Investigating Student Experiences of Engineering Culture During COVID-19: A Comparative Case Study

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Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
In
Engineering Education

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March 21, 2022
Blacksburg, VA

Keywords: engineering culture, student experiences, COVID-19, pandemic, case study

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Abstract

The COVID-19 pandemic sparked rapid shifts to engineering education, causing changes to course formats and student experiences. The culture of undergraduate engineering programs undoubtably affected this transition online and affected how students interpreted their experiences. To date, research on engineering culture has explored the values, beliefs, and underlying ideologies of the culture. However, what we know about engineering culture was captured predominantly during periods of stability. Because COVID-19 provides an opportunity to either challenge or uphold aspects of engineering culture, it was imperative to capture the experiences of students undergoing an engineering education during this time.

In order to understand what facets of engineering culture were salient in students' interpretations of their classroom experiences during the COVID-19 pandemic, I conducted a multiple case study exploring mechanical engineering students' constructions of their experiences taking second and third year courses during the pandemic. I compared two mechanical engineering programs – one in the United States and one in South Africa – by conducting semi-structured interviews with 10 to 11 mechanical engineering undergraduate students at each site as well as 1 to 2 key informants. My analysis identified the following cultural features that emerged as salient from students' perspectives during the pandemic at both sites: intrinsic hardness, differential access to resources, and application and design. Additionally, my analysis identified the following cultural features that emerged as salient at only one site: seeking help, job market, and scientific way of thinking. The key difference between sites appeared with respect to differential access to resources.

This study captures and reports critical data about students' constructions of their experiences during the COVID-19 pandemic. By investigating engineering culture during a time of stress, this research identifies the most salient features of engineering culture that remained constant through the pandemic as well as the features that changed due to the pandemic. Further, the global comparative aspect of this work highlights which features of engineering culture are universal and which are influenced by national context. Overall, this research aims to inform future educational responses to disasters as well as future change efforts in engineering.

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General Audience Abstract

The COVID-19 pandemic sparked rapid shifts to engineering education, sending students home and shifting classes online. The beliefs and values that engineering instructors and students have about how engineering should be taught and learned impacted this shift online in ways that could either help or hinder student learning. The pandemic provides an opportunity to understand which beliefs and values in engineering were stickiest and the most important to how students described their experiences.

In order to understand how students described their experiences taking classes online during the pandemic, I interviewed 10 to 11 mechanical engineering students at two universities – one university in the United States and one in South Africa. I asked students to share stories about taking classes during the pandemic. I then analyzed their responses and looked for commonalities across their stories. I found that students talked about six common features of their experiences. First, students felt like their classes were hard, and they felt their classes should have been hard because that was part of what it means to study engineering. Second, students noticed that having a laptop and Wi-Fi became very important when all teaching and learning was happening online, and not having that access made learning more challenging. Third, students missed their in-person laboratory classes, which they also saw as central to engineering. Fourth, students at the university in South Africa talked about challenges with getting help with their classes because virtual learning made accessing instructor and peer help more difficult. Fifth, students at the university in the United States had concerns about finding jobs because the pandemic was impacting the economy and their ability to obtain internships. Sixth, students at the university in the United States were frustrated that the response to the pandemic wasn't more rooted in science.

This study captures and reports students' stories about their experiences during the pandemic. By looking at how students talked about their experiences during the pandemic, this research identifies the stickiest features of engineering culture that remained constant through the pandemic as well as the features that changed due to the pandemic. Further, by comparing two countries, this work highlights which beliefs and values in engineering are widespread and which are not. Overall, this research aims to inform future educational responses to disasters as well as future change efforts in engineering.

Dedication

To the students who shared their stories with me. Thank you.

Acknowledgements

First and foremost, thank you to my family for supporting me through this journey. To my parents, brothers, cousins, aunts, uncles, and grandparents, your support is everything. A special thank you to Angie and Ramona, my PhD cousins, for supporting me and helping me grow, and my aunt Laura who transcribed many of the interviews used in this study.

Thank you to my advisor, Dr. Marie Paretti. Your support helped me grow as a researcher, an educator, and a person. I am forever grateful for you supporting my idea to completely change my dissertation topic in the middle of a pandemic and helping me develop this study. Thank you.

Thank you to my committee, who have supported me and pushed me to grow. A special thank you to Dr. Jenni Case who helped me pivot and develop this study in April 2020, and to Dr. Jon Leydens who helped me discover the field of Engineering Education, mentored me through my first research project, and has supported me as a committee member throughout my PhD journey. To Dr. Holly Matusovich who helped me scope and tell a cohesive story. To Dr. Margaret Cowell who helped me explore the pandemic as a disaster in interdisciplinary ways.

Thank you to my research group friends who have mentored and supported me through this process. From Amy and Cass to Racheida to Maya, Maggie, and Qualla. Thank you.

Thank you to KJ, Logan, Teirra, Maggie, Maya, Qualla, and Chris for your input and feedback on my dissertation throughout this process. A special thank you to Teirra and Logan for your friendship throughout this process and always knowing when to plan a nacho night. Thank you to Crystal and William for your support and helping broaden my perspective and goals.

