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Title: Covid-19 Pandemic Reveals Challenges in Engineering Ethics Education

Authors: Luan M. Nguyen, Cristina Poleacovschi, Kasey M. Faust, Kate Padgett-Walsh, Scott G. Feinstein, Bobby Vaziri, Michaela LaPatin, Cassandra J. Rutherford

Author Information

Affiliations

Iowa State University, Department of Civil, Construction, and Environmental Engineering, Ames, Iowa, USA

Luan M. Nguyen, nguyenl@iastate.edu ORCID: 0000-0002-3183-4804

Cristina Poleacovschi, poleacov@iastate.edu

Cassandra J. Rutherford, cassier@iastate.edu

Iowa State University, Department of Philosophy and Religious Studies, Ames, Iowa, USA

Kate Padgett-Walsh, kpadwa@iastate.edu

Iowa State University, Department of Political Science, Ames, Iowa, USA

Scott G. Feinstein, sgfeinst@iastate.edu

The University of Texas at Austin, Department of Civil, Architectural and Environmental Engineering, Austin, Texas, USA

Kasey M. Faust, faustk@utexas.edu ORCID: 0000-0001-7986-4757

Michaela LaPatin, mlapatin@utexas.edu

James Madison University, Department of Computer Information Systems and Business Analytics, Harrisonburg, Virginia, USA

Bobby Vaziri, vaziribx@jmu.edu

Corresponding Author

Correspondence to Luan M. Nguyen, nguyenl@iastate.edu

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The authors declare no conflicts of interest.

Availability of data and material

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COVID-19 Pandemic Reveals Challenges in Engineering Ethics Education

Abstract

Engineering ethics can be divided into three spheres, namely the technical, the professional, and the social. Ideally, engineering students should engage with all three spheres of ethics, but the literature suggests that this might not be the case. How do engineering students engage with the three spheres of engineering ethics during a global pandemic? The COVID-19 pandemic represents a dramatic and ongoing real-world challenge affecting many students personally. This research explores the extent to which engineering students engage with each sphere of engineering ethics by examining how engineering students understand their roles in addressing the pandemic and its implications. We conducted a survey with undergraduate engineering students (n=410) at a university in the Midwest. Qualitative analysis suggests that there was low engagement with both social ethics and professional ethics among respondents, while there was higher engagement with technical ethics. Quantitative analysis suggests that non-conservative engineering students from less wealthy families in our study show higher engagement with technical ethics as compared to conservative engineering students from less wealthy families. Non-conservative engineering students from wealthy families, however, show similar engagement with technical ethics as compared to conservative engineering students from wealthy families. In addition, engineering students from both wealthy and less wealthy families show higher engagement with technical ethics if they reside in urban areas as compared to engineering students from both wealthy and less wealthy families in non-urban areas. In addition, the difference in terms of engagement with technical ethics between non-urban engineering students from less wealthy families and urban engineering students from less wealthy families is larger than the difference in terms of engagement with technical ethics between non-urban engineering students from wealthy families and urban engineering students from wealthy families. Further investigation will be

needed to explain these findings. However, qualitative results confirm that, despite the potential for the pandemic to encourage engagement with all three spheres of ethics, there continues to be low engagement with ethics beyond the technical level.

Keywords

Engineering Ethics Education, Technical Ethics, Professional Ethics, Social Ethics, COVID-19

Introduction

In the U.S., there have been many notable changes in engineering education in recent years (Herkert, 2010). In particular, engineering educators have shifted towards teaching engineering students to be both ethically and technically competent (Herkert, 2010). Nevertheless, the current focus on ethics within engineering education is still quite narrow (Conlon & Zandvoort, 2011; Gunckel & Tolbert, 2018). For instance, engineering students are commonly taught to apply ethical codes when making engineering and professional decisions (Herkert, 2001; Colby & Sullivan; 2008; Bairaktarova & Woodcock, 2015). However, ethical codes primarily concern technical ethics, e.g., promoting safety and efficiency, and professional ethics, e.g., acting as faithful agents or trustees for clients (NSPE, 2021), with little regard to social ethics, e.g. addressing social inequalities or producing socially just designs (Canney & Bielefeldt, 2015a, 2015b; Dombrowski, 2017).

We define technical ethics as the sphere of ethics pertaining to how engineering products are designed and produced (Roddis, 1993; McLean, 1993; Vanderburg, 1995; Pantazidou & Nair, 1999; Stephan, 2001; Herkert, 2001; Fleischmann, 2004; Bucciarelli, 2008; Doing, 2010; Wang, 2017; Atak & Şik, 2019). Ethical design and production require promoting outcomes such as safety, quality, and efficiency throughout the technical processes of design and production. We define professional ethics as the sphere of ethics pertaining to how engineers interact with individuals and groups as part of their work (Roddis, 1993; Ladd, 1980; McLean, 1993; Devon, 1999; Herkert, 2001; Fleischmann, 2004; Bucciarelli, 2008; Stappenbelt, 2012; Farahani & Farahani, 2014; Atak & Şik, 2019; Snieder & Zhu, 2020). Ethical conduct in the profession requires treating clients, suppliers, and other engineers in ways that conform to professional standards such as integrity, conflicts of interest, non-discrimination, and equity. (McLean, 1993; Herkert, 2001; Bucciarelli, 2008). Finally, we define social ethics as the sphere of ethics pertaining to societal challenges and the potential impacts of engineering work upon society. (McLean, 1993; Vanderburg, 1995; Pantazidou & Nair, 1999; Devon, 1999; Herkert, 2001; Amadie, 2004; Pritchard & Baillie, 2006; Conlon, 2007; Hersh, 2015; Wang, 2017; Niles et al., 2020; Børsen et al., 2021). Ethical engagement with the social impacts of engineering requires identifying and responding to the social and political significance of engineering work in order to promote the well-being of members of society (McLean, 1993; Devon, 1999; Herkert, 2001). **Figure 1** illustrates these three spheres of engineering ethics. The distinctions between these spheres of ethics are constructed by the authors as a synthesis of different literature sources.

Engineering students should ideally engage with all three spheres of ethics (McLean, 1993; Herkert, 2001, 2002); without engagement with all three of these interconnected spheres of ethics, engineering designs and products could be inadequate or inequitable in terms of only serving a subset of the general population. For example, Herkert (2001, 2002) suggested that engineering students need courses focusing on both microethics and macroethics, encompassing all three spheres of ethics (technical, professional, and social). Technical and professional ethics, standardized in codes of ethics, help members of the engineering profession solve difficult ethical dilemmas (e.g., lack of accountability by collaborators or taking others' ideas without giving them credit;), which often arise during the production of engineering products and collaboration with other relevant professionals (Veach, 2006). In addition, technical ethics and professional ethics are necessary for the success and advancement of the engineering profession because they each deal with a different aspect of engineering practice, such as product quality or safety and harmonious interactions between engineers, clients, and others (Herkert, 2001). However, while engineering programs successfully focus on technical (Lynch & Kline, 2000; Herkert, 2001; Atak & Şik, 2019) and professional (Colby & Sullivan, 2008; Basart & Serra, 2013; Bairaktarova & Woodcock, 2015) ethics, there is increasing evidence that many engineering students and engineers do not sufficiently engage with social ethics (Cech, 2014; Bairaktarova & Woodcock, 2015; Bairaktarova & Woodcock, 2017). This lack of engagement with social ethics could have significant consequences because engineering decisions and products might perpetuate unequal social structures and practices for disadvantaged and minoritized groups in engineering education and beyond (Faulkner, 2000; Cech, 2014). For example, failing to use images of non-White faces to train face detection algorithms (Lohr, 2018) infamously resulted in Google Photos identifying Black faces as gorillas (Breland 2017; Vincent 2018). This example shows how a lack of concern for the impacts of engineering products on society can perpetuate racism and discrimination. Engineers are skilled at designing and producing responses to needs in the real world, but often without awareness of the social and structural implications of their work; in this example, awareness of how ignoring racial diversity can result in products that perpetuate racism. This example illustrates why engineering students must learn to move beyond formulaic ethical codes in order to adopt an ethically more holistic approach to engineering practice, one that takes into consideration the structural consequences, such as racism and sexism, of their decisions.

