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Integrating History and Engineering in the First-Year Core Curriculum at Boston College

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1. Introduction

In *What Can a Body Do? How We Meet the Built World,* the artist, design researcher, and Olin College professor Sara Hendren writes, "Engineering is not the science of the laboratory alone… It is fundamentally applied, which means its results live in the world. It belongs to people, not just as 'users' but as protagonists of their dimensional lives" [1, p. 23]. Hendren's invocation of a vision of engineering as radically human-centered provided the philosophical and humanistic core to our interdisciplinary teaching team as we embarked on designing a new course for first-year students at Boston College (BC). Our course, *Making the Modern World: Design, Ethics, and Engineering* (MMW), situated engineering practice and knowledge within its social, political, and historical context using a variety of instructional modes and pedagogical innovations.

This paper presents the experience of developing and teaching MMW for the first time in 2020 in the midst of the COVID-19 pandemic. MMW was designed and co-taught by an interdisciplinary faculty teaching team from the departments of history, theology, and environmental science. As a designated "Complex Problems" course, a type of first-year interdisciplinary Core course, MMW offered 70 students the opportunity to satisfy BC's Core requirements in Natural Science and History through three linked pedagogical components: lectures, labs, and reflection sessions. Our goal was to integrate engineering, the history of science and technology studies, and ethical and moral modes of inquiry across these formats.

We were in a unique position in designing MMW. Not only was this a new Core course for first-year students at BC, it was also a pilot course for BC's Department of Human-Centered Engineering (HCE), which will enroll its first cohort of students in the Fall of 2021. HCE is in the Morrissey College of Arts and Sciences (MCAS), the main liberal arts college at BC. As a result, HCE prioritizes deep connections with the humanities, social sciences, and natural sciences. Thus, in designing and teaching MMW, we had the latitude to experiment creatively with multiple modes of interdisciplinary inquiry across the natural sciences and humanities.

This paper addresses how our course design was informed by scholarship about integrating sociotechnical awareness into engineering education and by foundational theoretical frameworks from science and technology studies that emphasize the social, political, and cultural values inscribed into engineering artifacts and complex engineering systems. We also describe the experience of teaching MMW for the first time in the Fall of 2020, the modifications we adopted due to COVID-19 public health restrictions on campus, qualitative data related to student outcomes, and lessons learned for future course revisions.

2. Background and motivation

Institutional visions of the future of engineering education have long included calls for interdisciplinary coursework. Many current efforts to expand the scope of undergraduate engineering studies can trace their origins to the 1994 ASEE report *Engineering Education for a Changing World*, which, among many other recommendations, asserted that "engineering education must take into account the social, economic, and political contexts of engineering practice…" [2, pp. 20–21]. The report emphasized that contextual skills should be delivered through multi- and interdisciplinary coursework, integrated into the existing curriculum, and focused on an understanding of the ethical dimensions of engineering. A decade later, the National Academies report *Educating the Engineer of 2020* re-emphasized the importance of the themes of interdisciplinarity, societal context, and ethics to the engineer of the then-future [3].

In 2018, Dr. Ruth Graham, in her report on *The Global State of the Art in Engineering Education,* found that institutions identified as "emerging leaders" have embraced "work-based learning, multidisciplinary programs and a dual emphasis on engineering design and student self-reflection" [4, p. iii]. Graham anticipates these characteristics, part of "socially-relevant and outward-facing engineering curricula," to become widespread throughout global engineering education. Interdisciplinarity in undergraduate engineering programs often takes the form of courses that span multiple science and engineering disciplines. [5]. This arrangement is what is most commonly observed today, as an expansive review of the subject recently concluded [6]. Although technical interdisciplinary courses are valuable in preparing students for rapid changes that will surely come during their careers, it is not the sort of disciplinary barrier-breaking that matches the visions in the aforementioned reports.

We are motivated by efforts to substantially integrate the humanities and engineering, particularly at the introductory level. UC Berkeley Professor J. M. Prausnitz foreshadowed the 1994 ASEE report when he argued in 1989 that "[undergraduate] engineering should be taught in a social context" [7, p. 14]. Draw lessons from the humanities, he expands (addressing a likely reticent audience):

> Yes, teach science, teach phenomena, experiment, theory, and correlation. Yes, teach technology, plant design, and product development. But don't stop there. Teach also, or at least indicate, the social problems, the government's role, the ethical dilemmas, the legal implications, the effect of technology on health and medicine, the influence of international relations and cultural conflicts—in short, the human dimensions and consequences that interact with technology in a world populated by human beings [7, pp. 9–10].

An exciting model for the integration of humanities and engineering is that of Bucciarelli and Drew's proposed Liberal Studies in Engineering (LSE) [8], [9]. This proposed degree program inverts the orientation of engineering courses that engage societal context as a secondary concern by instead conceptualizing a set of liberal arts and humanities courses that engage engineering topics and skills. Bucciarelli, Drew, and colleagues have developed example modules of this type. One explores the historical development of the engineering of cantilever beam failure, a lesson that brings together the history and philosophy of science with static mechanics. Each module is problem-based and benefits from collaborative instruction. The LSE model has also been suggested as a "transformative solution" to the persistent problem of low enrollment of women in STEM majors and careers [10]. Although some courses and online modules in the

LSE mold exist, the broader curriculum remains, according to the authors, a "sociotechnical imaginary" useful for demonstrating to conventional engineering educators that real integration with the humanities is possible and even compelling [9, p. 4].

There are numerous examples of innovative, interdisciplinary, first-year engineering courses that also motivated our curriculum development. Some utilize project-based learning strategies to help establish an understanding of the nature and limitations of engineering models [11]. Some embrace role-play as a way to demonstrate the importance of context and perspective in defining, to say nothing of solving, sociotechnical problems [12]. Yet others have an explicit focus on ethics, having students grapple with real-world engineering ethics problems [13]. All of these courses prioritized communications and teamwork, and created opportunities for empathy building.

