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Full Paper: An integrated engineering/history/ethics first-year experience at Boston College

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1. Introduction to *Making the Modern World: Design, Ethics, and Engineering*

In the fall of 2020, a multidisciplinary teaching team at Boston College (BC) taught a new, first-year, interdisciplinary engineering course called *Making the Modern World: Design, Ethics, and Engineering* (MMW). This course combines history of science and technology studies, engineering design and fundamentals, and Jesuit-Catholic modes of ethical and moral inquiry. The goal of the course is to ground the practice and profession of engineering in its social, cultural, and historical contexts while offering students critical tools for ethically-informed engineering decision-making. Open to all first-year students, MMW satisfies Core requirements in history, natural science, and cultural diversity, and served as a pilot course for BC's new Department of Engineering which will enroll its first class in fall 2021. Seventy students enrolled in MMW, representing all the BC undergraduate schools and a number of different STEM and non-STEM majors.

As a designated "Complex Problems" course, MMW includes three pedagogical components: lectures, labs, and reflection sessions [1]. Lectures examine topics from major branches of engineering (civil, mechanical, and electrical) and the history of science and technology since 1800, with a focus on sociotechnical systems and their relationship to gender, race, disability, immigration, and nationality. Labs involve hands-on engineering modeling tasks as well as a multi-week human-centered design challenge focused on issues of access and accessibility on the BC campus. Weekly near-peer-led reflection sessions draw on BC's Jesuit-Catholic traditions of student formation in which small groups of students grapple with the ethical dimensions of engineering and consider how course content influences their personal and academic paths.

One of MMW's pedagogical challenges was how to create opportunities for students to take on the interdisciplinary learning outcomes of the course: namely, to think creatively across history, engineering, and ethics and to apply their learning to real world situations. Our solution was a series of interactive case studies to model the ways in which practicing and thinking about engineering connects with pressing social, environmental, regulatory, and political questions. Complementing conventional lectures, we conducted three major Engineering Case Studies (ECS) related to engineering failures, the contingency of engineering practices and decision-making, and the high-stakes relationship between making the modern world and risk, moral responsibility, and contemporary engineering cultures. This paper provides an overview of our ECS model, focusing on the learning outcomes and pedagogical methods associated with our Boeing 737 MAX case study.

2. MMW Engineering Case Study Approach

In the second half of the semester, MMW adopted a contemporary engineering case study approach to encourage students to integrate the various threads of the course—the history of science and technology since 1800 and basic engineering fundamentals from lecture; ethical and moral inquiry related to engineering problems from reflection; and elements of design and implementation from lab—and to observe how real-world engineering problems require a high degree of synthetic thinking.

We completed three Engineering Case Studies: ECS#1 on chemical plant disasters and spills, ECS#2 on the Boeing 737 MAX, and ECS#3 on the emerging challenges of geoengineering. We selected these cases to add additional depth to themes introduced during lecture in the first half of the course and to introduce students to engineering domains which were not explored elsewhere in the curriculum: chemical, aeronautical, and environmental engineering. In addition, each ECS represented a different configuration of stakeholders, time scales (past disaster, present conflict, and future challenge), and spatial and organizational scales. The three topics are all either themselves or closely associated with disaster or tragedy. Although not representative of the vast majority of engineering failure, the salience of our topics made it easier for first-year, non-engineering students to disentangle the complexities of real-world, sociotechnical problems.

We designed each ECS to offer students different methods of participation and engagement. In ECS#1, students worked in small groups to analyze an assigned chemical spill or disaster (the Love Canal toxic waste site, the 2005 Texas City refinery explosion, and the 2010 Deepwater Horizon oil spill) and then present their findings in the form of a group presentation to the class that had to address historical, technical, and ethical dimensions of their topic. In ECS#2, students role played stakeholders related to the Boeing 737 MAX disaster and debated their decisions and responsibilities in cross-stakeholder discussion sections. In ECS#3, students participated in open discussions about solar geoengineering and made policy recommendations. The unique challenges of teaching during the COVID-19 pandemic contributed to our decision to use ECS and shaped their formats. Lectures were held synchronously over Zoom, which made student engagement a priority. Designing interactive, student-led exercises that involved out-of-class group work and in-class peer teaching provided one tangible strategy for changing up the rhythm of the course and taking a break from remote lectures.

3. Engineering Case Study: Boeing 737 MAX

3.1. Overview: Pedagogical Approach to the Boeing 737 MAX Case Study

For ECS#2, our goal was for students to understand the social, cultural, technical, and political complexity of the Boeing 737 MAX tragedies of 2018–19 (case study documentation available upon request). This case covered three 75-minute lecture periods. In the first session, students completed background reading about the Boeing 737 MAX and instructors provided lectures about the history of Boeing as a corporation and changes in aviation regulation; airplane design and systems engineering; and the moral and ethical frameworks for whistleblowing. Students were then assigned to small groups to take on one of five stakeholder roles: pilots, FAA regulators, Boeing engineers, Boeing executives, and family members of those who died in the Lion Air Flight 610 and Ethiopian Airlines Flight 302 accidents. Each group received a packet of materials related to the specific perspective of their stakeholders, their role in the disaster, and their place in the broader sociotechnical system of air travel. In the second session, students met with their stakeholder groups (e.g. pilots met with other pilots and Boeing executives met with other executives) to clarify their perspectives and to write a two-page position memo that served as the basis for the next stage of the case study. Stakeholder groups reconvened in the third class period for a real-time debate. Instructors organized small cross-stakeholder groups of students and moderated discussions with the goal of understanding and demonstrating the complexity of the Boeing 737 MAX tragedies as they related to engineering design, risk, decision-making, workplace culture, and responsibility to the public.