Building upon this idea, this paper contributes to understanding how engineering students engage with each sphere of ethics by considering their responses to the COVID-19 pandemic. Given that the COVID-19 pandemic was highly disruptive to society and it heightened sociopolitical concerns, such as racial and gender inequalities (Barabino, 2021), we explore the extent to which students engage with each sphere of engineering ethics. This project draws upon and revitalizes the technical, professional, and social ethics framework initially proposed by McLean (1993), according to which each sphere of ethics addresses a different aspect of engineering practice to ensure the safety and well-being for everyone including clients, other stakeholders, different communities, and the engineers themselves. We see a need to revitalize this framework because each sphere of ethics described in this framework deals with a different aspect of engineering practice to provide a checklist or general guidance for engineers during the design and production process to prevent inadequate and inequitable outcomes. In addition, this guidance could help engineers to better comply with liability law. Thus, we ask, first: "How do engineering students engage with the three spheres of engineering ethics during a pandemic such as COVID-19?" We expect that students are not engaged with the three spheres of ethics equally based on previous research showing that engineering students lack training in social ethics in particular (Faulkner, 2000; Herkert, 2001; Riley, 2008; Cech, 2014). However, COVID-19 pandemic has heightened social challenges such as environmental degradation, racism, discrimination, and socioeconomic inequalities (Barabino, 2021). We, therefore, expect students to be aware of these social challenges. Additionally, we expect that students from different demographic groups might show different engagement with each sphere of ethics differently. For example, studies have shown that ethical reasoning might relate to socio-demographic characteristics (Choudhury et al., 2012; Miles, 2014). We expect that demographic factors, such as political views, geography, parental education, and family income may impact students' frequency of engagement with each sphere of ethics. Thus, we ask a second research question, “Do respondent variables such as political view, geography, parent education, and family income associate with students’ engagement with each sphere of ethics?” By understanding which demographic groups associate with which spheres of ethics, this study contributes to identifying how to shape the classroom environment, as well as which spheres of ethics need more attention and whom such changes might benefit.

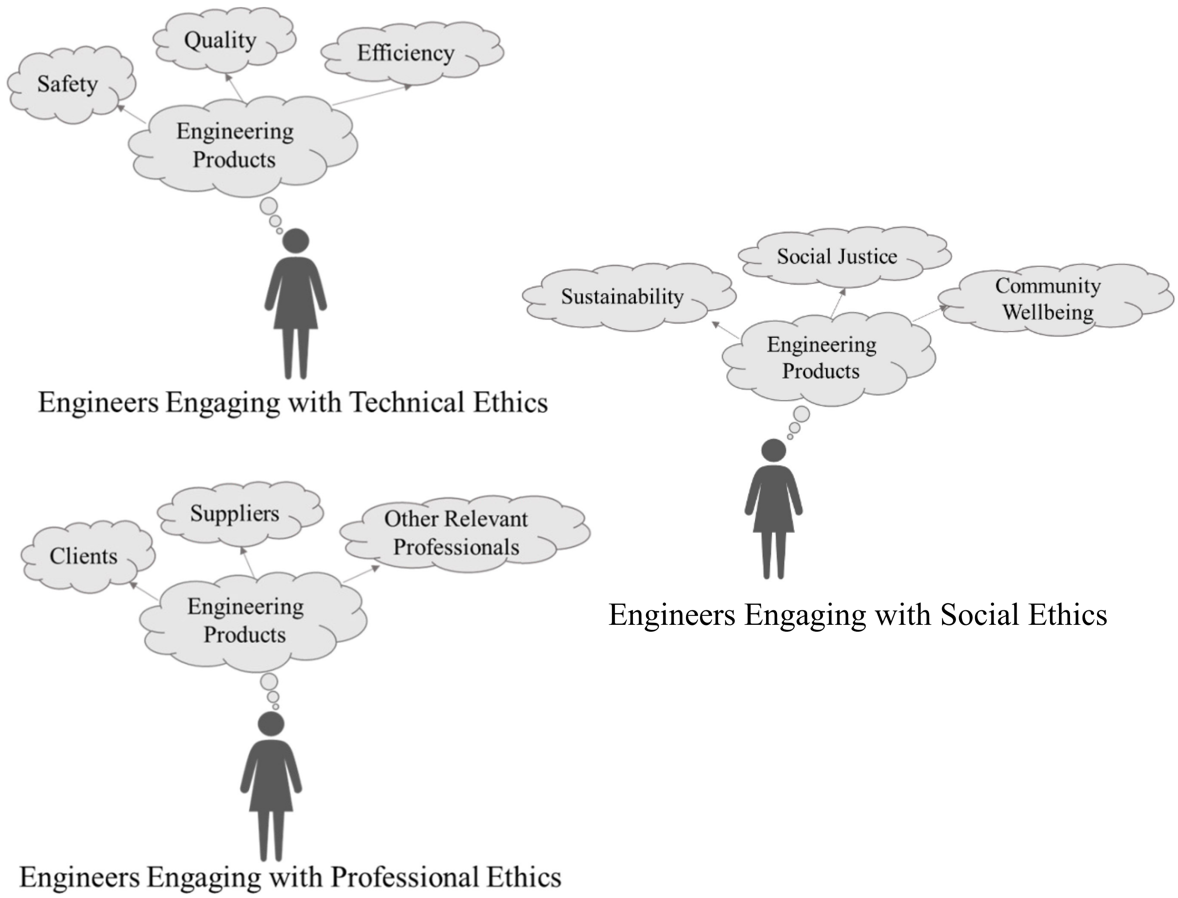


Figure 1: Illustration of the three spheres of engineering ethics (technical, professional, and social ethics)

LITERATURE REVIEW

Every engineering project entails numerous decisions that incorporate aspects of technical, professional, and social ethics. Consider the Golden Gate Bridge as an example (Golden Gate Bridge Highway and Transportation District, 2006; Hoena, 2014). Designed to connect San Francisco to Marin County, the bridge spans nearly two miles where the San

Francisco Bay meets the Pacific Ocean. The construction of the bridge, completed in 1933, was complicated, due to factors such as the scope, location, physical environment, safety, cost, and context. The design was changed to a suspension bridge after the initial design—a hybrid of traditional trusses and suspension cables—was considered visually unappealing. The construction of this project was dangerous and among the first of its kind. Yet, there was initially little concern for safety and safety measures were only implemented after the deaths of many construction workers. The implementation of such safety measures to protect construction workers provides an illustration of the need for technical ethics in engineering practice. In addition, disputes between financers, engineers, tradesmen, and the general public ensued over the duration of construction. Prior to construction, civic leaders and prominent businesses were hesitant or even resistant to building the bridge because of fear that it would impede shipping and take away from the natural beauty of the area. Cooperation between engineering professionals and these stakeholders during the construction of the bridge provides an illustration of the need for professional ethics in engineering practice. Finally, in both planning and construction phases, the project was also culturally, environmentally, politically, and socially complex. Opponents of the bridge, including Ansel Adams and the Sierra Club, feared that it would ruin the beauty of the area and lead to environmental degradation. To address their protests, engineers worked to communicate reasons for constructing the bridge and to address concerns from the community such as the aesthetic beauty of the Gate, the increase in property tax for residents near the bridge, or local shippers' worry that the construction of the bridge would negatively affect their businesses. The engineers took these concerns into consideration, which eventually resulted in strong public support for the bridge. This responsiveness to objections and community concerns provides an illustration of the need for social ethics in engineering practice.