3. Course overview

Making the Modern World challenges a class of 70 first-year students at BC to develop foundational skills in engineering and design while carefully discerning the historical and ethical contexts of science and technology. MMW is a six-credit course in the BC Core Curriculum, satisfying requirements in both history and natural science. As a Core course, MMW has no prerequisites and is open to students from across the university, irrespective of school or intended major. As a result, students come into the class with widely varied experiences, ambitions, and comfort levels with math, science, writing, and history, not to mention exposure to Jesuit-style reflective practices. Notably, in the Fall of 2020, none of the initial cohort of 70 MMW students were engineering majors (as BC's did not have an engineering department at the time). Instead, students represented all of BC's undergraduate colleges and a wide variety of both STEM and non-STEM departments.

We adopted a multi-modal pedagogical approach for MMW, as illustrated in Figure 1. For content delivery, students met for 75-minute lectures twice per week. Practical skill-building, engineering content reinforcement, and group design projects were conducted in two-hour lab sections of 8-10 students each. The class also gathered in small groups of 12-15 students on Thursday evenings for 75-minute weekly reflection sessions, each group led by a pair of third- or fourth-year student mentors. For the first half of the semester, lectures were split between engineering and history content (albeit with considerable coordination of topics, as will be discussed in section 6). For the second half of the semester, lectures transitioned into a series of integrated engineering case studies that engaged material from both disciplines as well as critical tools from reflection. Lab activities were similarly organized with the first half-semester hands-on applications of basic engineering principles and the second half an integrated, seven-week human-centered design project focused on issues of access and accessibility on the BC campus. Reflection utilized BC's innovative small group Purposeful Ongoing Discussion (POD) model of near-peer mentors guiding students through various reflective practices to grapple with the ethical and moral dimensions of engineering. A summary of the MMW curriculum can be found in Appendix A.

Figure 1. Schematic overview of *Making the Modern World* course curriculum

Fall 2020	**First half of semester**	**Second half of semester**
Lecture	Engineering fundamentals	Integrated engineering case studies
	History of engineering & technology since 1800	
Lab	Practical engineering design activities	Interdisciplinary human-centered design project
Reflection	Ethics, justice, and personal moral development / POD program	

4. Institutional context at Boston College

The course design for MMW was informed by a number of institutional educational initiatives and programs at BC, including BC's identity as a Jesuit, Catholic institution, its Renewed Core Program, and its development of a new Human-Centered Engineering Department.

First, as a Jesuit, Catholic university, BC is committed to educating the "whole person" and embraces courses that advance aspects of social justice. Particularly in the Fall of 2020, when layered crises of COVID, racial injustice, climate disruption, and the presidential election placed high burdens on universities to respond, we were encouraged by the university administration to embrace these challenging topics in class. We emphasized the humanity of the engineering design process and profession, highlighting ways that engineering historically has reinforced structural inequalities and exploring ways that engineers—with an understanding of the historical injustices of their field—can move to rectify some of them.

Second, the Jesuit educational philosophy is also embodied in the BC Core Curriculum, a set of 15 courses drawn from disciplines across the university that all students, irrespective of major, must complete. In 2014, BC embarked on an effort to renew its Core as part of a generational update of traditional liberal arts education in light of new ways of knowing the world available to us in the 21st century. Core Renewal offers courses that sit at the intersection of multiple disciplines and that address either "Enduring Questions" (e.g. what is the relationship between humans and nature") or "Complex Problems" (e.g. migration and immigration) [14]. Complex Problems courses, like ours, are co-taught by faculty from different disciplines and involve six credits of lecture, lab, and reflection session time, with a maximum enrollment of 76 students.

The university administration strongly supports the new Core model, providing generous incentives for faculty willing to develop and teach Enduring Questions and Complex Problems courses. Faculty are given stipends for completing an intensive course development workshop and for the six-credit Complex Problems courses, all three instructors (two lecturers and one lab instructor) are granted six credits towards their teaching responsibilities. Syllabi for these courses are reviewed by the University Core Renewal Committee (UCRC), which encourages experimental, innovative offerings that elevate the vision of the BC Core Curriculum. So far, the investment in the Renewed Core has yielded positive results, with the annual State of the Core Reports documenting Complex Problems and Enduring Questions courses regularly filling to near-capacity and receiving very strong course evaluations, even as they are seen by students as more challenging than conventional introductory courses.

As anyone who has team-taught interdisciplinary courses before can attest, the teaching effort can far exceed that of solo-taught credit-equivalent courses, especially in the first couple years. With this in mind, BC supports a cohort of full-time, non-tenure track Core Fellows, early-career postdoctoral faculty who have demonstrated interest and skill in interdisciplinary research and education, who develop and teach Enduring Questions and Complex Problems courses. Before MMW, all Complex Problems courses were developed by tenure-track or full time non-tenure track faculty with Core Fellows serving as lab instructors. MMW is the first Complex Problems course to be developed and taught by postdoctoral Core Fellows. Core Fellows are hired initially with one-year contracts with the possibility of renewal for up to three years.

All three MMW instructors have comfort and experience with interdisciplinary work. Jonathan Krones received his PhD from an interdisciplinary engineering program; Jenna Tonn earned her PhD in an interdisciplinary history of science program; and Russell Powell is a theologian and environmental ethicist. We acknowledge that our positionalities as individuals and as a group of Core Fellows affects the way we have conceptualized and delivered this class, as articulated by Secules *et al.* [15].

The learning objectives of Complex Problems courses, stated in *The Vision Animating the Boston College Core Curriculum* [16], provided the scaffolding for a curriculum that would satisfy the ambitions of the Renewed Core. These general learning objectives, such as “to understand the major ideas and methods of inquiry of the scholarly disciplines that comprise the university and be able to use those methods of inquiry as beginning practitioners to address complex contemporary problems;” and “to demonstrate the ability to examine their values and experiences and integrate what they learn with the principles that guide their lives” sit at the core of the specific learning objectives of our course, which can be seen in Appendix B.

