program and profession. Please read the scenarios and respond to the questions below each of them.

A. *Sample #1 "General":* Co-op interviews have begun, and you have spent weeks preparing to impress the best companies in your area. You need to get a good placement this term to maximize your chances for securing a position after graduation. On the weekend before your most lucrative interview, you hang out with a friend who graduated last year, and they tell you about the new product they just started working on at their current co-op job. At the interview, you are asked if you have any new ideas you'd like to pursue, and you can't help but remember how innovative your friend's product sounded.
B. *Sample #1 "Technologist":* For a final design project, your group is designing an application that allows online shoppers to try clothes on their avatar. The deadline is in two days and your prototype is working great. It was hard work, but your team managed to incorporate 80% of the North American population's body sizes and skin tones. Your group's user personas are mostly represented by this sample, but you wonder if there might be any comments from your professor on the remaining 20%.
    a. *For the BME sample ONLY*, they received this version of scenario B*:* For a final design project, your group is designing an application that makes contactless optical vital signs measurements. The deadline is in two days and your prototype is working great. It was hard work, but your team managed to incorporate test subjects representing 80% of the North American skin tones. You wonder if there might be any comments from your professor on the remaining 20%.

C. *Sample #1 "Engineering":* For your co-op job, you are working at a renewable energy firm that does projects overseas for remote communities. The community needs a better lighting system for their homes and your company proposes to install solar panels. Based on the project budget and selected technology, you can tell that this is an expensive and high-maintenance project, and you aren't sure if it's the best solution for the community's needs. The project's lead has made it clear that they don't want input from a co-op student.
D. *Sample #2 "General":* You are a research assistant in a lab for your co-op job; it is a good position, and you hope to come back for another placement after graduation. One day, you find out that another researcher, someone you are friends with, has been under extreme pressure from the Professor to get results in time to present at an important conference. The researcher has been fudging the data to get results for the study.
E. *Sample #2 "Engineering":* For a final project, you acquire a dataset to build a facial recognition model to predict a subject's age. You train a model, and your initial results achieve 95% accuracy on the testing set. When you dig into the 5% incorrect samples, you realize that the accuracy is very high for lighter skinned individuals but very low for darker skinned individuals. Your project's intended population is mostly accounted for within the

test set. You know that your project will surely receive a high grade if you report your initial results.

F. *Sample #2: "Technologist":* It's the last week of your co-op term at the Rapid Growth Institute and you're proud of the work you've done this term. You got along with your coworkers and fully expect to get an Outstanding rating from the manager. Before your exit meeting and final good-byes to the staff, you notice a significant error in your code that will cause a delay when preparing for the next software update. You don't want to draw attention to your mistake before the performance review, but you also don't want to cause issues for the staff after you leave.

Likert scale: Scenarios

Note: These questions will appear below each of the three scenarios that are given.

1. This scenario could:

(1) Not serious at all (2) Slightly serious (3) Moderately serious (4) Very serious (5) Extremely serious

A. Have consequences for me, my education, or career that are:
B. Have consequences for my classmates or co-workers that are:
C. Have consequences for other stakeholders, such as users, the environment, or members of the community that are:

2. I have been involved in a scenario like this:
Never (2) Once or twice (3) Occasionally (4) Often (5) Very often

A. In courses and/or projects at school
B. In co-op placement or work experience

3. I have heard of a scenario like this happening to someone:
(6 Never (2) Once or twice (3) Occasionally (4) Often (5) Very often
A. In courses and/or projects at school
B. In co-op placement or work experience

4. If I were in this scenario:
1. Strongly disagree (2) Disagree (3) Neutral (4) Agree (5) Strongly Agree
A. I would feel responsible for and obligated to address the issue or conflict.

B. I would feel confident addressing the issue or conflict.
C. I would not address it because it is not my responsibility.
D. I would not address it because I am unsure of how to respond.

Short Answer: Scenarios

5. Please explain how you would respond to this scenario.
6. Please explain what you see as the most important considerations are in this scenario.
7. Please explain what you see as the least important considerations are in this scenario.

(END OF SCENARIO SECTION)

Likert Scale + Short Answer: About STV Course

Please consider the content you learned and discussed in the course (STV ###) while answering these questions.

1. What are some of the topics, concerns, issues, principles relating to society and technology you discussed in this course?