The following section provide a brief review of the literature that helped us formulate this framework. We identified these literatures through searching for the following keywords: microethics and macroethics. Then, after finding some initial literature on microethics and macroethics, we expanded our search using the following keywords: technical ethics, professional ethics, and social ethics. We then synthesized and simplified the literature to formulate this framework.

Technical Ethics

Technical ethics concerns making technical decisions such as the selection of component materials and fabrication methods, while weighing risk factors in order to achieve values such as quality, safety, and efficiency (Roddis, 1993; McLean, 1993; Vanderburg, 1995; Pantazidou & Nair, 1999; Fleischmann, 2004; Bucciarelli, 2008; Wang, 2017). This is the sphere of ethics that most engineers are familiar with because it concerns engineers making technical decisions regarding the engineering products they are working on (Roddis, 1993; McLean, 1993; Vanderburg, 1995; Herkert, 2001; Bucciarelli, 2008; Doing, 2010; Wang, 2017; Atak & Şik, 2019). The principles of technical ethics are best laid out in the various codes and standards of each technical discipline (McLean, 1993). For example, the various building codes are used to guarantee the quality of civil constructions, but equivalent standards exist for other disciplines (McLean, 1993). However, these standards are not dictated by the limits of feasibility; instead, they represent a codification of the accumulated experience of the engineering profession (McLean, 1993). Technical ethics is closely connected to technical knowledge (Atak & Şik, 2019), which represents the specialized knowledge and expertise (e.g. understanding of codes, structural design) needed to accomplish complex actions, tasks, and processes relating to engineering technology. For instance, choosing safe and non-hazardous materials for designing toys is an ethical decision that requires technical knowledge of materials. Thus, to sustain their understanding of technical ethics, engineers must continuously keep up to date with research and developments in their areas of expertise. For example, consistently updating safety codes and conducting quality control inspections are ways to ensure technical ethics is being considered.

Current literature suggests that an over-focus on technical ethics relative to the other two spheres of ethics (professional and social ethics) in engineering education is problematic because it leads to engineers overlooking the impacts of their products on the community (Stappenbelt, 2013; Cech, 2014; Bairaktarova & Woodcock, 2017). In addition, an understanding of technical ethics does not always result in ethical behavior (Harding et al., 2004; Stappenbelt, 2013; Bairaktarova & Woodcock, 2017). Many ethical dilemmas are difficult to resolve at the level of technical ethics alone (Conlon & Zandvoort, 2011), since technical decisions are naturally enmeshed within broader professional and societal considerations. For instance, safety incidents on a construction project site can be prevented through technical ethics (e.g. provide proper safety gear, implement technology that can identify and avoid hazards) but will not be sufficient to address all safety concerns if the existing safety practices are racist in that they do not provide the proper tools and education to non-white workers (The Center for Popular Democracy, 2013). Indeed, history shows that racism has been responsible for reduced safety at some worksites, such as in the case of the Transcontinental Railroad, where a significantly higher number of workers of Asian heritage died compare to that of white workers (National Park Service, 2021). These workers were provided with fewer resources for ensuring safety than their white counterparts, as well as lower wages, at least initially. This example shows that an understanding of technical ethics is not sufficient for responding to ethical dilemmas and responding to real social problems.

Professional Ethics

Professional ethics concerns standards of ethical behaviors expected from professional engineers when it comes to working with clients, suppliers, and other engineers (Roddis, 1993; Ladd, 1980; McLean, 1993; Davis, 2001; Fleischmann, 2004; Bucciarelli, 2008; Stappenbelt, 2012; Farahani & Farahani, 2014; Atak & Şik, 2019; Snieder & Zhu, 2020). These standards are guidelines, driven primarily by industry norms to establish rules for ethical collaboration and cooperation between engineers and others. For instance, engineers have obligations to act with integrity and act in good faith to meet their clients' needs. As such, professional ethics protects the viability of the engineering profession as well as the reputation of individual engineers.

The current literature on professional ethics focuses on ethical codes and the role of professional societies (e.g. NSPE, ASCE, IEEE) in establishing these codes (Mitcham, 2008; NSPE, 2021) that engineers are expected to follow once they enter the work field (Colby & Sullivan, 2008). These codes act as a reference point for engineers when they encounter a difficult ethical situation, and they clearly lay out guidelines for ethical behavior. Professional engineering societies contribute to making sure that professional ethics are upheld by engineering professionals and students through the establishment of Codes of Ethics (Mitcham, 2008; Bucciarelli, 2008; Herkert, 2010). However, while engineering professionals and students are expected to be familiar with professional standards of behaviors through these codes (Mitcham, 2008; Bucciarelli, 2008; Herkert, 2010), current teaching methodologies and requirements are not sufficient to enhance students' understanding of professional ethics or ethical codes.

Most students are not required to take dedicated ethics courses, leading to students having limited exposure to ethical codes and expected standards of behavior (Mitcham, 2008; Colby & Sullivan, 2008; Bairaktarova & Woodcock, 2017). Additionally, these courses usually adopt a case-study approach typically detailing breaches of professional codes of conduct (Veach, 2006; Stappenbelt, 2013). Even though the case-study approach is useful, it has limitations, such as cases being conceived too narrowly and technically (Veach, 2006; Stappenbelt, 2013). For example, one study found that when students discussed the Chernobyl disaster as a case study, their ethical understanding did not significantly improve after the discussion (Wilson, 2011). Such case studies can present a narrow and simplified view of ethics that students may struggle to integrate with their broader experience as engineers (Herkert, 2001). The case study approach can thus be ineffective for training students to understand professional ethics because it turns the focus on technical mistakes, such as a flawed reactor design (Herkert, 2001; Wilson, 2013). This means that students ignore human behaviors and norms, instead focusing on the technical errors of the disaster, which might lead to students thinking they can just blame irresponsible or reckless decisions on technical errors. Finally, case studies are often presented in a very abstract and distanced manner, as historical events that only occurred in the past, rather than as potentially still relevant today (Bairaktarova & Woodcock, 2017).

Social Ethics

Social ethics applies engineering expertise and practice to address social challenges (McLean, 1993; Vanderburg, 1995; Pantazidou and Nair, 1999; Devon, 1999; Herkert, 2001; Amadie, 2004; Pritchard & Baillie, 2006; Conlon, 2007; Hersh, 2015; Wang, 2017; Niles et al., 2020; Børsen et al., 2021). Social ethics identifies and addresses the social and political dimensions of engineering projects by shifting the focus to the larger societal impacts of the technical and professional decisions made by engineers (McLean, 1993; Vanderburg, 1995; Devon, 1999; Herkert, 2001; Conlon, 2007; Zandvoort, 2008; Niles et al., 2020). For instance, some new technologies have widened technology gaps rather than narrowing them. Consider the case of global health technologies, where patent laws and the interests of engineering companies in developing medical equipment can have the effect of raising the cost of health care. Social ethics considers how underlying interests and values are promoted within particular research agendas, as well as the relation of new technologies to challenges of global justice (Haker, 2013).

However, previous literature has emphasized a lack of focus on engineering students' engagement with social ethics. Avoidance of sociopolitical topics is ubiquitous in engineering (Bielefeldt & Canney, 2014; Gunckel & Tolbert, 2018) and engineers often struggle to justify the value of nontechnical work and its relevance to engineering (Cech, 2014). Engineers also regard the issues that arise within social ethics as ambiguous (Niles et al., 2020) because of their wider scope (see **Figure 1**). In addition, social ethics is complex in that it examines sociopolitical structures and processes, i.e., it examines social relations, their structure, and the norms and policies that characterize them (Devon & van de Poel, 2004). Consider the Golden Gate Bridge example above. Public support for the bridge varied widely; in 1930, 2300 lawsuits were pending against it. One notable opponent was the Southern Pacific Railroad, which owned 51% of the ferry company that transported people across the Golden Gate Strait. Southern Pacific feared that the bridge would disrupt their ferry business. Further, local unions wanted guarantees that local workers would be favored for construction jobs. However, notable proponents included automobile companies who thought construction of the bridge would increase auto sales (Galloway Collection 2006; Golden Gate Bridge, Highway and Transportation District, 2006; Weingroff, 2017). The engineers working on this project needed to engage with all of these concerns in order to proceed in an ethical manner and gain public support; for example, they painted the bridge "international orange" to make it more visible to ships and ferries.