The third institutional condition that made MMW possible was the announcement that BC is developing its first engineering program, a Department of Human-Centered Engineering (HCE). This program, which will enroll its first cohort of students in Fall 2021, will be a general engineering curriculum that sits in the Morrissey College of Arts and Sciences (MCAS) along with the social sciences, humanities, and natural sciences, rather than in its own College or School, as is often the case at other universities. The placement of the department in MCAS is intended to facilitate engineering as a liberal arts subject. The plan is for the program to become accredited as well. These institutional factors meant that we had a substantial amount of institutional support to design an ambitious, interdisciplinary program of study for our students.

5. Theoretical frameworks

In thinking about how to develop MMW into a Core course that fulfills requirements in natural science and history (as well as a course that can contribute to ABET accreditation), we decided to introduce students to a series of theoretical frameworks that integrate engineering and technology with problems of context.

One of the central argumentatives through lines in MMW emerges from Langdon Winner's foundational article "Do Artifacts Have Politics?" [17] with an important update in Ruha Benjamin's *Race After Technology* [18]. Technologies and large-scale sociotechnical systems are not value neutral. They carry with them the social, cultural, political, and economic values of their innovators, engineers, funders, and developers. These artifacts and systems shape users' experiences in large and small ways. We drew on interdisciplinary scholarship from the history of science and technology, science and technology studies, feminist and indigenous studies, and critical design studies to illustrate the history and politics of engineering practices.

As noted above, one important approach to developing a broader understanding of engineering history is to ground students in critical concepts like the "social construction of technology" and the development of "large-scale sociotechnical systems" [19]–[21]. Emerging from the history of technology and science and technology studies, these concepts embed engineers and engineering practice within complex networks of technical artifacts, institutions, consumers, funding mechanisms, and state and federal political systems. Systems-level thinking aids in illustrating the complex and often unintentional ways in which engineering knowledge can make and remake the world, for instance the multi-decade-long shifts in the electrification of America which revolutionized mass production, shifted energy use and production, and remade conditions of living and working for everyday people [22]–[24].

We paired an understanding of the social construction of technology with a deep knowledge of the history of the engineering profession. Engineers embody particular historically informed forms of representation, drawing on the nineteenth-century from artisan and military cultures and later on populations of upwardly-mobile working and middle-class men [25]–[27]. Women and minoritized groups, including men and women of color, were largely excluded from the rapid expansion of engineering as a profession in the twentieth century in ways that we are still coming to terms with [28], [29].

Topics in engineering history often unintentionally amplify the presumed racialized and gendered characteristics of engineers, focusing on large-scale steam-powered machinery in the nineteenth-century rather than advances in corsetry and domestic appliances or emphasizing histories of aircraft and military weapons over reproductive technologies like birth control [30]–[32]. An overriding emphasis in privileging innovators and geniuses in engineering contributes to this asymmetry of historical representation.

In the discipline of history, integrating primary sources into a course syllabus is one of the most effective ways to address how people understood and experienced engineering practices. Primary source materials (or first-hand accounts produced during a period in time which include correspondence, newspaper articles, material culture, advertisements, diaries, film, etc.) offer a direct and tangible window into the past. In an engineering studies course, witnessing, for instance, the problem of representation from the writings of a British woman engineer in the 1920s struggling in a male-dominated field [33]; or reconceptualizing the mass production of automobiles and the transformation of American culture through automobility through the lens of Black drivers consulting *The Green Book* to avoid racialized violence under Jim Crow [34]; or viewing the Love Canal environmental disaster through the testimony of families impacted by toxic pollution grounds engineering history in the lived experience of people [35] provides a vivid account of the relationship between technical systems and everyday life [36].

Thinking about engineering ethics and engineering and social justice is critical to the training of young engineers [37], [38]. First-year students in MMW started to build skills in grappling with the complex interplay between what has been called "the engineering mindset," or an emphasis on technical expertise and robust problem-solving methods, and the often unintended consequences that engineers and technical systems have on society. While we addressed engineering, ethics, and justice in our reflection curriculum, we also decided to focus lecture content, engineering content, and a seven-week hands-on human centered design lab on issues of access, design, and justice.

Focusing on access is one of the most explicit ways students can put together historical problems of representation in engineering, critical problems related to the politics of sociotechnical systems, ethical issues about accessibility, usability, and justice, and an awareness of engineering as a practice can only benefit by taking into account the unique and varied ways that humans experience the built environment. We drew on the research and design practices of artists and educators like Sara Hendren [1] and Sasha Costanza-Chock [39] to frame this project, who argue broadly that design solutions must develop in close collaboration with communities of users. We also engaged with recent scholarship from critical access scholars including Aimi Hamraie [40] and historians of disability such as Bess Williamson [41], [42] that situates practices like universal design, adaptive technologies such as wheelchairs, prosthetics, and low-tech DIY innovations, legislation including the Americans with Disabilities Act (ADA), and the voices of disability rights advocates in the context of design, engineering, and technology in the twentieth- and twenty-first centuries [43]. Questions of disability and access shape everyone's lives, as everyone navigates a built world not constructed exactly to their specifications [44]. Centering our seven-week human centered design lab on these issues brought these theoretical and historical discussions into the real world in significant ways.

6. Fall 2020 MMW curriculum narrative

MMW turned into a large, complex, multi-faceted course. With three faculty instructors, one each coming from perspectives of history, engineering, and theology, the process of developing a coherent curriculum was iterative and in constant motion. We constructed the course starting with a set of clear learning objectives we created from the BC Core requirements [16] and the list of ABET student outcomes [45]. The set of learning objectives, along with descriptions and their mapping to these BC and ABET objectives, is reproduced in Appendix B.