Thank you to all of the students who have been a part of my PhD journey. From my RSAP students to my IRES students and my Sigma Kappa collegians, thank you for helping me grow as a teacher, mentor, and advisor. A special thank you to the participants of this study who shared their stories with me.

Thank you to Taylor Swift for showing me how productive I could be by releasing four albums and rereleasing another two albums all since I started graduate school in August 2017. Her music got me through the highs, lows, and long writing days.

Thank you to the Disaster Resilience and Risk Management (DRRM) Program for pushing me to take an interdisciplinary approach and providing resources for me to quickly pivot my dissertation topic and study an ongoing disaster. And a shoutout to the students and faculty in the DRRM program whom I have learned from and been challenged by throughout the last four years. I am incredibly grateful for the learning and growth I experienced because of the DRRM Program, and I am incredibly grateful for the financial support I received through the program.

Attributions

This material is based on work supported by the National Science Foundation under Grant No. DGE - 1735139. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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1 Introduction[1]

1.1 The Need for this Study

Increasing diversity in engineering has been a major focus in the U.S. for decades. Significant resources have been invested in improving diversity in engineering, but the numbers have stayed relatively stagnant. To move beyond this stagnation, research on engineering culture suggests that we must look inside the engineering classroom in order to understand why engineering remains largely white and largely male (Cech & Sherick, 2019; Lichtenstein et al., 2015). In order to successfully increase diversity in engineering in a sustainable and ethical way, we must not only examine but work to change the culture of engineering. To date, research on engineering culture has explored the values, beliefs, and underlying ideologies of the culture. For example, Cech (2014) described a culture of disengagement in engineering education and defined three underlying ideological pillars (meritocracy, depoliticization, technical/social dualism). Her work and the work of others demonstrates the ways in which this culture is exclusive of students from underrepresented minority groups (Cech & Rothwell, 2018; Lichtenstein et al., 2015).

Importantly, however, what we know about engineering culture was captured predominantly during periods of stability – that is, outside the kind of disruption seen in 2020 resulting from a global disaster, compounded by social unrest and economic turmoil. The COVID-19 pandemic has not only exacerbated challenges around diversity and inclusion in engineering (Addo, 2020; Coley & Holly, 2021; Sealey et al., 2021; Sheppard, 2020), but also provided an opportunity to either challenge or uphold the dimensions of engineering culture.

[1] Portions of this introduction section were published in an early conference proceeding (Deters & Paretti, 2021)

Many students face more barriers than before as they juggle COVID-induced challenges with their education (Gelles, Lord, Hoople, Chen, & Mejia, 2020; Wang et al., 2020). At the same time, research on disasters shows us that extreme events, like COVID-19, can reveal a culture's core beliefs and values, helping to illuminate underlying structural challenges and inequalities (Gelles, Lord, Hoople, Chen, & Meija, 2020; Swartz et al., 2018) – structures and beliefs that are not necessarily apparent otherwise. The COVID-19 pandemic thus provides an opportunity to investigate dimensions of engineering culture during a crisis, which can open new avenues for conversations about equity and accessibility in engineering by identifying which aspects of culture are more and less amenable to change. In other words, disasters can help uncover 'what really matters' and potentially offer a new avenue for cultural change.

1.2 Purpose of the Study

To leverage this opportunity, I conducted a comparative case study of two universities – one in the U.S. and one in South Africa – framed by the dimensions of engineering culture developed by Godfrey and Parker (2010). Drawing on the work of Schein (1985, 1992), Godfrey and Parker (2010) mapped the cultural landscape of engineering education and developed a framework with six dimensions: an engineering way of thinking, an engineering way of doing, being an engineer, acceptance of difference, relationships, and relationship to the environment. Godfrey and Parker's framework offers a useful starting point for this study because it provides a concrete, pragmatic way to map classroom practices and student experiences onto a range of different explicit and implicit assumptions, beliefs, and values. At the same time, as discussed in Chapter 2, these six dimensions can also be mapped to underlying ideologies, such as those identified by Cech (2014), in order to explore the power structures that resist change and serve as barriers to a more inclusive engineering culture.

The purposes of this comparative case study are to 1) understand what facets of engineering culture were salient in students' interpretations of their classroom experiences during the COVID-19 pandemic and 2) investigate how salient facets of culture differed across national contexts in order to 3) understand what an exploration of engineering culture during a disaster tells us about the culture itself.

First, using the dimensions of engineering culture as a lens to understand student experiences during COVID-19 documented the ways in which engineering culture emerged in classroom-level practices during the pandemic. This aim is motivated by a fundamental tension: engineering culture has proven difficult to change and yet COVID-19 prompted rapid shifts in the educational enterprise. Understanding and documenting the ways in which the dimensions of engineering culture were embodied in students' experiences during the pandemic informs future change efforts in engineering education. Further, comparing features of engineering culture that emerged as salient during COVID-19 to features that emerged in non-disaster times can reveal elements of culture that are particularly persistent.