Studies have suggested that incorporating social ethics in the engineering ethics curriculum requires reform and innovation of both content and pedagogy (Herkert, 2004; Riley, 2008). The content needs to change because topics within social ethics are constantly changing, presenting engineers with new and different problems (Riley, 2008). The pedagogy also needs to change because thinking in terms of social ethics requires a large range of knowledge outside of engineering (Riley, 2008). For example, previous literature has proposed various approaches and terms for introducing social ethics to engineering students, such as the terms ‘political dimension’, ‘legal and regulatory dimension’, ‘environmental dimension’, and ‘social dimension’ (Didier & Huet, 2008; Riley & Lambrinidou, 2015; Bielefeldt et al., 2021). The literature also includes discussion of service learning approaches (Bielefeldt & Canney, 2014; Berg et al., 2016; Bielefeldt et al., 2021). Additionally, Bucciarelli (2008), Conlon (2008), and Drake et al. (2021) suggest that considerations of the organizational, social, legal, and political contexts in which engineers operate need to be included as part of engineering problem-solving and teaching in order to prepare graduates adequately for engaging with social ethics.

Comparing the Three Spheres of Ethics

This framework identifies and distinguishes three ethical dimensions of engineering work. One strength of the framework is thus that it allows us to see more clearly how individual engineers understand the ethical dimensions of their own practice. One engineer might excel at professional ethics, for instance, but be more minimally engaged with social ethics. Another might be highly interested in social ethics, but place less emphasis on professional ethics. The framework thus allows us to examine how engineers and engineering students understand their own work, rather than treating all of engineering ethics as homogenous. A second strength of the framework is that it allows us to study how individuals think about ethics within engineering, without assuming any particular values or principles. Rather than specifying a utilitarian or virtue theoretic approach, for instance, or stakeholder theory, the framework is consistent with a wide variety of theories of ethics. It is focused on the kinds of concerns and questions that arise within the practice of engineering and how actual engineers and engineering students understand them. In the process of developing technical solutions to challenges, engineers encounter ethical questions about the nature of those technical solutions, e.g. quality and efficiency. In the process of interacting with clients and other professionals, engineers encounter ethical questions about how to treat one another, e.g. with honesty and respect. And throughout engineering practices, engineers encounter ethical questions about broader and long-term impacts of their work, e.g. upon local communities and the environment. The three spheres thus can best be understood as different ethical domains that naturally arise within engineering work. Most obviously, engineers are taught to focus on technical excellence, i.e. designing and creating technically strong products. Values such as quality, efficiency, aesthetic design, and even sustainability are central to this dimension of engineering ethics, as engineers focus on creating results that excel at solving technical challenges. Given that engineering education prioritizes the acquisition of technical skills, it is reasonable to expect that engineers and engineering students are interested and engaged with this ethical dimension of their work.

The final and broadest ethical dimension of engineering work is that of social ethics. Even if an engineer has achieved technical and professional excellence in their work, questions about the broader and long-term impacts of that work arise. How does one's work impact society, broadly conceived? Notice that this dimension of engineering ethics could be interpreted through the lens of specific moral theories, but doing so is neither necessary nor desirable for the purposes of understanding the extent to which engineering students engage with this dimension of work. Individuals bring different values and principles to how they think about the broader impacts of their work. Yet, such concerns as community interests, environmental impacts, spiritual commitments, and economic impacts are often relevant for individuals engaged with this ethical dimension of engineering work. Given that engineering education does not address this dimension as systematically or thoroughly as it does technical and professional ethics, it is reasonable to expect that engineers and engineering students may be somewhat less attentive to these kinds of broader considerations or may be uncertain how to integrate them into engineering practice.

Promisingly, the established codes of conducts put out by many professional societies touch on all of these spheres of ethics. In addition to technical competency, engineering students are also taught to focus on professional excellence, i.e. interacting with clients and other professionals in ethically appropriate ways. Values such as honesty, respect, fairness, and so on are central to this dimension of engineering ethics, as engineers engage as part of their work with others in professionally appropriate ways, taking care not to violate established codes of conduct. **Table 1** provides a summary of the different aspects of this technical, professional, and social ethics framework.

Table 1: Aspects that vary across the three spheres of ethics

	Aspects that vary across the spheres					
Spheres of ethics	**Focus**	**Codification (Example codes from NSPE Code of Ethics)**	**Values & Principles**	**Expression**	**Immediacy**	**Interests Considered**
Technical Ethics	The engineering product itself	Engineers shall perform services only in the areas of their competence	Excellence in technical creation	In technical work	Immediate need	Primarily those of clients
Professional Ethics	Colleagues & clients	Engineers shall be guided in all their relations by the highest standards of honesty and integrity.	Professional behavior	Through interactions with colleagues & clients	Medium need	Those of clients and colleagues
Social Ethics	Justice, environment, communities, society more broadly	Engineers shall at all times strive to serve the public interest.	Contributing to societal well-being	In the broader impacts of technical and professional work	Long-term thinking	Communities and future generations

Method

We address two research questions. The first research question asks the extent to which engineering students engage with each sphere of ethics, the technical, the professional, and the social, while simultaneously experiencing a problem of significant magnitude such as the COVID-19 pandemic.

This study focuses on this pandemic because it encompasses aspects of technical, professional, and social ethics. The COVID-19 pandemic is both the context of and the case addressed in the study. Aside from the technical contributions that engineering professionals can make to addressing the pandemic, aspects of professional ethics (e.g., ethical collaborations with other professionals) and social ethics (e.g., racial and socioeconomic inequalities) are often presented to students through various media (Barabino, 2021). In addition, many students themselves experienced social or economic hardships during the pandemic (Pokhrel & Chhetri, 2021). Therefore, the pandemic presents a heightened opportunity for students to engage with all three spheres of ethics. It should be and, indeed, is within the scope of engineering and engineering ethics. We would like to note that the National Academy of Engineering had an article on how engineers are responding to the problems arising from the COVID-19 pandemic (https://www.nationalacademies.org/news/2020/09/engineering-a-response-to-the-covid-19-pandemic). For example, during this time when the COVID-19 pandemic is crippling various industries, public construction has been one of the few industries that has been maintained to some extent. Although activity will likely continue in the short-term, the work is expected to halt soon given various factors including supply chains disruption, shortage of subcontractors and materials, and the termination of contracts to control expenses. Additionally, engineers can address the COVID-19 pandemic in various ways. For example, the genetic structure of the virus [SARS-CoV-2] was sequenced within weeks of its discovery, and it was done with the help of both scientists and engineers (National Academy of Engineering, 2020). Another area where engineers are playing a role is in the scale-up of therapeutics and vaccines. Scientists are discovering the vaccines, however, when you go from making 100 doses to a billion doses, that is a huge engineering challenge. The same is true for manufacturing therapeutics. Furthermore, engineers are also working on maintaining the integrity of the supply chain such as getting equipment such as masks to where they're needed, and getting the right chemicals together to make vaccines and therapeutics. These are just a few of the many examples of engineers contributing to fighting the pandemic.

Here, we used COVID-19 as both context and a case study to illustrate to what extent engineering students engage with the three spheres of ethics. Other real-world engineering ethics issues are a great for educating students on relevant ethical issues; however, we believe students could relate to COVID-19 pandemic as an ethical issue more because it affects them personally.