Engineering and History Lectures. We started the semester in lecture thinking about engineering fundamentals from the perspective of engineering fields and the history of science and technology studies. We learned from an intake survey of the class that many of our students had never met a professional engineer. Thus, it was important to introduce students to the practice and profession of engineering. In lecture, the engineering faculty instructor embarked on a tour through four major branches of engineering—mechanical, civil, electrical, and chemical—and exploring foundational topics, such as simple machines and mechanical advantage (ME); static mechanics and the analysis of trusses (CE); open- and closed-loop control (EE); and engineering systems thinking (ChemE). The first half of the semester ended with a discussion of engineering for sustainability, which challenged students to think through the long-term implications of engineering decisions.

At the same time, in parallel, students learned about the history of science and technology in the U.S. context since 1800. Moving chronologically, history lectures covered important theoretical frameworks for approaching science, engineering and technology, such as the social construction of technology, technological determinism, the "dangers" of technology as a sign of progress, and the development of large-scale sociotechnical systems. History lectures also provided examples of the complex relationship between engineering practice and society by addressing the history of the engineering profession; the transformation of sociotechnical systems like electricity, railroads, and automobility; the impact of factory systems, scientific management, and automation on labor and worker's rights; and the way that federal and military funding transformed the scope and scale of engineering projects during the New Deal, WWII, and the Cold War.

We strove to demonstrate the synergy between the engineering and historical perspectives during the first half of the course by organizing weekly course themes. For example, in Week 3, "Work and Power," history lectures examined factory systems and social control enabled by scientific management and Fordism, while engineering lectures provided mathematical and scientific proofs of mechanical advantage and simple machines. The following week, "Building Big," was much more tightly coupled. Engineering lectures on static forces and material failure met history lectures on infrastructure construction and infrastructure failure, all in the context of a discussion of the Central Artery/Tunnel Project (aka the Big Dig). The technical content offered a physical explanation for catastrophes like the 1907 Quebec Bridge Collapse while the historical content defined the human stakes of engineering failure.

Engineering Case Studies. The relationship between the disciplinary perspectives became much more apparent and necessary in the second half of the semester, structured as a series of engineering case studies. These case studies were developed to build directly on content introduced in the first half of the course while also introducing new historical, engineering, and ethical concepts. We foreshadowed this pedagogical model in our very first class of the semester, where we demonstrated the value and interplay among the three constituent disciplines in understanding the causes and consequences of the Boston Molasses Flood of 1919, a common case study for engineering ethics classes.

Four additional week-long case studies were originally developed: chemical disasters (e.g., Union Carbide Bhopal); the Boeing 737 MAX; geoengineering the climate; and automation. For each (one historical, two contemporary, and one near-future), students grappled with the historical contingency of engineering decisions. Rather than approaching these episodes with a presentist lens, using today's scientific and ethical models to criticize past decisions that may have led to disaster and death, we challenged the students to empathize with key stakeholders and understand their rationales. We then examined how the outcomes of each of the cases affected future engineering practice (or in the case of geoengineering, how to think about potentially existential uncertainty in engineering decision making). The case studies are the highlights of the lecture portion of MMW and we look forward to refining them further in future iterations of the class.

Engineering Labs. Lab activities in the first half of the semester provided hands-on reinforcement of engineering content (with one exception: a lab on reading historical primary sources). In the week where the lecture was about mechanical advantage, students were given supplies to construct a variety of simple machines and measure force multiplying effects of different configurations. Given the makeup of the students in the class, this relatively simple activity, which is more commonly found in K-12 STEM programs, was intended to forge initial connections between science and math concepts and a tactile experience. The next lab began a three-week popsicle stick truss bridge design, construction, and testing arc. Students did background research on common truss bridge designs, learned to solve truss problems, and brainstormed designs that would satisfy one or more of the design objectives: strongest bridge, highest specific strength, and aesthetics. As lecture material progressed past the static mechanic content, lab assignments included problem sets on modeling dynamic control systems and life cycle assessment, while students continued to prepare their bridges for testing.

Labs in the second half of the semester were entirely dedicated to small-group human-centered design projects focused on issues of access and accessibility on the BC campus. This topic is deeply rooted in historical questions of who our built environments are designed and engineered for, a theme that was systematically constructed in the first half semester of history lectures that interrogated questions of normate bodies; issues of race, gender, and physical ability; and representation in the engineering and other design professions. This product design project was distinct from the engineering design task of the truss bridge. Students were not expected to develop mathematical or scientifically-informed models of their designs; rather, the focus was on understanding the interplay between design, designer, user, and the built environment. As with many early career design projects, a key objective was also to empower the students to see the world as engineerable and designable, and demonstrate that they have the ability, and in some cases obligation, to use their skills, in whatever career they end up , to improve it for those around them.

Reflection. The third component of the course, the weekly reflection sessions, began with a distinct curriculum of moral philosophy and reflective practices. Over the course of the semester, it moved closer and closer to the themes of the lecture and lab components and ended with the construction of a model of engineering ethics that transcends the conventional perspective of professional responsibility and is much more in line with models of engineering justice [46]. The overarching point of inquiry for the reflection session was, "As we learn to make and remake the engineered world, we are also learning to make and remake ourselves." This perspective not only fits into the Jesuit mold of reflective practice and the overarching objectives of the BC Core Curriculum, it also reinforces that engineering is a human endeavor, often times closer to the humanities and social sciences in its reflection of the needs and desires of the humans involved than the purported objectivity of the natural sciences.

7. Adapting to teaching during the COVID-19 pandemic

Due to the COVID-19 pandemic, we had to quickly adapt our original plans to hold in-person lectures, labs, and reflection sessions to a new reality. Our goals in doing this were two-fold: first, experimenting with a range of pedagogical methods to maximize student engagement and avoid Zoom fatigue; second, prioritizing flexibility of instructional modes in the case that we had to move to entirely remote teaching. BC brought students back to campus in the Fall of 2020, but public health recommendations and classroom space constraints on campus meant that we held our twice-weekly 75-minute lectures synchronously online, mixed in-person and remote engineering labs, and held our reflection sessions synchronously online. Given these constraints, we experimented with pedagogical methods and instructional modes in the following ways.