Second, investigating differences across national contexts allowed me to identify aspects of engineering culture that potentially transcend national boundaries, as well as aspects where national culture seems to have a larger influence than engineering culture. Looking across contexts allows for a deeper investigation of *relationship to environment*, one of Godfrey and Parker's (2010) dimensions of engineering culture, leading to a more nuanced understanding of the role of national context verses engineering culture in the classroom-level decisions made during the pandemic.

Third, understanding how engineering culture responded to a significant disruption (i.e., the pandemic) can reveal which parts of the culture are more and less likely to change. As disasters become more frequent and more intense (Iglesias et al., 2021), educational disruptions will likely become more frequent as well. Moreover, the changes implemented because of the pandemic – namely remote learning – are likely to remain in some form as the world recovers from the pandemic. Understanding how key cultural features of engineering respond when disrupted can inform future responses to disasters and inform future change efforts in engineering.

1.2.1 Research Questions and Research Design.

To achieve these goals, I posed the following research questions:

RQ 1: How do the dimensions of engineering culture emerge in students' constructions of their experiences during the pandemic?

RQ 2: How did the presence of the dimensions of engineering culture vary across sites?

To address these research questions and understand how students' experiences map onto the dimensions of engineering culture (Godfrey & Parker, 2010) and map across national contexts, I conducted a comparative case study (Yin, 2018). Using this methodology, I designed a study in which 23 interviews were conducted with mechanical engineering student participants at two large public comprehensive research-focused universities, one in the United States and one in South Africa, during September, October, and November 2020. Additionally, interviews with three key informants (i.e., mechanical engineering faculty members) across both sites and relevant national and institutional policy decisions provide background information for each case. Mechanical engineering was chosen because of its prevalence as an engineering discipline across universities as well as its versatility as a discipline. This choice of discipline is further discussed in Section 3.2.4.

Case study as a methodology is well-suited for this study because there is alignment between the *purposes* of case study research and my research, the *use of theory* in case study research and my research, and the *types of data collected* in each. First, case study research is well-suited for studying contemporary phenomena, like mechanical engineering student experiences during the COVID-19 pandemic, within its real-world context. Second, case study research supports the use of guiding frameworks; my study uses Godfrey and Parker's (2010) dimensions of engineering culture as a theoretical framework. Third, case study research supports the use of multiple sources of data. In this study, each mechanical engineering department constitutes a case and the case data for each site includes interviews with students and key informants.

1.2.2 Scope of the Study

The primary goal of this study is to capture engineering student experiences during the COVID-19 pandemic in two different national contexts as a means of exploring underlying practices, beliefs, and assumptions of engineering culture as they emerge under stress. National context was a key consideration, given that Godfrey and Parker (2010) developed their framework in New Zealand, and work by Downey and Lucena (Downey & Lucena, 2005; Lucena et al., 2008), among others, indicates that national culture plays a role in shaping engineering culture. The pandemic afforded a rare opportunity in comparative engineering education research to explore the same event across different nations. Potential nations were limited to those with English as at least one language of instruction and were selected based on existing relationships that facilitated access. While national context provided the key differentiator across sites, the selected universities have similar institutional profiles; that is, both universities are large, public, comprehensive, and research-intensive. Within these contexts, mechanical engineering was chosen as the discipline of focus in order to reduce variables associated with differences in engineering subdisciplines and curricula and because mechanical engineering is a common discipline across most engineering programs. Next, students taking second- and third-year courses were chosen because the middle-year courses tend to be the most discipline-specific (Lord & Chen, 2014), so these students were engaging in the most technical, discipline-specific courses of their degree program during the pandemic. Thus, these students had sufficient experience in their discipline (as opposed to first-year courses) and could speak to how traditional engineering courses adapted to the pandemic.

1.3 Significance of the Study

This work yielded significant outcomes for the engineering education community, namely in its contribution to the engineering culture literature, historical documentation, and role in aiding future change efforts. First, this study yielded new insights into engineering culture. By comparatively studying engineering culture during a crisis, this study has illuminated dimensions of engineering culture that are enduring as well as dimensions that are more malleable. That is, understanding how students interpreted their pandemic experiences in terms of engineering culture provides significant insight into what students believe to be the most central elements of an undergraduate engineering education: intrinsic hardness and application and design. Further, this study has identified aspects of engineering culture that were common across two national contexts amidst the same disaster as well as aspects that were different. In particular, the perception that engineering not only is hard, but should be hard, emerged among participants at both sites. Similarly, the importance of hands-on laboratory and design work spanned sites; students at both universities identified the lack of hands-on experiences as a key gap in their education resulting from the pandemic. This study explored the reasons for these national differences – like different national pandemic responses and different university approaches to equity.

Second, this study has historical significance. It documents mechanical engineering student experiences during the pandemic, which is expected to be useful historical data as future researchers aim to understand both the impact of the pandemic on engineering education as well as life during the pandemic more broadly.