The second research question asks how different student demographic variables increase or decrease students' likelihood of engagement with each of these spheres of ethics. To address these research questions, we employed mixed methods based on survey data with undergraduate engineering students at one university in the Midwest. The qualitative analysis provides us an understanding into the extent to which engineering students engage with each sphere of ethics. Then, the quantitative part allowed us to see how different student demographic variables increase or decrease students' likelihood of engagement with each of these spheres of ethics. The methodology is mixed as we used a concurrent nested approach by having a quantitative analysis nested within a major qualitative analysis. The survey itself consists of both a qualitative part and a quantitative part. The survey has been included in the appendix.

1. Data Collection

The survey was distributed by college-wide listserv in the fall semester of 2020 to all undergraduate engineering students (n=410) using an anonymous link generated from Qualtrics. This survey was distributed approximately six months into the pandemic. The survey had a total of 22 question and was completed on average in 15 to 20 minutes. One reminder was sent to students three weeks after the first email was sent. Five gift cards worth $100 each were used to encourage participation in the survey. Survey fatigue could influence the results of the study (Porter et al., 2004). To account for this, one question asking the respondents to select a specific response was introduced halfway through the survey. Responses that failed to answer this question were removed. The survey was developed by the research team which consists of two graduate students and five co-principle investigators with expertise in the disciplines of engineering, ethics, and political science. The survey underwent review by the Institutional Review Board at (anonymized) and (anonymized).

The survey consisted of two parts. The first part contained an open-ended question aimed at capturing the three spheres of ethics through students' perception of the role of engineers in addressing the pandemic: "*What are some ways that engineers could address the COVID-19 pandemic? Please explain.*" The second part contained questions regarding demographics information, including race, gender, class standing, political view, religiosity, geography, and family income among others. See **Appendix** for more information on this survey.

2. Qualitative Coding

We performed content analysis of students' responses to the open-ended question. Content analysis is used to determine the presence of certain themes or repeating concepts within a given text (Hsieh & Shannon, 2005; Elo et al., 2014). We used a hybrid approach of deductive and inductive coding (Fereday & Muir-Cochrane, 2006). This approach complemented the first research question by allowing the technical, professional, and social ethics framework to be integral to the process of deductive thematic analysis while allowing for themes to emerge direct from the data using inductive coding. The deductive coding included the three spheres of ethics as macro-codes (technical, professional, and social ethics), under which 22 subcodes emerged inductively (see **Table 3**). Determining engagement with each sphere of ethics was not based on quality of the response; instead, we looked for presence of at least one of these three spheres.

The coding was performed by two coders. Intercoder reliability test was performed for each macro-code (see **Table 5**) in order to ensure the two independent coders could evaluate a characteristic of a message or artifact and reach the same conclusion (Lombard et al., 2002). The two coders categorized the responses into either one of the three macrocodes, and then using these categorizations to calculate a numerical index of the extent of agreement between the two coders (see **Table 5** for percent agreement per macro-code) (Lombard et al., 2002).

3. Logistic Regression and Interaction Analysis –

Table 2: Coding of variables

Variable Type	Variable	Coding
Dependent	Technical ethics	1=engaged with technical ethics, 0=did not engage with technical ethics
	Professional ethics	1=engaged with professional ethics, 0=did not engage with professional ethics
	Social ethics	1=engaged with social ethics and 0=did not engage with social ethics
Independent	Political view	1=non-conservative, 0=conservative
	Religiosity	1=think of themselves as more religious than others, 0=do not think of themselves as more religious than others
	Geography	1=urban, 0=non-urban
	Family income	1=less wealthy, 0=wealthy
	Self-perceived ethicality	1=do not think of themselves as more ethical than others, 0=think of themselves as more ethical than others
Control	Gender	1=male, 0=female
	Class standing	0=freshmen-sophomore 1=junior-senior

Table 2 shows how the variables were coded. Gender was included as a control variable because studies suggest that the social desirability response bias appears to be

driving a significant portion of the relationship between gender and ethical decision-making (Glover et al., 2002; Dalton & Ortegren, 2011; Capraro & Sipple, 2017)). Specifically, females are more prone to responding in a socially desirable fashion (Dalton & Ortegren, 2011). Class standing was a control variable because studies suggest that students become less concerned with social aspect of engineering decision making at the end of their undergraduate education than at the beginning of their undergraduate education (Cech, 2014).

Because the dependent variables were binary, logistic regression was used for this analysis. In addition, interaction analysis was performed to see if there were interaction effect between independent variables.

Limitations/Future Works

First, the question posed to students in this study "*What are some ways that engineers could address the COVID-19 pandemic? Please explain.*" could lead them to think more in terms of one sphere of ethics over others. The phrasing of the question could lead students to think more in terms of one sphere of ethics than others. In this case, most students could be leaning towards technical ethics because this was what came up first in their minds, particularly because they are more knowledgeable regarding technical issues. Some students might be able to base their moral standards on principles that they themselves have evaluated and that they have accepted as inherently valid, regardless of society's opinion (Kohlberg, 1984). Because this study was looking for engagement with all three spheres of ethics, it could be possible that professional ethics and social ethics were not what first came to students' minds. Future studies will include more specific questions for each sphere of ethics in the survey. Future research will also explore why some students engage with certain sphere of ethics more than others.

Second, the R^2 value was low. However, because of the exploratory nature of this research and due to the uncertainty in human cognition and behavior, low R^2 values can be justified for building an exploratory model (Newman & Newman 2000; Rua, 2016; Moshagen & Hilbig, 2017).

Third, the study was done at one Midwestern university and cannot be generalized to all undergraduate engineering students. Organizational culture might have a strong influence on students. For example, some institutions could focus more on teaching ethics to students than others. Students from an institution focusing more on promoting sociopolitical awareness might be more likely to engage more with social ethics. More in-depth studies evaluating organizational cultural differences are necessary to improve the understanding of students' engagement with each sphere of ethics.

Results

1. Qualitative Analysis Results

Figure 2 shows the frequency of engagement with each sphere of ethics (technical, professional, and social ethics). We found that there was a lower frequencies of engagement with social ethics and professional ethics as compared to technical ethics as measured by whether each student had mentioned items that are characteristic of each sphere of ethics. There was minimal difference between the frequencies of engagement with social and professional ethics. While the low frequency of engagement with social ethics was expected, the frequency of engagement with professional ethics was much lower than expected.

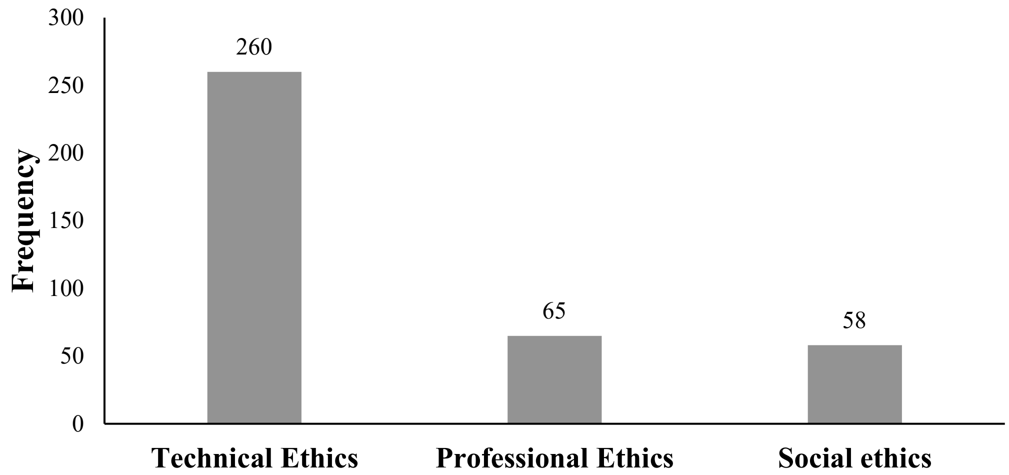


Figure 2: Frequencies of engagement with technical ethics, professional ethics, and social ethics