Experimenting with lectures. As soon as we learned that our twice-weekly 75 minute lectures would be held synchronously online, we decided to adopt four different pedagogical methods.

(1) *Flipped classroom.* For some lecture sessions, we utilized the flipped classroom model. Instructors pre-recorded their lectures on engineering history and engineering fundamentals and assigned the lectures (as well as some readings) in advance of lecture time. During our synchronous lecture time, we started off with a short in-class four question lecture and reading comprehension quiz. We used the quiz to launch a structured discussion about course content based on the questions, comments, and interests of our students. After this discussion, we guided students through a pre-planned engagement and reinforcement activity, such as a primary source analysis in small breakout-groups or a communal Jamboard activity thinking about connections across readings and disciplines.

(2) *Live lectures*. To vary our lecture delivery methods, we also held more traditional live lectures during our assigned lecture time. Instructors divided the time, offering first a short history lecture and then a short engineering lecture. During live lectures, students asked questions and offered comments verbally and in the Zoom chat and instructors made it a point to informally draw out connections and divergences in their co-instructors' lectures.

(3) *Live mini-lectures*. Since our course had 70 students, we also wanted to find ways to break up the class during our lecture sessions to give it more of a seminar-style feel and to lower the barriers for student participation. Therefore, we incorporated live mini-lecture days into our curriculum. On a live mini-lecture day, each instructor prepared a short 15-20 minute content lecture. During our session, we assigned students into three breakout rooms (of around 25 students each) and had the instructors rotate between rooms, giving their short-lectures, offering discussion questions, and then jumping into the next breakout room.

(4) *In-class case studies*. We wanted our course to have a different pace and rhythm at the beginning of the semester and starting at the midpoint of the semester. In the first seven weeks of the semester, we focused on frameworks, foundational knowledge, and content delivery. In the second half of the semester, we put together these knowledge bases in a series of interactive and interdisciplinary engineering case studies (ECS). Each ECS took three class sessions.

In the first session, instructors set up the case with short live lectures about the history, engineering practices, and ethics around engineering accidents. We then divided students up into groups of four or five to tackle their own engineering cases with similar themes but different specifics. Each group received a packet of case materials that included: historical documentation about their case; a technical analysis of engineering designs and failures; first-hand evidence of how it impacted everyday people; and a framework for thinking about engineering ethics, environmental justice, and human rights.

In the second session, students arrived to lecture for an ECS workday. We assigned them to breakout groups to process their case materials and work on how they would present them to the class (e.g. one case study required a short two-slide presentation that integrated the historical, engineering, and ethical aspects of their case and another required a short memorandum written from the perspective of a particular stakeholder in an engineering disaster).

In the third session, we divided students up into breakout groups depending on their case and had them present their results, look for commonalities and differences across the cases, and connect their new expertise to course themes.

Experimenting with labs. Although we had planned to hold all of our engineering labs in person, the COVID-19 pandemic required flexibility in thinking about in-person lab activities. We needed to design labs that could be conducted in-person but also labs that could be adapted to the requirements of students taking the course remotely and students on campus who might be in quarantine. In-person labs would also have to be done individually because of public health restrictions on classroom interaction, a departure from our planned group lab activities.

(1) *Flexible in-person labs*. During the first half of the semester, we designed a series of individual engineering labs using materials that could easily be shipped to students in the form of engineering kits. This transition was made easier than it might otherwise have been because of the introductory nature of the class. On the other hand, in order to provide 70 students with hands-on, in-person lab experience, we scaled back the design and material complexity of the lab activities (the latter to stay within our course budget, since the original course design assumed in-person group lab tasks, something made impossible by COVID public health restrictions). The class of 70 was divided into eight lab sections, each meeting for two hours per week. Within this constraint, we still experimented with different lab designs, from a single session on mechanical advantage to a three week truss bridge design, construction, and testing arc (which required careful management of bridges-in-progress by the instructors, since all materials had to remain in the classroom).

(2) *Remote human-centered design labs*. During the second half of the semester, we piloted a fully remote seven-week human-centered design (HCD) practicum with the idea that it was

likely to occur that students who left for Thanksgiving break would not be allowed to return to campus. We ran the HCD practicum as a series of workshops. Students arrived on Zoom at the beginning of their two-hour lab session and instructors set up the design task for the day in a short interactive activity. Students, who had been sorted into three-to-four-person HCD lab groups using the team management platform CATME, then worked in small breakout groups to complete their design tasks (sometimes using Jamboard-based graphical brainstorming and design templates), plan for their next weekly checkpoint, and organize their group work for the following week. If we had been in-person, instructors would have circulated through the room informally to offer advice, answer questions, and underscore likely next-steps. Instructors, on Zoom, popped into the different breakout rooms to try to replicate that creative flow.

We found that the remote HCD environment did offer students some advantages. Remote interviewing enabled a richer and more varied set of user interviews. At the beginning of the design process, students interviewed friends, family members, and acquaintances about their experiences with access and disability. Instead of conducting these interviews in person, they were able to do them remotely, allowing for a much broader set of interviewees, user data which ended up deeply enriching student projects. Similarly, once students developed their first prototypes, they engaged in a session of testing and getting user feedback. Students, who at this point in the semester were exhausted, reported that talking to other students, family members, and acquaintances about their projects was incredibly valuable and offered surprise twists and turns to their prototypes.