Third, this study can aid future change efforts in engineering. Documenting what did and did not change in mechanical engineering education during the pandemic and identifying the ways in which dimensions of engineering culture impacted these changes allows future change efforts to build off of pandemic-induced changes and better understand the barriers in place preventing change. Specifically, this work opens conversation about where hardness in engineering should come from. That is, should the content be hard or should the experience itself be hard? Moreover, this work highlights the criticality of ensuring all students have access to the necessary resources to successfully engage in their education. Should remote learning be necessary, universities can take steps like distributing laptops and data to ensure that students are able to be successful in the remote environment. Lastly, this work highlights the centrality of application and design – that is, laboratory sessions and hands-on learning – to students' perception of engineering.

1.4 Limitations

The scope of this study bounds and limits the findings in a number of ways. First, my study developed two cases that were purposely bounded by institution type, field of study, and national context and thus is not generalizable to other settings. While this work is not intended to be generalizable, a rich description of each case is provided in order to facilitate the transferability of the study. Moreover, my multiple case study design only has two cases due to the resource and time constraints of this dissertation. Yin (2018) recommends 6-10 cases in a multi-case design and having six or more cases would have allowed me to make stronger recommendations. At the same time, I have sought to address this limitation by situating the work within larger discussions of engineering culture and research conducted in different national contexts; the findings here both echo and extend prior research, which points to the potential transferability of the findings and points the way toward additional research.

Second, I rely primarily on student interview data, with other sources of data providing important contextual information but not undergoing detailed analysis. However, while the data do not necessarily represent “what really happened,” I chose to adopt a constructivist lens and focus this study on students’ perceptions of their course experiences precisely because, regardless of what faculty or institutions intended with their decisions, the lived impacts as students experience them are dominant factors in retention and persistence across demographic groups. Moreover, because of the constructivist lens through which this research is conducted, relying primarily on student interview data is less a limitation and more a function of the study’s design.

Finally, the study is limited because participants self-selected into the study. I was only able to talk with the subset of participants who chose to take part in interviews, and I may have missed students who had more technology limitations or faced other difficulties because of the pandemic. In order to address this limitation, I provide detailed information about my sample to make it clear what identities are represented in this study and to help other researcher effectively transfer the findings.

1.5 Overview of Chapters

This chapter addressed the need, purpose, and significance of the study; provided the research questions; discussed potential limitations; and described how the study enhances our understanding how dimensions of engineering culture impacted student experiences during the COVID-19 pandemic and how these impacts differed across national contexts. In Chapter 2, I review literature regarding engineering culture, cultures of teaching and learning, times of crisis in higher education, and current COVID-19 related work. In Chapter 3, I describe the multiple-case study design, including recruitment, participants, and data collection and analysis techniques. In Chapter 4, I present the salient themes that emerged from the cases and conduct a cross-case comparison. In Chapter 5, I discuss the results in the context of existing literature. In Chapter 6, I discuss conclusions and implications from this study.

2 Literature Review[2]

Research on engineering culture has explored its values, beliefs, and underlying ideologies (e.g., meritocracy, rigor, depoliticization, technical/social dualism), showing us the ways in which this culture is exclusive of students from underrepresented minority groups and is highly resistant to change (Cech & Rothwell, 2018; Leydens & Lucena, 2018; Lichtenstein et al., 2015). More broadly, research on teaching and learning in higher education has highlighted several key features of engineering education, such as Bradbeer's (1999) work positioning teaching in civil engineering between the abstract conceptualization and active experimentation of Kolb's learning cycle (Bradbeer, 1999). Such work both highlights the limits of dominant pedagogical models and points to challenges in helping engineers move beyond taken-for-granted disciplinary norms.

Although much of this research into engineering culture has aimed to increase equity by sparking large-scale changes, the culture has proved highly resistant to such change. Moreover, what we know about engineering culture was captured predominantly during periods of stability – that is, outside the kind of disruption seen in 2020 resulting from a global disaster, compounded by social unrest and economic turmoil. Yet research on disasters shows us that extreme events, including the COVID-19 pandemic, can help illuminate underlying structural challenges and inequalities as well as tacit beliefs that motivate decisions (e.g., Gelles et al., 2020; Swartz et al., 2018) that are not necessarily apparent otherwise. For example, in response to an extreme event in South Africa (widespread student protests) that led to campus closures in 2016, faculty members reflected on their core beliefs about education as well as their ethical

[2] Portions of this literature section were published in an early conference proceeding (Deters & Paretti, 2021)

considerations around how to continue teaching during an event designed to disrupt the educational enterprise (Swartz et al., 2018). COVID-19 thus provides an ideal opportunity to investigat dimensions of engineering culture during a crisis, which can open new avenues for conversations about equity and accessibility in engineering by identifying which aspects of culture are most and least amenable to change. In other words, disasters can help uncover 'what really matters' and offer a new avenue for cultural change.