Subcodes such as “developing vaccine” and “improving virus tracking” were classified under technical ethics because they dealt with the moral principle of making technical decisions in engineering without much consideration for the wider societal issues created or amplified by technical decisions. Professional ethics included subcodes concerned with how engineers interact with individuals and groups as part of their work. For example, subcodes such as “cooperating with others” and “creating inclusive/safe work environment” were classified under professional ethics. Lastly, social ethics included subcodes concerned with considering societal challenges and the potential impacts of engineering work upon society. For example, subcodes such as “addressing social inequalities” and “prioritizing public safety and well-being” were classified under social ethics. Some responses could not be classified under any of the three spheres of ethics and were coded under the “Other” macrocode. **Table 3** includes a summary of students’ responses classified under these three spheres of ethics. Technical ethics included eleven subcodes, which was 50% of all subcodes. Improving and maintaining infrastructure systems, designing/manufacturing PPE and medical equipment, and improving social distancing measures were the most mentioned subcodes under technical ethics. Professional ethics included five subcodes, which was 23% of all subcodes. Staying informed or sharing information, following public guidelines, and cooperate with others were the most mentioned subcodes under professional ethics. Social ethics included four subcodes which was about 18% of all subcodes. Addressing social inequalities, prioritizing public safety and well-being, and engaging in politics were the most mentioned subcodes under social ethics. Lastly, the macrocode "other" included responses suggesting that engineers should do nothing regarding the COVID-19 pandemic, which was about 9% of all subcodes. Some students' responses were classified under two or more categories; therefore, the frequencies do not add up to the total of 410 students taking the survey.

Table 3: summary of responses classified under the three spheres of ethics.

Macro-codes	Subcodes	Freq.	Total
Technical Ethics	Address Environmental Issues	12	260
	Build Medical Facilities	3	
	Improve Building Design	16	
	Improve Supply Chain Logistics	13	
	Improve COVID-19 Testing	17	
	Improve Social Distancing Measures	37	
	Improve and Maintain Infrastructure Systems	59	
	Improve Virus Tracking	15	
	Design/Manufacture PPE and Medical Equipment	48	
	Develop Vaccine	33	
	Design Vaccine Distribution Systems	7	
Professional Ethics	Create Inclusive/Safe Work Environment	5	65
	Follow Public Guidelines	19	
	Cooperate With Others	7	
	Stay Informed or Share Information	29	
	Volunteer or Donate	5	
Social Ethics	Stimulate Economy	4	58
	Prioritize Public Safety and Well-being	10	
	Address Social Inequalities	37	
	Engage in Politics	7	
Other	Do Nothing	7	43
	Unrelated to Ethics	36	

2. *Quantitative Analysis Results*

Table 4: Logistic regression analysis of each sphere of ethics

Model	(1)	(2)	(3)	(4)	(5)
Gender	-0.247	0.454	-0.335	-0.235	-0.284
Class Standing	-0.158	0.171	-0.010	-0.116	-0.130
Political View	-0.232	-0.219	-0.873**	-0.028	
Religiosity	0.130	-0.290	0.100		
Geography	-0.564	0.510	-0.628		-0.832
Family Income	0.114	-0.733	0.040	-1.274	1.702*
Self-perceived Ethicality	-0.069	0.853***	0.824**		
Political View*Family Income				1.565*	
Geography*Family Income					1.827*
Constant	0.792***	-2.258***	-1.720***	0.668***	-1.040
n =	336	336	336	336	336

*** $p<.01$, ** $p<.05$, * $p<.1$

Table 4 summarizes the results of logistic regression analysis. The first three models (1-3) included all demographic variables and the three dependent variables (technical ethics, professional ethics, and social ethics respectively). Model (1) tested the relationships between the independent variables (political view, religiosity, geography, family income, and self-perceived ethicality) and technical ethics, controlling for gender and class standing. No significance was found for this model (p-value>0.1). Model (2) tested the relationship between the independent variables (political view, religiosity, geography, family income, and self-perceived ethicality) and professional ethics, controlling for gender and class standing. Self-perceived ethicality (p-value<0.01) was found to be significantly correlated to professional ethics. Students who thought of themselves as more ethical than others were more likely to engage with professional ethics. Model (3) tested the relationship between the independent variables (political view, religiosity, geography, family income, and self-perceived ethicality) and social ethics, controlling for gender and class standing. Self-perceived ethicality (p-value<0.1) and political view (p-value<0.1) were found to be significantly correlated to social ethics. Students who thought of themselves as more ethical than others were also more likely to engage with social ethics. Students who identified as conservative were more likely to engage with social ethics than students who identified as non-conservative.

The last two models (4-5) included the interaction effects of family income on political view and family income on geography to determine their relationship with a student's technical ethics score. Model (4) tested the interaction effect of family income on political view. This interaction had a significant relationship to technical ethics (p-value<0.1). Model (5) tested the interaction effect of family income on geography. This interaction also had a significant relationship with technical ethics (p-value<0.1). These significances will be discussed below. See **Table 5-7** for further information regarding reliability, events per variable, and multicolinearity.

Table 5: Intercoder Reliability Test

Spheres of Ethics	Percent Agreement	Krippendorff's Alpha	N Agreements	N Disagreements	N Cases	N Decisions
Technical Ethics	91.42857	0.830467	32	3	35	70
Professional Ethics	94.28571	0.801724	33	2	35	70
Social Ethics	94.28571	0.852564	33	2	35	70
Other	88.57143	0.680556	31	4	35	70

Table 6: Events per Predictor Variable (EPV). All three models satisfy rules for events per predictor variables (Vittinghoff & McCulloch, 2006).

Code Value	Technical ethics	Professional ethics	Social ethics
1 (present)	205	**60**	**54**
0 (non-present)	**131**	276	282

Table 7: Multicolinearity Check

Statistic	Ethicality	Income	Political	Religiosity	Geography	Class	Gender
R^2	0.064	0.038	0.16	0.16	0.028	0.028	0.028
Tolerance	0.94	0.960	0.84	0.84	0.97	0.97	0.97
VIF	1.07	1.04	1.19	1.19	1.03	1.03	1.03

Figure 3 shows that non-conservative engineering students from less wealthy families in our study show higher engagement with technical ethics as compared to conservative engineering students from less wealthy families. Non-conservative engineering students from

wealthy families, however, show similar engagement with technical ethics as compared to conservative engineering students from wealthy families.

Figure 3: Engagement with technical ethics as function of political view and family income