(3) *Remote Design Conference*: At the end of the semester, we held a remote MMW Design Conference for students to present their prototypes to the BC community, their friends and family, and an invited group of guest judges. Each group presented a poster featuring their design process and prototype, prepared a five-minute design pitch, and answered questions from our panels of judges. At the end of the session, the judges conferred to select the top three prototypes in each session. Our multi-disciplinary panels of judges included Elizabeth Shlala (Assistant Dean of the Core, BC), Yasmin Zaerpoor (Visiting Assistant Professor of Environmental Studies, BC), Lyel Resner (social entrepreneur and ethical technology advocate), Nora Gross (Visiting Assistant Professor of Sociology, BC), Phoebe Kuo (artist, woodworker, and design ethnographer), and Brian Rodriguez (Director of People and Culture at Hopelab). Over 150 people attended our MMW conference via Zoom. The panels of judges, BC faculty, staff, and parents, and students provided enthusiastic feedback about the event. While it would have been fabulous to hold this conference in person, we acknowledge that the remote environment did allow for family members and friends outside of Boston to fully participate.

Experimenting with reflection. Weekly evening reflection sessions provided students an opportunity to integrate course content into peer-led discussions about their own moral and ethical development. We developed a curriculum that translates Ignatian reflection activities (e.g. the Examen) to a Zoom format. We also adopted BC's innovative PODs (Purposeful Ongoing Discussions) model wherein our students meet remotely in groups of 10-12 with a pair of third- or fourth-year BC students. Our POD leaders worked closely with us to implement weekly lesson plans, which ensures that the POD leader program builds leadership skills and provides opportunities for student formation among the POD leaders. During reflection sessions, POD leaders led students through reflection exercises grounded in the Jesuit tradition, discussions about the relationship between course content and the daily lives of our students, and regular journaling activities to encourage self-reflection. We were grateful to our POD leaders for going above and beyond to not just offer academic support but also to act as important resources for our first-year students transitioning to college life during a challenging semester.

8. Student outcomes

During the semester, as a faculty teaching team, we were very open with our students that MMW was a new pilot engineering course at BC and that we would be experimenting with multiple modes of content delivery, course organization, and assessments. The COVID-19 pandemic only sharpened this experience of experimentation.

Mid-semester evaluations. To gather qualitative data about MMW in the middle of the semester, we designed a mid-semester survey that asked students to reflect on their experiences to date. Twenty-five out of 70 students completed the survey. There was one clear consensus in terms of student preference: students enjoyed the in-person bridge building labs since they were in-person and provided an opportunity to do hands-on work. In terms of lecture format, some students preferred the live or live mini- lectures because it meant less course prep and offered space for real time questions and discussions; others, however, preferred the flipped classroom model so they could watch the lectures on their own time and pause or rewind while taking notes. Students also generally valued the POD-leader led reflection sessions which offered a more informal space to think about course materials and have meaningful and often personal conversations with their peers.

Two of the big challenges students identified during the first half of the semester had to do with navigating a steep learning curve in two disciplines while also transitioning to college. These challenges centered on learning how to read and comprehend history sources and becoming conversant with math, logic, and engineering analysis. In future iterations of the course, we will need to find ways to scaffold student learning in these areas even more strategically in the first six to eight weeks of the semester.

End-of-semester evaluations. We conducted multiple rounds of end-of-semester evaluations. One set of qualitative evaluations centered on group reflection and was based on the student groups that formed to conduct the seven-week human centered design project. A second set of qualitative evaluations was directed to individual students, asking them for their own personal reflections on the course and their learning during the semester. We also participated in BC's official course evaluation program, which pulls qualitative and quantitative data.

(1) *Lab group evaluations and reflections.* In this qualitative survey, we asked groups to define their biggest success, their biggest challenge, to reflect on their learning process through the design lab, and to offer suggestions or advice to future lab groups. Three themes emerged:

(a) The challenges and successes of working as a team and the strategies groups used to allocate work, manage a rapidly-moving project with regular deadlines, and collaborate remotely (often across time zones) during a busy semester. As one group noted: "Our biggest success throughout this semester was definitely our group's teamwork. Throughout the entirety of the process, we were able to efficiently work as a team. A key part of this was good communication (i.e. group chat, zoom, group facetime)." As another group stated: "One piece of advice that we would give a future MMW lab group early in the process is to get to know the members of your group. By understanding the strengths and weaknesses of those you are working with, your group will be able to divide work amongst members in a manner that ensures great quality and collaboration throughout all parts of the design process."

(b) The importance of the prototyping and testing phase of the design project. Groups commented on how valuable rounds of feedback were from potential users and how exciting and difficult it was to realize that they had a problem with their design that required going back to the drawing board. As one group explained: "Our biggest challenge this semester was detaching ourselves from our original design and completely changing course after we became aware of a major design flaw. After this road block we encountered, we also found it difficult to narrow down our ideas and only include the most important and most relevant information. We thought through all of the specific details of our design and we were excited with the ideas we came up with, so it was difficult to cut portions out due to a lack of time and space to fully discuss them." Another group stated: "A piece of advice we might give to a future MMW lab group early on in the process would be to take the interviews seriously and to use what your interviewees say to develop your design. Our group's interviews were the basis for a lot of our design decisions that helped us create a useful and inclusive product."

(c) The realization that human-centered design is all about process. Groups commented on how fast the HCD process felt with seven weeks to think about a design problem, brainstorm, ideate, quick prototype, get feedback/test, and redesign their prototype before presenting it at the design conference. As one group explained, "We learned that the process of human-centered design and prototyping is certainly not an easy process. It is a multi-step process and is more time consuming than just coming up with an idea and presenting it. We did not realize how much brainstorming and interviewing actually goes into the process. There is so much that goes into designing something before you can actually craft and engineer the project itself. The most important factor was thinking about how the app would actually interact with its users and environment rather than the way we expect it to be."