Current work around the COVID-19 crisis has focused on diversity and inclusion, student-centered concerns (e.g., Atman, 2020; Danowitz & Beddoes, 2020; Miller & Jensen, 2020), faculty-centered concerns (e.g., Gamage et al., 2020), and online learning (e.g., Qadir & Al-Fuqaha, 2020), but it has not yet pushed beyond those immediate issues to look at the ways that existing belief systems impacted students' experiences and whether those belief systems remain resistant to change. This dissertation aims to capture student experiences and reflections, in their own words, in order to understand how dimensions of engineering culture (Godfrey & Parker, 2010) interacted with practices in engineering education during COVID-19. This research project allows for future work that examines whether the rapid changes in higher education due to COVID-19 prompted sustained change to engineering culture.

2.1 Cultures of Teaching and Learning

There is a long history of treating academic disciplines as cultures (Becher, 1981) and examining the relationships between these disciplinary cultures and the discipline's teaching and learning practices. This research on teaching and learning in higher education seeks to understand broader cultural phenomena as well as disciplinary differences in cultures of teaching and learning. For example, Roxå, Mårtensson, and Alvetg (2011) take an organizational and network theory approach to understanding teaching and learning cultures in higher education.

Organizations can have a dominant culture, but often have several subcultures that “may more or less explicitly oppose the norms and value systems dictated by the predominant culture” (Roxå et al., 2011, p. 100). Academic cultures are comprised of networks of people, they argue, some of whom are “key-players in the cultural process” (Roxå et al., 2011, p. 101). This broader view of academic culture is important because it allows us to understand how academic cultures are formed and maintained. Further, this broader view offers another perspective on how to influence culture. Roxå, Mårtensson, and Alvetg (2011) argue that academic cultures can be influenced by influencing the communication patterns amongst network members.

Research on cultures of teaching and learning has also identified common features of engineering and other technical disciplines. For example, Neumann, Parry, and Becher (2002) argue that engineering is a hard applied discipline that emphasizes problem solving and practical skills. Engineering curricula are restrained by a fixed knowledge base, dictated by external accreditation bodies, and heavily oriented towards the engineering profession (Neumann et al., 2002). Large lectures, lab work, and professionally oriented course work are common in engineering programs (Neumann et al., 2002). Assessments are often used to weed out students, especially in the first years of the curriculum, and students are expected to have good memories and problem solving skills (Neumann et al., 2002).

While much work has already been done to understand engineering culture, the disruption caused by COVID-19 provides an opportunity to explore how engineering culture responds to disaster. Investigating engineering culture during a disaster allows us to consider which beliefs and values persisted through the disaster and are reflected in teaching and learning practices and which beliefs and values shifted in response to the pandemic. To conduct this exploration, I relied on the work of Godfrey and Parker (2010), who posited that explorations of culture are an essential first step in achieving change.

2.2 Engineering Culture

Notably, while Godfrey and Parker (2010) developed their framework based on Schein's earlier work (1985, 1992) on organizational culture, in more recent studies Schein and Schein (2017) have modified the framework and terminology in ways that are salient to the present study. In particular, Schein's initial framework (1985, 1992) used the terms artifacts, values and behavioral norms, and shared beliefs and assumptions. In more recent work, Schein and Schein (2017) have revised these terms to artifacts, espoused beliefs and values, and basic underlying assumptions, as detailed in the next section. In both iterations of Schein's framework, there is a continuum from the most to least visible aspects of culture, where artifacts are the most visible aspects of culture and shared beliefs and assumptions / basic underlying assumptions are the least visible and require extensive ethnographic research to uncover. For this study, while I draw on Godfrey and Parker's (2010) framework to guide my data collection and analysis, I use Schein and Schein's more recent terminology in my discussion of culture more broadly. I opted to use the most updated frameworks available for both engineering culture (Godfrey, 2015) and organizational culture (Schein & Schein, 2017) in order to reflect the most recent thinking and research in both domains.

2.2.1 Definition of Culture

While definitions of culture are complex and often contested, Schein & Schein's (2017) work on organizational culture offers a useful starting point because the early versions of their framework (Schein, 1985, 1992) have already been adapted to higher education broadly (Kuh &

Whitt, 1988) and to engineering in particular (Godfrey & Parker, 2010). Most recently, Schein & Schein (2017) define the culture of a group as:

> The accumulated shared learning of that group as it solves its problems of external adaptation and internal integration, which has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think, feel, and behave in relation to those problems. This accumulated learning is a pattern or system of beliefs, values, and behavioral norms that come to be taken for granted as basic assumptions and eventually drop out of awareness. (p.6)

Schein & Schein (2017) argue that there are different levels at which culture can be analyzed: artifacts, espoused beliefs and values, and basic underlying assumptions. Table 2-1 highlights the definitions of each level. Artifacts are visible products – observable phenomena of the group like observed behaviors, structures, and processes (Schein & Schein, 2017). In education, examples of artifacts include written documents, buildings, and styles of dress (Godfrey & Parker, 2010). While artifacts are easy to observe, they are difficult to decipher (Schein & Schein, 2017). Observers can see the artifact but are limited to their own cultural lens when trying to infer the meaning behind the artifact (Schein & Schein, 2017). Schein & Schein (2017) recommend asking insiders "why they do what they do" in order to begin to uncover the meaning behind artifacts, which they call espoused beliefs and values (p. 19).