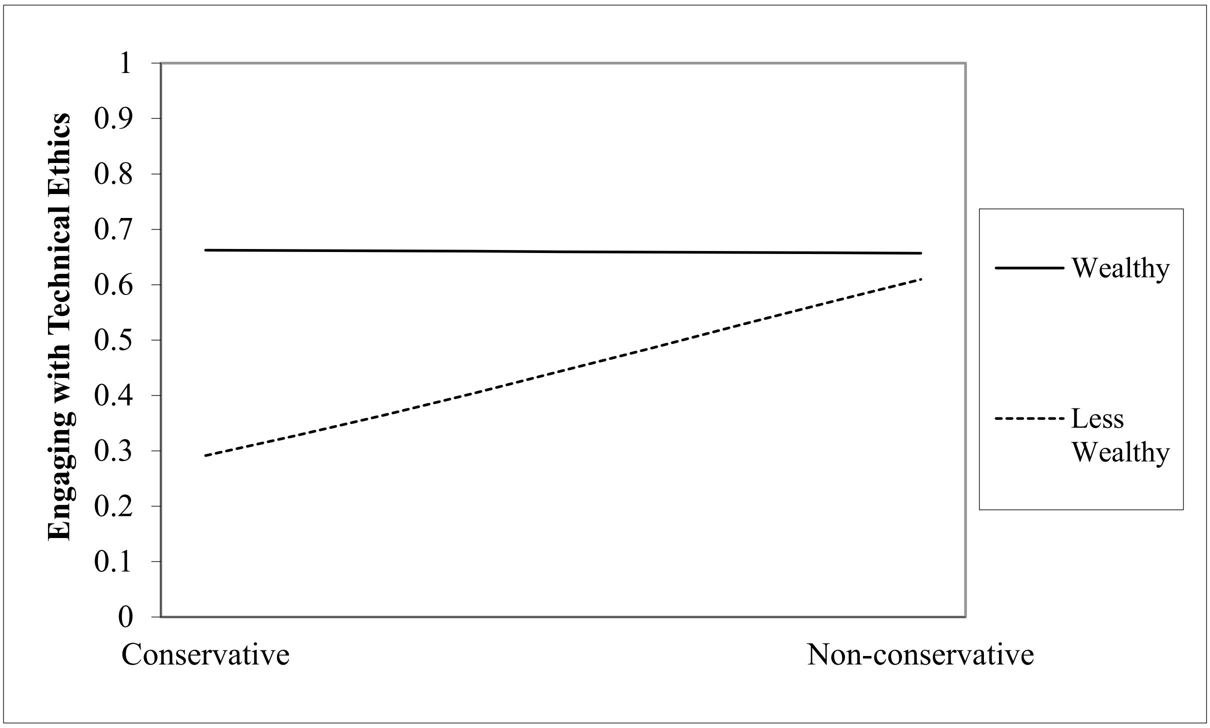
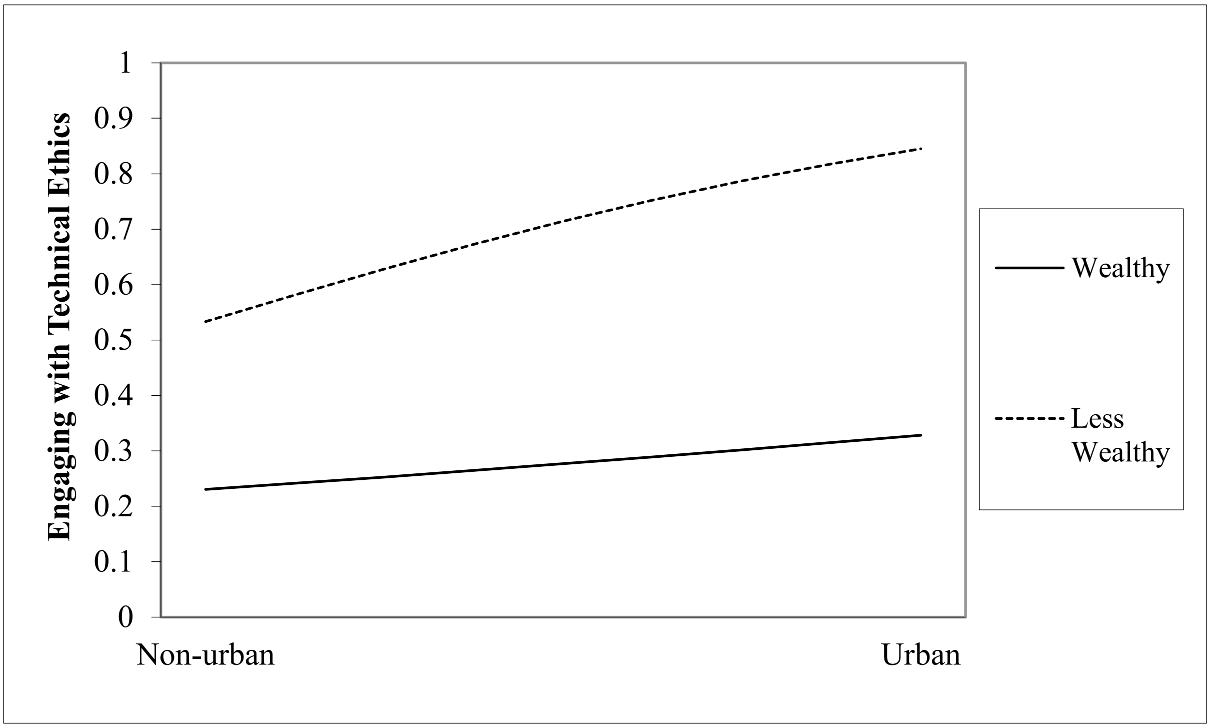


Figure 4 suggests that engineering students from both wealthy and less wealthy families show higher engagement with technical ethics if they reside in urban areas as compared to engineering students from both wealthy and less wealthy families in non-urban areas. In addition, the difference in terms of engagement with technical ethics between non-urban engineering students from less wealthy families and urban engineering students from less wealthy families is larger than the difference in terms of engagement with technical ethics between non-urban engineering students from wealthy families and urban engineering students from wealthy families.

Figure 4: Engagement with technical ethics as function of geography and family income



Discussion

Implied within the theory of a culture of disengagement from sociopolitical matters proposed by Cech (2014) is the idea that engineering products or technologies are value-neutral and that sociopolitical matters are irrelevant to "real" engineering work. This idea has detrimental consequences because it perpetuates unequal structures and practices for disadvantaged and minoritized groups (Cech, 2013; Cech, 2014). By analyzing the different ways that engineering students perceive their roles as engineers in addressing the COVID-19 pandemic and its associated social problems, we found evidence that there is indeed a low frequency of engagement with social ethics as compared to technical ethics. This does not come as a surprise because engineering education programs in the U.S. often focus on technical competency over social competency, leading students to become insensitive or even indifferent to pervasive sociopolitical issues (Cech, 2014; Bairaktarova & Woodcock, 2015; Bairaktarova & Woodcock, 2017; Nguyen et al., 2020). However, the frequency of engagement with professional ethics was much lower than that of technical ethics and there is not a large difference between the frequencies of engagement with professional ethics and social ethics. Why might this be? The subsequent paragraphs aim to provide some possible explanations.

Among the top subcodes within technical ethics were improving social distancing measures, improving and maintaining infrastructure systems, and designing/manufacturing PPE (personal protective equipment) and medical equipment. It is understandable that these were mentioned the most because these are within the realm of the technical, in which these students are trained. At the level of technical ethics, the engineers act within the well-defined range of their expertise (McLean, 1993), meaning that technical ethics only requires the individual to act as professional engineer while remaining mostly indifferent to the larger societal issues (Roddis, 1993; Vanderburg, 1995; Herkert, 2001).

The results evaluating the role of demographics on engagement with technical ethics showed that non-conservative engineering students from less wealthy families in our study show higher engagement with technical ethics as compared to conservative engineering students from less wealthy families. Non-conservative engineering students from wealthy families, however, show similar engagement with technical ethics as compared to conservative engineering students from wealthy families. This is perhaps because when family income is challenging, people might start thinking about their own socioeconomic status, particularly when they are at the center of debates regarding inequalities and welfare. Additionally, our results suggested that engineering students from both wealthy and less wealthy families show higher engagement with technical ethics if they reside in urban areas as compared to engineering students from both wealthy and less wealthy families in non-urban areas. Plus, the difference in terms of engagement with technical ethics between non-urban engineering students from less wealthy families and urban engineering students from less wealthy families is larger than the difference in terms of engagement with technical ethics between non-urban engineering students from wealthy families and urban engineering students from wealthy families. However, this result is complicated and will need further study to explain the role of family income.

Among the top subcodes within professional ethics were following public guidelines and staying informed or sharing information with others. At this level of ethics, students are mostly concerned with the interactions between cooperating or competing individuals and groups (McLean, 1993, Herkert, 2001). They focus on how members of the engineering profession relate to specific others as part of their work; however, the wider societal issues created or amplified by professional decisions are often overlooked (McLean, 1993; Herkert, 2001).

