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RESEARCH ARTICLE

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Fostering responsible innovation with critical design methods

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ABSTRACT

In light of increasingly harmful social, psychological, and environmental impacts stemming from the tech industry, this article contributes to ongoing conversations regarding the need for more rigorous ethical deliberation in the engineering design workflow. We present two examples of pedagogical interventions dedicated to injecting critical design methods into the education of future tech developers to help foster responsible innovation: 1) a cross-disciplinary curricular intervention with English and Systems Design Engineering students; 2) a series of Responsible Innovation workshops conducted with students. Critical design, an arts-based research practice that resists unreflective technological progress, is uniquely situated to enhance current approaches in engineering ethics curricula by creating space for reflection about and design-based responses to the impacts of tech innovation. We argue that methods and expertise from the arts and humanities – disciplines that excel in the critical contextualization of technological progress – can help foster an ethos of responsible innovation in engineering education.

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Introduction

In 2018, the *Globe and Mail* reported on the growth of what some reporters called 'tech-lash,' 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 and Walsham 2021), the online

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spread of misinformation (Vraga, Tully, and Bode 2020), and concerns about privacy and surveillance (Vitak and 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 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, Owen, and Macnaghten 2013, 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, Hale, and Archambault 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, 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 classes (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). Dunne and 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, Tabas, and York 2022; Fuenfschilling, Paxling, and Vico 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 1), there are four main sections in this article:

- Section 2 provides an overview of RI discourse and a detailed description of critical design and examples of its use in previous pedagogical interventions.
- Section 3 defines critical design and provides background on its theoretical and methodological origins and examples of pedagogical applications.
- Section 4 describes the specific methods we used in our interventions, the student project results, and our pedagogical outputs.
- Section 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.

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 valorization of scientific knowledge' (Owen and Pansera 2019, 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 and Pansera 2019, 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 ("The Mozilla Manifesto," n.d.; "AI Principles," 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, Deloitte, and Rideau Hall Foundation 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, Paxling, and Vico 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 and Pansera 2019).

Many of the students at our institution take co-op terms at MAANG (Meta, Amazon, Apple, Netflix, Google) 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, Stone, and Marin 2023, 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 and Frey 2003; Hoven 2019; Li and Fu 2012). 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 approach used in RI pedagogy (Bardone et al., 2023; Conley, Tabas, and York 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 and Radke 2023; Truax, Orchard, and Love 2021). Students also embrace the idea that new technologies can and should be used to address society's most urgent ethical challenges (van Grunsven, Stone, and Marin 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.

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, Paxling, and Vico 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 and Raby 2013) or 'discursive design' (Tharp and 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 2020; 2015). 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 2020; 2015), are physical products like the DIY cellphone (Mellis and Buechley 2014) or Resistor Case ("Resistor Case" 2021) (see Figure 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.

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 and 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.

Figure 1. Photo of Resistor Case. Image property of Marcel O'Gorman.

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 D. 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.

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, Tabas, and York 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.

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 Figure 2). 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

Figure 2. a. Cover of speculative fiction magazine *Parcel and Package*. Reproduced with permission from student Christopher Rogers. b. Advertisement from speculative fiction magazine *Parcel and Package*. Reproduced with permission from student Christopher Rogers.

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 Figure 3). 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.

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.

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.

Figure 3. a. Screenshot of actress holding spoiled food in commercial. Reproduced with permission from students Olivia Roth and Lisa Brackenridge. b. Screenshot of actress using the *Envirocene* in commercial. Reproduced with permission from students Olivia Roth and Lisa Brackenridge.

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.

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 Figure 4). 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?

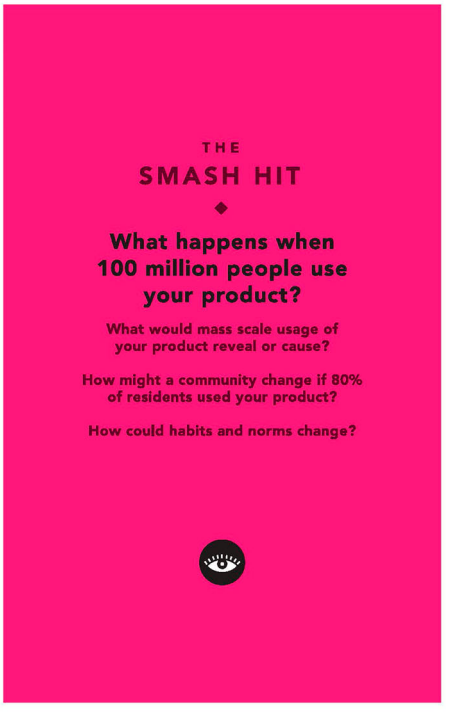
One reason we often employ the *Tarot Cards of Tech,* in this workshop and across many others, is because the card prompts are imaginative and engaging regardless of a participant's background; therefore, it is easy for us to reuse and adapt the card prompts while accommodating the appropriate complexity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

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*

(a)



(b)

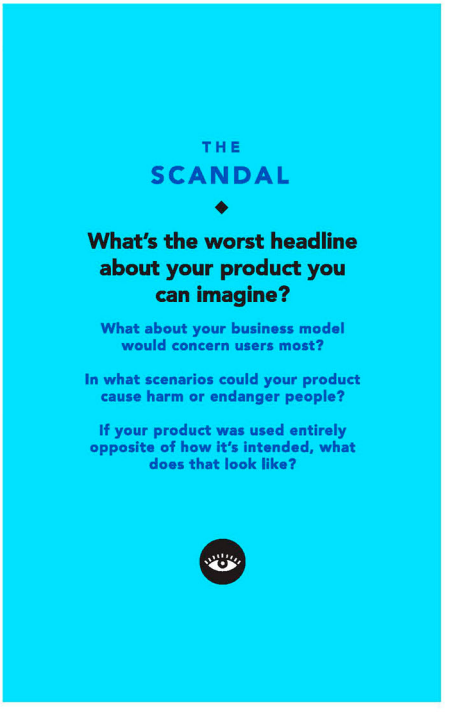


Figure 4. a. The 'Smash Hit' card from the Tarot Cards of Tech designed by Artefact (2018). b. The 'Scandal' card from the Tarot Cards of Tech designed by Artefact (2018).

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 humor 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 and 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, Stone, and Marin 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 and 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 behaviors.

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, 421). 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.

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Research ethics for human participants

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