Table 2-1: Levels of Culture

Level of Culture	**Definition**
Artifacts	"The phenomena that you would see, hear, and feel when you encounter a new group with an unfamiliar culture. Artifacts include the visible products of the group." (p. 17)
Espoused Beliefs and Values	"Ideas, goals, values, aspirations, ideologies, and rationalizations" (p. 18).
Basic Underlying Assumptions	"Unconscious, taken-for-granted beliefs and values" (p. 18)

Source: (Schein & Schein, 2017)

Espoused beliefs and values are "ideas, goals, values, aspirations, ideologies, and rationalizations" (Schein & Schein, 2017, p. 18). Importantly, espoused beliefs and values are what individuals and organizations *say* they believe. Espoused beliefs and values may not accurately reflect basic underlying assumptions and may not be reflected in observable artifacts. In education, espoused beliefs and values can be school mottos and departmental mission statements as well as course learning objectives and descriptions. Sometimes, observed artifacts can differ from espoused values (Schein & Schein, 2017). For example, an organization or course can espouse a value of teamwork while rewarding competitiveness and divisiveness through performance evaluation and promotion structures; thus, observations may reveal a lack of teamwork despite the organization saying they value teamwork. Schein & Schein (2017) warn that researchers must differentiate between espoused values that are congruent with the organization's philosophy and espoused values that are only "rationalizations or aspirations for the future" (p. 21).

Basic underlying assumptions are "unconscious, taken-for-granted beliefs and values" (p. 18). These basic assumptions affect individual behavior and decision making, and often deal with "fundamental aspects of life" (p. 25) like epistemology and relationships. Basic underlying assumptions can be uncovered by identifying the ways in which artifacts and espoused beliefs do not align. In education, an espoused belief may be that all students can be successful, but an instructor may opt to or be instructed to grade on a curve, thus ensuring that a certain percentage of students will not succeed. This misalignment in espoused beliefs (i.e., that all students can be successful) and artifacts (i.e., grading on a curve) indicates a basic underlying assumption that differs from the espoused belief.

Schein & Schein (2017) argue that engineering can have a unique culture if "there is strong socialization during the education and training period and if the beliefs and values learned during this time remain stable as taken-for-granted assumptions even though the person may not be in a group of occupational peers" (p. 13). That is, if students experience strong socialization to the beliefs and values of engineering during their education, they will maintain those beliefs and values even if working amongst non-engineers. Such perceptions of engineering as a culture echo work by Beecher (1981) and others who explore variations in disciplinary academic cultures, as described in the previous section. However, while engineering enculturation can be strong, other large-scale national cultures can impact how engineering is taught and practiced in a particular country (Lucena et al., 2008). Lucena et al. (2008) highlight that "what it has meant to be an engineer, where engineers have tended to work, and what forms of knowledge engineers have come to value has varied significantly from country to country" (p. 433). Thus, looking at engineering culture across national contexts can help us understand the extent to which characterizations of engineering culture are or are not unique to individual countries.

2.2.2 Defining Engineering Culture

As Godfrey (2015) notes, prior research on engineering culture has addressed a wide range of issues and is part of a larger body of work on academic disciplinary cultures broadly. Work on disciplinary cultures traces back to Becher's (1981) work on academic tribes and is situated within calls for cultural change (Godfrey, 2015), as is work on engineering culture specifically. Engineering culture work traces back to investigations sparked by women's lack of participation (Tonso, 1996) and has spanned investigations of attrition (Courter et al., 1998), development of engineering identity (Tonso, 2006a), as well as sub-disciplinary (Agrawal et al., 2018; Gilbert, 2009), campus (Tonso, 2006b), and national cultures (Downey & Lucena, 2005).

This study is framed specifically by the work of Godfrey and Parker (2010) because it offers an empirically developed framework for understanding engineering culture that aligns with other key work on engineering culture (e.g., Cech, 2014; Cech & Rothwell, 2018; Faulkner, 2007). Drawing on Schein (1985, 1992), Godfrey & Parker conducted an ethnographic case study of a school of engineering at a large, research-based university in New Zealand in order to "develop a conceptual framework of cultural dimensions that had the potential to guide the understanding of culture in the context of engineering education" (p. 5). Godfrey and Parker (2010) adapted Schein's framework for studying organizational cultures, focusing primarily on the first level of Schein's framework (artifacts) in their data collection, and identified shared values, norms, beliefs, and assumptions (espoused beliefs and values) as well as "less conscious shared beliefs, assumptions, and understandings" in their data analysis (p. 8). Through their ethnographic data, they identified six cultural dimensions, which capture the values and cultural norms of engineering: an engineering way of thinking, an engineering way of doing, being an engineer, acceptance of difference, relationships, and relationship to the environment. These dimensions, defined in Table 2-2 and discussed in subsequent sections, serve as the theoretical framework for this dissertation and are critical to understanding the culture of engineering before COVID-19.