(2) *Individual evaluation and reflection.* In a separate qualitative survey, we asked students to reflect individually on their group work experiences, on their own learning outcomes, and on the skills that they found they were able to grow and develop in class. Across the board, students arrived at MMW uncertain about what they would find in terms of coursework and lab work and most students reported finding the human-centered design process as an activity that tied together content across lecture, lab and reflection in challenging but meaningful ways. Two themes emerged:

(a) Students had different comfort levels with STEM related content but found ways to contribute to the lab group's process that worked with their skill sets. As one student reflected: "In general, science is not a strong point for me and engineering was an entirely new concept to me before this semester, so I was unsure of how I would fare in the lab environment. For me, labs were the most challenging part of this course, however I felt I had the resources to handle them and succeed. Specifically in the design project, collaborating with my group helped to feel the gaps where each of us were not as confident as the others in certain areas.... I felt that in my group, I tended to focus on the overall big picture of our project as opposed to the small details, making sure that we were connecting course themes and creating a project with a coherent storyline and a focused target."

(b) Students also commented on how the group element of the human-centered design process expanded their skills as communicators, editors, leaders, and thinkers. For instance: "My expectations for the lab design project were that I was going to be able to create a really interesting prototype with a solid team of students who also wanted to make something meaningful and work productively. I think my greatest strengths as a group member would be organizing our meetings and work. I was generally the one who would take the initiative to schedule a meeting or try to find time when we could all work on the documents. I really enjoyed getting to coordinate the meeting times; it gave me a sense of leadership even though we all split the actual work evenly. I have always liked being able to lead one portion of a particular project as I think that when people run different parts it helps keep everyone in check, so this role was very satisfying for me."

(3) *Official BC course evaluations*. The end-of-semester official course evaluations are often challenging to extract meaning from, particularly in a course with so many moving parts as ours (because of the interface between MMW and the course registration system, students were asked to complete four separate evaluation forms). In addition to providing quantitative 1-5 Likert scale feedback on aspects of the course like organization, difficulty, and overall rating, the evaluations offered space for open-ended comments on course strengths, areas for improvement, and whether students would recommend the course to friends. Overall, the class rated MMW well above the BC average: 4.12 vs. 3.94 (out of 5). Beyond this general rating, two themes emerged:

(a) This was a challenging course, but the content that was challenging differed based on comfort with STEM. The Likert score for "The course was intellectually challenging" was above the university average: 4.65 vs. 4.45. Students also indicated that MMW required much more effort than other core classes, a response that many of the Complex Problems courses get in these evaluations. The critical feedback ranged from complaints about the amount of history reading ("Maybe by doing less history in the beginning of the course and more engineering concepts!") to the difficulty of the math and physics parts of the course ("I think that there should be less focus on doing physics and engineering problems and more on teaching us how to actually write memos and about safety precautions.") to feeling blindsided by the ethics curriculum ("I was expecting an engineering class, as it did fulfill a natural science core, but instead, I got an ethics course that happened to be about engineering.")

(b) Students enjoyed the sites of the most interdisciplinarity. Overall, the parts of the course that receive the most laudatory comments were the case studies. One student wrote, "I really enjoyed the case study portion of the class in the second half as well as the design conference project. It was definitely my most intellectually engaging course (the most energy from profs and students out of my schedule as well as the most work assigned)." Others advocated the entire course be given over to case studies, even at the expense of introductory lectures that provided the basis for our case study units: “I think this class should be mainly case study, as that portion of the class made me feel like I was an engineer making the modern world.”

To close, we take great pride in receiving feedback like the following, which a student offered in their course evaluation: “I think all students should take this course, actually, it really changed my perspective on the built world. As a STEM major, in particular, this course helped me to think deeper about how I can use my knowledge to improve the world.”

8. Conclusions

Designing, re-designing (because of COVID), teaching, and now reflecting on MMW has been a fulfilling experience for all three faculty members. Repeatedly throughout the semester we would remark to each other about how we wished a course like this was offered when we were undergraduates. We learned a tremendous amount from each other, as is so often the case with interdisciplinary co-taught classes. As early career faculty, we also relished this opportunity to develop a highly complex, introductory course. It challenged us to start from a place of clear learning objectives, justify the inclusion of each reading, each topic, and each assignment, and gain facility with a range of pedagogical techniques and classroom activities.

We believe that MMW was a resounding success. It exemplified the spirit of the BC Renewed Core and was an example of the strengths and weaknesses of a liberal arts engineering curriculum. That being said, there is clearly room for improvement as we prepare to teach the class again next year. For one, a transition back to primarily in-person instruction will require a wholesale redesign of the labs as well as a critical look at how lectures designed for remote learning will fare with the possibility of in-class interaction. Secondly, the success of the engineering case studies in not only demonstrating the virtue of interdisciplinary inquiry but also teaching real, generalizable content suggests that students who advocated for more case studies and fewer traditional lectures may get their wish. By interweaving lectures with case studies throughout the semester, we can likely achieve a good course rhythm without sacrificing much in the way of fundamental content. MMW will also need to be adapted for the incoming HCE students who will expect MMW to satisfy ABET engineering graduation requirements. On this point, we are unsure of the best way to proceed. We are reluctant to radically increase the technical difficulty of engineering content for the sake of the engineering students because of the success we had with our non-STEM students. On the other hand, we are not confident the course would provide the necessary three credits of engineering content that the HCE department needs to meet accreditation standards.

Our experience teaching first-year students in an interdisciplinary, project-based, and integrated humanities-engineering format offers some lessons for teaching upper-level engineering students. We found that the introductory levels of technical competence of our students limited our ability to fully investigate the historical contingency of engineering design. At more advanced levels, engineering students could, for example, substantially investigate the technical aspects of past engineering failure. Our Boeing 737 MAX case study described at a high level some of the control system failures that grounded that plane and killed 346 people; advanced engineering students could model the dynamics of the control system and or critique the engineering design decisions from a systems engineering perspective.

The ethical and reflective components of the class would be extremely valuable for upper class HCE students. In fact, based on our experience, we have proposed that all HCE students engage in structured, weekly reflection during their four years at BC. This would be an approach to engineering ethics education that is far different from the professional responsibility courses that often satisfy that requirement. As students advance through their degree programs, their perspective on responsibility and ethical engineering practice will likely change and evolve, especially as they work on internships or capstone projects.