2. Going forward, how confident do you feel applying the concepts you've learned:
   (Very unconfident, unconfident, neutral, confident, very confident)

   a. On school projects or in other courses?
   b. In your future job or co-op placement

3. Going forward, how likely are you to apply the concepts you've learned:
   (Very unlikely, Unlikely, neutral, likely, very likely)

   A. On school projects or in other courses?
   B. In your future job or co-op placement?

4. Have you applied or are you applying concepts from this class in other courses or projects at school. If so/not, please explain:

5. Have you applied or are you applying concepts from this class in your co-op placements? If so/not, please explain:
6. What are some of the obstacles to incorporating these concepts into your other courses or projects at school?

7. What are some of the obstacles to incorporating these concepts on your co-op placements, and/or your work experience?

Short Answer: What is ethics in engineering?

8. In your own words, what is ethics in engineering?

    - What does it mean to be an ethical engineer?
    - What does it mean to be ethical in the engineering profession?

(Short Answer Box)

9. In your own words, what is responsible design in engineering?

    - What does it mean for an engineer to practice responsible design?
    - What does it mean to practice responsible design in the engineering profession?

(Short Answer Box)

Next page →

Statement for students to read:

*The Professional Engineers Association of Ontario [Code of Ethics] defines **ethics in engineering** as "the duty of a practitioner to the public, to the practitioner's employer, to the practitioner's clients, to other licensed engineers of the practitioner's profession, and to the practitioner to act at all times with,*

- *fairness and loyalty to the practitioner's associates, employers, clients, subordinates and employees;*
- *fidelity to public needs;*
- *devotion to high ideals of personal honour and professional integrity;*
- *knowledge of developments in the area of professional engineering relevant to any services that are undertaken; and*
- *competence in the performance of any professional engineering services that are undertaken."*

*Thinking and acting **ethically and responsibly in engineering** also includes creating and using technology for the good of humanity and of the planet. According to Love, Lajoie, and Boger (2021), "ethical thinking" in engineering is the ability and willingness to engage with, think about, and prioritize the social, cultural, environmental implications of tech innovation, design, development, and/or deployment. The Tech for Good Declaration, presented by the [Canadian Innovation Space], identifies a set of guiding principles for building ethical and responsible technology:*

- *Build Trust and Respect Your Data*
- *Be Transparent and Give Choice*
- *Reskill the Future of Work*
- *Leave No One Behind*
- *Think Inclusively at Every Stage*
- *Actively Participate in Collaborative Governance*

10. Do these definitions align with your understanding of "engineering and tech ethics"? Do you agree or disagree with any of these definitions? If so/not, please explain why.

(Short Answer box)

Demographics

11. What is your major/discipline?
12. What year of study/stream/degree program are you in?
13. What gender do you identify as?
14. Have you taken a co-op placement before? If yes, how many, and in what types of industry?
15. STV courses taken before this term (0-3)

Appendix B

Problem Finder Dartboard Worksheet

In class, you will have the opportunity to work with the Problem Finder Dartboard. After each round, you will write down the Technology (the Dart you chose) and the Problem (Space on the board you landed on) on this worksheet.

After your round at the dartboard is complete, you will think about the opportunities or challenges that you could foresee at the intersection of the technology and the problem.

Submit your completed worksheet to the LEARN Discussion Board after class for Participation marks.

Part 1

Technology (Dart)	Problem (Space on Board)	Potential Opportunities	Foreseeable Challenges or Issues

Note: Add more rows as needed.

Part 2

Describe your topic in 1-2 sentences. State your research question/problem.	
Describe the specific technology in your topic: its main function, key properties/attributes, and how it is used in the context of your topic.	
What places are related to your topic? (e.g. physical: country, city, hospital, classroom; digital: platforms, forums, online spaces)	

What populations are related to/impacted by your topic? (e.g. types of occupations – doctors, bus drivers; demographics - age, gender, race, education, economic status, where they live; types of non-humans – plants, birds, fish, etc.)	
What are some examples of the technical jargon associated with your topic? Add the words/terms here with a definition in plain language. (Be sure to keep the citation from where you get this definition.)	
Write the keywords/search terms you are using when you do online research. (Hint: In the sources you find, look for other common phrases/terms and try using those in your next search to get different results. E.g. if you search "AI Safety" and find sources about "Value Alignment" – try searching that, too)	
Find a Tarot of Tech card, copy its questions into this box and then answer them in the right column. http://tarotcardsoftech.artefactgroup.com/	
Find a Tarot of Tech card, copy its questions into this box and then answer them in the right column. http://tarotcardsoftech.artefactgroup.com/	

Note: Worksheet Part 2 sections referring to jargon and keywords are not discussed in Paper 5 but were included in this activity to help students keep track of their research process.