Table 2-2: Dimensions of Engineering Culture (Godfrey & Parker, 2010)

Dimension	**Definition**
An engineering way of thinking	The kinds of knowledge that are valued and the prevalent way of thinking within engineering
An engineering way of doing	Shared beliefs about how teaching and learning should be done within engineering
Being an Engineer	"Beliefs and assumptions around the attributes and qualities inherent in being an engineer" (p. 14); engineering identity and enculturation into engineering
Acceptance of Difference	Issues of diversity and homogeneity in engineering; values and norms associated with the dominant group(s)
Relationships	Beliefs around the right way for people to relate to each other within engineering
Relationship to the Environment	How engineering education interacts with broader systems (i.e., university, higher education, engineering profession, national context)

An Engineering Way of Thinking

An engineering way of thinking refers to the kinds of knowledge that are valued and the prevalent ways of thinking within engineering programs (Godfrey, 2015). Key beliefs associated with this dimension are that 1) the most valued knowledge is practice-based and relevant to real life, 2) the prevalence of mathematics and visual tools as communication devices, and 3) the "focus on "best" rather than "right" answers" (Godfrey, 2015, p. 441). Godfrey (2015) found that design "seemed to epitomize the essence of what faculty and students believed to be an engineering way of thinking" (p. 441). Importantly, Godfrey and Parker (2010) also found an unquestioned assumption amongst faculty that the knowledge within engineering, including problem definition and solution techniques, were free of race and gender. This belief that engineering is apolitical can prevent faculty from questioning the ethnocentricity and masculinity of engineering knowledge (Godfrey, 2015).

An Engineering Way of Doing

An engineering way of doing refers to shared beliefs about how teaching and learning should be done within engineering programs (Godfrey, 2015). This dimension deals specifically with decisions and artifacts about *how* engineering is taught and how it should be learned. For example, this dimension captures beliefs about how to teach, assessment methods, curriculum design, plagiarism, difficulty, and time management (Godfrey, 2015). A key belief that permeates the design of engineering curriculum is *hardness* – engineering education should be hard, and the workload should be heavy (Godfrey, 2015). Students and faculty tend to associate "hardness" with "worth and status" (Godfrey, 2015, p. 442). Importantly, hardness in this dimension has to do with beliefs about how engineering is taught and how it should be learned.

Being an Engineer

Being an engineer captures engineering identity and enculturation into engineering (Godfrey, 2015). As students spend more time in their engineering program, they often identify more strongly as an engineer (Godfrey, 2015). Godfrey found that engineering has a special, valued identity that stems from "getting a job, working harder, and doing something practical and useful" (Godfrey, 2003). This strong identity as an engineer is reflected in "language and dress," and language that positions engineering as a "hard" degree (Godfrey, 2015, p. 443). Importantly, teaching and learning practices related to hardness fall under *an engineering way of doing*, while language about hardness as related to one's identity as an engineer falls under *being an engineer*. This engineering identity has been linked to a masculine norm, where belonging is associated with "being one of the guys" (p. 443). Being an engineer is specifically about engineering identity and enculturation, while an engineering way of doing is about how teaching and learning are carried out.

Acceptance of Difference

Acceptance of difference reflects the ways in which homogeneity is desired or assumed within engineering (Godfrey, 2015). Typically, students must fit in with the engineering norm in order to gain acceptance as an engineer (Godfrey, 2015). This engineering norm that they must mold to is nearly always shaped by white and male cultural values (Godfrey, 2015). Studies of non-white, non-male students in engineering reveal how the tendency towards homogeneity in engineering can marginalize students who do not fit the "typical" engineering mold (Godfrey, 2015; Jawitz et al., 2005; Lichtenstein et al., 2015).

Relationships

Relationships refers to beliefs around the 'right' way for people to relate to each other within the broader culture of engineering (Godfrey, 2015). A key relationship belief in engineering programs is the importance of friends (Godfrey, 2015). Godfrey (2015) recognized that engineering is very difficult for students who do not have a group of friends to rely on. Students rely on their friends as working partners throughout their time in engineering programs (Godfrey, 2015). With working friendships being integral to student success, students who are viewed as different may not be admitted to these working friendships and thus face greater barriers to success in engineering (Godfrey, 2015). Additionally, *relationships* captures beliefs about norms in instructor to student interactions. Godfrey (2015) acknowledges that the values students and instructors bring from "family, church, schooling, and community" also impact individual beliefs about how relationships should work in engineering education (p. 444).

Relationship to the Environment

Relationship to the environment refers to the systems within which engineering education operates, including individual institutions, higher education as a whole, the engineering profession, and the national context (Godfrey, 2015). Godfrey (2015) found that the engineering program believed in its self-sufficiency and members prided themselves on being separate and unique from the rest of the university. However, while engineering programs tend to believe in self-sufficiency and espouse a "go it alone" attitude, they still operate within the constraints of larger systems (Godfrey, 2015, p. 445). Further, Godfrey (2015) found that the engineering program had a close relationship with industry, and it was "assumed that the curriculum would be not only monitored but also shaped by the needs of the profession" (p. 445). Lastly, while broader events like demographic and policy shifts "may not affect the espoused values and ideals of engineering education," they do "affect the reality of the enacted values and cultural norms by which the culture is sustained" (Godfrey, 2015, p. 446). That is, espoused values and ideals may persist through changes (like remote learning), but the environmental changes will affect the reality in which engineering is taught and learned. Variations in engineering culture across countries would be captured in this dimension.