3.2. ECS#2 Engineering Learning Objectives

The engineering learning goals for the Boeing 737 MAX case study centered on issues of tradeoffs and complexity in engineering design. The case built on engineering concepts learned earlier in the course, including forces and control systems, and introduced multiple new concepts, including general topics like systems engineering as well as topics more specific to this case like aerodynamics. Before being able to understand tradeoffs in design, students had to first become familiar with the technical narrative of the Boeing 737 MAX story. What was the design objective? What were the design constraints? What were the outcomes? Most of our first-year students were learning about the basics of flight for the first time, which necessitated a somewhat simplified technical narrative, summarized in the following paragraph.

The central design tension that existed in the MAX case stemmed from Boeing's desire to increase the fuel efficiency of their best-selling 737 aircraft model in order to compete with Airbus's A320neo [2]. Fuel costs can exceed 20% of an airline's operating expenses [3], so even a small improvement in fuel economy can justify a redesign. In the case of the Boeing 737 MAX, most of the efficiency gains came from the adoption of a larger, high-bypass engine, which could not fit below the wings, where previous engines had been located. The larger engine necessitated some other changes, but to avoid redesigning the entire airplane, Boeing engineers opted to place the engines in front of and slightly above the wings. Changing the position of the engines affected the forces experienced by the airplane, and led to the plane's angle of attack (AoA) becoming too steep during takeoff, threatening a stall. Boeing's solution to this problem was a software system linked to the AoA sensors called the Maneuvering Characteristics Augmentation System (MCAS). The behavior of the plane during takeoff as well as the existence and function of MCAS were not widely revealed by Boeing. The two crashes were caused in part by faulty AoA sensors leading MCAS to put the plane into a dive against the pilots' wishes.

Even this simplified narrative contains a large number of technical concepts for students to learn: forces acting on an aircraft, lift and angle of attack, control surfaces, energy efficiency, turbofan engine construction and bypass ratios, fly-by-wire, closed-loop control systems, and others. Once they had a handle on some of these concepts, students could begin to understand design tradeoffs facing Boeing engineers and the cascade of dependencies that arise from any one design or engineering decision. The case study also reveals the real world tensions that engineers experience when working in a particular context. Design objectives and available paths were demarcated in large part by the competitive environment of the commercial aerospace industry. Finally, and tragically in this case, decisions about the implementation and use of particular technical systems are taken out of the hands of the design engineers, adding new pressure to ensure that designs are robust and resilient.

3.3. ECS#2 History Learning Objectives

One history learning objective in our Boeing 737 MAX case study was for students to be able to situate technical and regulatory decisions about engineering design within the broader landscape of risk, responsibility, and complexity in the modern aviation industry. A central aspect of highly complex sociotechnical systems is the possibility of what the sociologist Charles Perrow has called "normal accidents," or the risk that trivial errors can magnify with catastrophic effects [4]. Due to the innate complexity of these technologies, engineers, safety representatives, corporate structures, and users often have partial perspectives on the system as a whole [5]. For this assignment, we wanted students to inhabit a specific stakeholder role in the Boeing 737 MAX disaster to illustrate how these partial perspectives develop and have significant consequences in engineering history.

Each group of students received a carefully curated set of materials that they used to reconstruct the perspective of their assigned stakeholders. Students playing Boeing engineers, for instance, watched *CBS This Morning* reporting on Boeing whistleblowers, read articles from the *Seattle Times* and *New York Times* about Boeing workplace culture, and combed through internal Boeing messages about the 737 MAX's recurring problems. To put Boeing into historical context, they also read a chapter of Polly Reed Myers's 2005 book *Capitalist Family Values: Gender, Work, and Corporate Culture at Boeing* [6], which links changes in Boeing's organization and workplace culture with engineers' reports of their technical concerns being overlooked by management. Students playing the family members of crash victims watched family members testify in front of a 2019 House Transportation subcommittee hearing on the crash, watched *BBC* interviews with family members, and read *NPR* and *New York Times* investigations into the personal consequences of these tragedies. To put this perspective into a legal and moral context, stakeholders in this group also read the aviation law expert Anna Konert's 2019 article "Aviation Accidents Involving Boeing 737 Max: Legal Consequences" in *Ius Novum* [7]. The complete list of materials for all stakeholder groups is available in case study documentation upon request.