Among the top subcodes within social ethics were prioritizing public safety and addressing social inequalities. Students who mentioned these might be thinking in terms of post-conventional morality, which identifies the ethical reasoning of moral actors who make decisions based on rights, values, duties, or principles that are universalizable (Kohlberg, 1981; Green & Snarey, 2011). These principles are separable from the authorities/persons who hold them and they are open for debate and generally agreeable to individuals who seek to live in a fair and just society (Green & Snarey, 2011). In addition, they withstand tests of logical comprehensiveness (Green & Snarey, 2011). At the level of social ethics, societal challenges are addressed by building on and extending engineering expertise (McLean, 1993; Vanderburg, 1995; Devon, 1999). These students are able to identify and respond to the social and political dimensions of engineering projects. They focus on the wider societal impacts of the technical and professional decisions made by engineers. Therefore, the lower frequency of engagement with social ethics was expected.

The results from this study contradicted some of our initial expectations for students' engagement with professional ethics. This study initially expected students to be much more engaged with professional ethics than social ethics because of the available ethical codes set by professional societies and professional development programs at many universities. One other reason to expect that engineering students might be more engaged with professional ethics than social ethics is because engineering programs heavily rely on outlining the importance of professional ethics in the curriculum. Professional ethics is heavily stressed by ABET professional learning outcomes, which are incorporated in the majority of civil engineering programs. Indeed, engineering students perceive teamwork and communication – both which are related professional ethics – as the two most important competencies (Passow 2012). However, despite this our results show that there is little difference in their engagement with social and professional ethics.

However, the much lower frequency of engagement with professional ethics compared to the frequency of engagement with technical ethics came as a surprise, particularly because many engineering programs and codes of ethics tend to focus on professional ethics (Herkert, 2001). One possible reason for this observation could be that engineering students do not see addressing COVID-19 pandemic as an engineering problem but rather as a health issue that requires attention from medical professionals. Students may be engaging more with technical ethics because they think about the pandemic primarily in terms of individual ethics. Technical ethics thus might be easier for them to engage with because it tends to focus on the decisions of individual engineers. Professional ethics adds a layer of complexity because it pertains to how they relate to others while working on a project. Social ethics adds yet another layer of complexity because it involves thinking beyond technical knowledge and expertise to weigh the impacts of engineering decisions on society more generally.

Conclusion

This paper explores how engineering students engage with all three spheres of ethics, namely technical, professional, and social ethics. However, current literature suggests that they might not be well educated in the sphere of social ethics. The COVID-19 pandemic and the corresponding sociopolitical problems that emerged present an opportunity to examine frequencies of engagement with technical, professional, and social ethics by engineering students. The study suggests that there is a low frequency of engagement with both professional ethics and social ethics and a high frequency of engagement with technical ethics, based on qualitative analysis of students' responses. Social ethics has the lowest frequency of engagement from students in this specific scenario, followed closely by professional ethics. Low engagement with social ethics, in particular, represents a major challenge for engineering ethics education because it can have the effect of perpetuating social inequalities and injustices because engineering students are disengaged from sociopolitical issues. Low engagement with professional ethics similarly indicates a misalignment between current engineering ethics instructional methods, such as teaching ethical codes, and students' understanding of their professional responsibilities.

These findings suggest that engineering ethics education needs to be revisited, specifically concerning the spheres of professional and social ethics. We recommend that engineering programs deliberately focus on training students to engage with all three spheres of ethics. Based on logistic regression analysis, the results also suggest that non-conservative engineering students from less wealthy families in our study show higher engagement with technical ethics as compared to conservative engineering students from less wealthy families. Non-conservative engineering students from wealthy families, however, show similar engagement with technical ethics as compared to conservative engineering students from wealthy families. In addition, engineering students from both wealthy and less wealthy families show higher engagement with technical ethics if they reside in urban areas as compared to engineering students from both wealthy and less wealthy families in non-urban areas. In addition, the difference in terms of engagement with technical ethics between non-urban engineering students from less wealthy families and urban engineering students from less wealthy families is larger than the difference in terms of engagement with technical ethics between non-urban engineering students from wealthy families and urban engineering students from wealthy families. Further investigation will be needed to explain these findings. However, one possible suggestion is that engineering ethics education research needs to focus on socioeconomically disadvantaged students by taking an approach that aims to understand their perspectives towards each sphere of ethics. In addition, these students likely bring personal experiences to the classroom that might be more aligned with social ethics. This approach might prove useful as minoritized groups are often at the center of sociopolitical debates such as inequalities and discriminations. This study demonstrates the usefulness of revitalizing the technical, professional, and social ethical framework to conceptualize and assess students' understanding of engineering ethics. Lastly, this study, to our knowledge, is the first to measure, simultaneously, students' engagement with each of the three spheres of ethics.

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APPENDIX

Survey used in this study

Part 1: Open-ended

What are some ways that engineers could address the COVID-19 pandemic? Please explain.

Part 2: Demographics

Q1 What is your current class standing at Iowa State University? (*a) Freshman (b) Sophomore (c) Junior (d) Senior*

Q2 Are you a transfer student? If yes, please specify from where did you transfer to Iowa State University? *(a) No (b) Yes* ____

Q3 How long have you been at Iowa State University? Select from the list.
▼> *8 Semesters*

Q4 Are you a first-generation college student? *(a) Yes (b) No (c) Prefer not to respond*

Q5 What is/are your engineering major(s)? Please select all that apply (Ctrl/⌘ + Select to select multiple). ☒ *Undecided* ☒ *Aerospace Engineering…*

Q6 With what gender do you identify? *(a) Man (b) Woman (c) Prefer not to respond (d) Other (Please specify)* ____________________

Q7 What is your age? Select from the list. ▼ *Prefer not to respond*

Q8 What is your identified race/ethnicity? Please select all that apply. *(a) American Indian or Alaska Native (b) Asian (c) Black or African American (including African and Caribbean) (d)Native Hawaiian or Other Pacific Islander (e) White (Including Middle Eastern) (f) Hispanic or Latinx (g) Prefer not to respond (h) Other (Please Specify)*
____

Q9 Which of the following statements do you agree with? *(a) "I consider myself a lot more religious than other engineering students" (b) "I consider myself more religious than other engineering students" (c) "I consider myself as religious as other engineering students" (d) "I consider myself less religious than other engineering students" (e) "I consider myself a lot less religious than other engineering students"*

Q10 How would you describe your political views? (*a) Very Conservative (b) Conservative (c) Moderate (d) Liberal (e) Very Liberal (f) Prefer not to respond (g) Other (Please Specify)*
____

Q11 In which state do you currently reside? Choose from the list. ▼ *Alabama*

Q12 What is your country of citizenship? Please select all that apply. (Ctrl/⌘ + Select to select multiple) ☒ *Afghanistan*

Q13 How many languages do you speak? Choose from the list. ▼ *1*

Q14 How would you classify the area you grew up in? *(a) Urban (b) Suburban (c) Rural*

Q15 Select “*C*?” *(a) A (b) B (c) C (d) D*

Q16 What is your marital status? *(a) Single, never married (b) Married or domestic partnership (c) Widowed (d) Divorced (e) Separated (f) Prefer not to respond*

Q17 Do you have any siblings? *(a) No (b) Prefer not to respond (c) Yes*

Q18 Do you have any children? *(a) Yes (b) No (c) Prefer not to respond*

Q19 What is your or your family's approximate annual income range? (*a) <$19,999 (b) $20,000-$34,999 (c) $35,000-$49,999 (d) $50,000-$74,999 (e) $75,000-$99,999 (f) >$100,000 (g) Prefer not to respond*

Q20 Do you have a part/full time job while attending classes? *(a) Yes, part time (Please Specify) _____(b) Yes, full time (Please Specify)____ (c) No (d) Prefer not to respond*

Q21 How often do you participate in community services? *(a) Very frequently (b) Frequently (c) Occasionally (d) Rarely (e) Never*