Finally, the communications intensivity of MMW can only benefit more advanced engineering students. As our modern world continues to transform and expand in its sociotechnical complexity, we will need engineers who can communicate clearly and marshal critical arguments not only about the suitability of one engineering design decision over another but also about the social, political, environmental and ethical consequences of complex systems and technologies.

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Appendix A. Semester-at-a-glance

Week	Lecture	Lab	Reflection
1: 8/3	What is engineering?	What is design?	Introductions
2: 9/7	Science and engineering frameworks	Witnessing engineering history	Reflection as (social) practice
3: 9/14	Work & power	Lifting heavy things	St. Ignatius goes to Yosemite
4: 9/21	Building big	Building a bridge	Introducing modern moral philosophy
5: 9/28	Systems, feedback & control	Dynamics of complex systems simulation	"Professional" ethics with Professor Andrea Vicini
6: 10/5	Engineering the environment	Life cycle assessment & exam review	Justice and (/as) loyalty
7: 10/12	Midterm 1	Introduction to HCD project	Bodies in the built environment
8: 10/19	Designing for accessibility	HCD: Work the problem	Accessibility, inclusion, and politics
9: 10/26	ECS1: Chemical hazards & risks	HCD: Work the problem	Ethics & environmental justice
10: 11/2	ECS2: Aerospace & complexity	HCD: Quick prototype	Forum on the US presidential election
11: 11/9	ECS3: Climate adaptation & geoengineering	HCD: Prototype analysis	Slow violence
12: 11/16	ECS4: Automation & AI	HCD: Prototype v2	Conceptualizing justice in modern engineering
13: 11/23	Midterm 2	No labs - Thanksgiving	No reflection - Thanksgiving
14: 11/30	Engineering & pop culture	HCD: Prototype v2	Toward a theory of engineering justice
Design Conference on Sunday, Dec. 6th			
15: 12/7	Engineering the future	No lab	No reflection
Final paper due on Thursday, Dec. 17th			

HCD: Human-centered design | ECS: Engineering Case Study

Appendix B. Learning objectives for *Making the Modern World*

*These learning objectives have been designed to address two sets of curricular requirements: the BC Core Curriculum (indicated by **HIST II** and **NAT SCI**) and an engineering accreditation by the Accreditation Board for Engineering and Technology (**ABET Student Outcomes**). [ABET 2018]*

Historical knowledge
Students will learn major events and figures in the history of engineering and technology in a global perspective since 1800. Students will explore contemporary engineering case studies and develop critical and analytic skills in comprehending the complex relationship between engineers, the built environment, regulatory power, corporate structures, the application of engineering logic to larger problems, and the consequences these relationships have for everyday people. (**HIST II**)

Engineering knowledge
Students will learn what engineering is as a profession and a practice. Students will understand key scientific concepts like risk, unintended consequences, complexity, and systems; and become familiar with scientific laws and principles relevant to engineering analysis and design like force, energy, and transport. Through a tour of the major engineering fields (e.g. mechanical, civil, electrical, etc.), students will learn about engineering as a profession. (**NAT SCI**)

Historical methods
Students will gain facility in methods critical to the practice of history as a field of intellectual inquiry. This includes careful reading and analysis of historical sources; situating historical sources in their own time periods; and developing written arguments that connect historical sources to course themes and contemporary life. (**HIST II**)

Engineering methods
Students will learn foundations of engineering analysis and engineering design, including the application of appropriate mathematics and scientific principles to solve engineering problems (**ABET Student Outcome 1**). In engineering laboratory modules, students will learn to test materials, gather data, and critique design decisions to draw conclusions (**ABET Student Outcome 6**). In their human-centered engineering project, students will learn to elicit and synthesize a wide range of societal, stakeholder, and user needs and constraints to develop and refine a specific design solution (**ABET Student Outcome 2**). Students will learn to approach design creatively, with an open mind, and with a deep appreciation for the historical context of their problem and of their work. (**NAT SCI**)

Critical disciplinarity
Through course discussion and regular reflection, including engagement with guest speakers from a variety of disciplinary perspectives in and outside of the academy, students will learn to see the boundaries and limits of the disciplinary approaches taken in this complex problems class. Students will be given the opportunity to develop critiques of how expertise has been institutionalized in academic, governmental, and other hierarchical settings. Students will think

about how gender, race, class, and disability intersect in the construction of the engineering profession and in the impact of engineering knowledge. (**HIST II**, **NAT SCI**)

Communication
Students will learn how to communicate engineering history and practice in a variety of different formats to a range of audiences. Students will be able to explain how and why engineering decisions have been made in the past and the impact of those decisions on society. Students will write persuasively about engineering problems, explain scientific findings, and deliver creative oral presentations to the Boston College community. (**HIST II**, **NAT SCI**, **ABET Student Outcome 3**)

Leadership and responsibility
Students will learn the importance of humility in the design process and how engineering decisions can affect people's lives. In the human-centered engineering project, they will take on leadership roles in creating engineering solutions for the common good. Students will have the responsibility to conduct oral interviews, collaborate as a group, and gain skills in team management which will include establishing group dynamics, determining clear goals, and meeting design objectives. (**HIST II**, **NAT SCI**, **ABET Student Outcome 5**)

Ethics and engineering justice
As a class, we will develop an engineering justice approach that builds on engineering ethics and rules of professional responsibility and embeds them in a larger conversation about the ethical and moral implications of engineering as a profession and practice. Coursework and discussion will demonstrate the connections among engineering solutions and their specific global, economic, environmental, and societal contexts. Students will think about how engineering decisions have been made in the past and what ethical rules were followed or broken in historical engineering case studies. Students will apply these lessons to their own engineering design projects. (**HIST II**, **NAT SCI**, **ABET Student Outcome 4**)