A second history learning objective was for students to sharpen their skills in historical reading, analysis, and writing. Reading and understanding the significance of such a wide array of primary sources is a critical skill associated with historical argumentation, the theme of the stakeholder memo assignment. The memo required stakeholder groups to clarify the perspectives and motivations of their assigned stakeholders and to articulate their particular roles in the Boeing 737 MAX disaster. It also asked them to take a step back and explain how they conceptualized levels of acceptable risk, influenced decision-making about the Boeing 737 MAX, and thought about their ethical responsibilities and/or moral standing in the disaster. Part of historical argumentation is understanding perspectives different from one's own. Therefore, an important aspect of the stakeholder memo—and the jumping off point for our debate in class—was how students' stakeholders might view other stakeholders in this larger system. How did pilots, for instance, think about Boeing executives or FAA regulators? Where did they see overlap in perspectives or vast differences in motivations and experiences? Successful stakeholder memos tackled these issues directly, rigorously cited evidence from their primary sources, and offered a grounded argument about aviation and complexity.

3.4. ECS#2 Ethics and Reflection Learning Objectives

The Boeing 737 MAX case provided an opportunity to introduce students to the descriptive basis of virtue ethics. For virtue ethics, the question of what makes something moral does not solely turn on what we are obligated to do, but what kind of person performs a moral sort of action [8]. One expression of virtue in modern engineering is the practice of whistleblowing, which requires deploying the virtue of courage. While modern engineering ethics gives us some tools for considering when whistleblowing is warranted [9], which our students considered, we wanted our students to consider to go beyond this sense of professional ethics to consider what *kind of* *person* chooses to blow the whistle on their company or organization, and in the process, help to stave off disaster.

We asked students to think about what it might be like to work for as large and as established a company as Boeing and to consider the question: What can just one person do to change sprawling organizational problems? In this sense, whistleblowing takes courage. Specifically, it takes courage to cut against the grain of institutional inertia, whether that is in speaking up about oversights in aviation design at Boeing, or speaking up about other flaws woven into the modern world's engineering fabric. Using the Boeing 737 MAX case study as an example, students can take a step back to reflect on how ethically speaking *nothing* in the world is fixed. In the context of MMW, the things in our daily lives—from the products we rely on to the engineering and organizational systems that make modern life possible—have been designed and conditioned by the needs and interests of real people. The things and systems that make up our world tell a story about their users. Those things are always being tested, scrutinized, and revised. In MMW, we aim to argue that we, in fact, continually make and re-make our world.

In MMW, the aim of ethical reflection was to go beyond reconceiving of the world in this way to invite students to reconceive of themselves. We wanted students to consider how *they* were changing over the course of the semester; how *they* were encountering the world anew. Just like the objects and ideas that constitute the modern world, we as individuals are continually in process; we are continually being made and re-made. Providing space to reflect on this process is a hallmark of BC's Jesuit-Catholic-style education. Ultimately, the ethical challenge for our students was not only that they consider how the world can be made better and more just, but also to remain critical of whether *they themselves* are being made into the sort of people who are well-suited to transform the world we share for the better.

3.5. ECS#2 Outcomes in Student Engagement

Feedback about MMW in the Fall 2020 BC course evaluations demonstrated that students found the engineering case studies to be some of the most tangible ways in which they engaged with interdisciplinarity and engineering. Three students communicated that the case studies crystallized their learning in the course:

- Student #1: "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."
- Student #2: "The case studies that we did at the end of the course were super interesting and really helped to piece together the major themes of the course."
- Student #3: "Working on case studies helped solidify my knowledge of key topics, so more of those would help improve the course. It also avoids big lectures which were difficult over Zoom."

In addition, two students mentioned the Boeing 737 MAX engineering case study as one that stood out and one that, for one student, offered the potential for a more intensive engagement with Jesuit-Catholic ethical modalities:

- Student #4: "I think the strengths of this course were some of the creative assignments that the instructors came up with, such as the Boeing 737 MAX activity, because it made me interested in the material."
- Student #5: "I really liked the ethical aspect of this course and I really think it can be incorporated even more. Dedicating [a] 15 minute lecture once a week on the ethical dimension of the course themes could really help us grasp the Jesuit and ethical dimensions of engineering. Especially for the Boeing case study I think an in depth lecture on ethics and Catholic Social Teaching perspective would have been very powerful."

4. Conclusion

MMW's engineering case studies provided students the opportunity to see engineering's real-world consequences. They also gave students the chance to insert themselves into a meaningful reflection space so as to consider how *they* might respond to the nuanced and ethically ambiguous challenges of contemporary engineering. We aimed for students' interdisciplinary knowledge of the modern world to be fluid enough to encounter the complex situations emerging across modern engineering's vast landscape. To see our students effectively and flexibly deploying the methods and approaches of modern engineering learned in class to the idiosyncratic dimensions of engineering case studies was especially gratifying to us as faculty. We will be teaching MMW again in spring 2022, and lessons learned from our first ECS experience will be useful in improving the student experience in the future, especially as BC's new Department of Engineering begins its operation.

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