2.2.3 Alignment Across Research Findings on Engineering Culture

Although Godfrey and Parker (2010) developed their conceptual framework from data collected in New Zealand, these dimensions closely align with larger underlying ideologies in undergraduate engineering programs as identified by scholars in the U.S.: sociotechnical dualism, depoliticization, and meritocracy (Cech, 2014; Cech & Sherick, 2019; Godfrey, 2015; Godfrey & Parker, 2010; Leydens & Lucena, 2018). Thus, while their dimensions offer a pragmatically useful framework for data analysis, their connections to deeper underlying ideologies are critical in understanding the structures of power and exclusion embedded in engineering culture. Table 2-3 provides brief definitions of these ideologies, followed by more detailed discussions that connect them to Godfrey and Parker's (2010) framework.

Table 2-3: Ideologies of Engineering Culture (Cech, 2014)

Ideology	**Definition**
Sociotechnical Dualism	The belief that social and technical dimensions of engineering are (and should be) separate; the technical is more important than the social
Depoliticization	The belief that "cultural and social concerns like inequity can and should be stripped from engineering to maintain its objectivity" (Cech & Sherick, 2019, p. 1)
Meritocracy	The belief that "social advancement structures in the United States are fair and just" (Cech, 2014, p. 49)

Sociotechnical Dualism

Sociotechnical dualism is the belief that the social and technical dimensions of engineering are separate, and that the technical is more important than the social (Faulkner, 2007). Moreover, sociotechnical dualism mirrors typical binary gender stereotypes, where "society" is feminine and "technology" is masculine (Faulkner, 2007, p. 332). Thus, the highly masculine culture of engineering (Jawitz et al., 2005; Male et al., 2018) aligns with sociotechnical dualism; 'technical' is associated with masculinity, which is more valued than the femininity-associated 'social'. Ascribing more value to the technical aspects of engineering than the social implicitly ascribes more value to masculine aspects of and participants in engineering.

Sociotechnical dualism underlies several of Godfrey and Parker's (2010) dimensions. The gendered binary of social and technical aligns with *acceptance of difference* (i.e., values and norms associated with the dominant group). That is, dominant masculine norms and values associated with masculinity are valued over feminine norms and values associated with femininity (e.g., Faulkner, 2007). Moreover, sociotechnical dualism connects to *an engineering way of thinking* (i.e., what kinds of knowledge are valued); technical knowledge is valued, and social knowledge is devalued (e.g., Cech, 2014). Finally, sociotechnical dualism connects to an *engineering way of doing* (i.e., shared beliefs about teaching and learning). Those holding this belief believe that technical elements should make up the bulk of the engineering curriculum, and social elements are relegated to the sidelines (Leydens & Lucena, 2018).

Depoliticization

Depoliticization is the belief that "cultural and social concerns like inequality can and should be stripped from engineering to maintain its objectivity" (Cech & Sherick, 2019, p. 1). That is, even as much of the larger narrative about engineering work focuses on its ability to solve global challenges (Downey, 2014; National Academy of Engineering, 2004), that broad framing still ignores the social inequities that can be created and perpetuated through the systems, products, and practices of engineering work. The ideology of depoliticization allows engineers to believe that engineering work is “neutral and objective by default” (Cech & Sherick, 2019, p. 2), despite research in science and technology studies that shows that engineering work has always been cultural and political (e.g., Knorr-Cetina, 1995; Winner, 1980). Depoliticization thus allows engineers to ignore equity and social justice concerns, labeling them as subjective and pushing them aside.

Depoliticization connects to several of the dimensions of engineering culture (Godfrey & Parker, 2010). First, depoliticization connects to *an engineering way of thinking*; engineering should be objective and thus political and social concerns (like race, gender, disability) are often not valued in engineering or engineering education. Second, depoliticization connects to *an engineering way of doing*; engineering curricula, instructors, and students should strive to be objective and political and social concerns should be kept outside of the classroom. Third, depoliticization connects to *acceptance of difference*; if social concerns have no place in engineering, then there is little space to challenge the homogeneity of engineering or the centering of white, male values. Thus, depoliticization further centers masculine culture and exacerbates inequities.

Meritocracy

Meritocracy is the belief that “social advancement structures in the United States are fair and just” (Cech, 2014, p. 49). This ideology centers hard-work; anyone who works hard enough can succeed, and those who do not succeed must lack the work ethic and dedication of those who are successful (Cech, 2013). Meritocracy ignores the social systems that are specifically designed to advantage some and disadvantage others (Cech, 2013). Further, meritocracy provides an excuse for those who benefit from biased systems: instead of recognizing that the systems provide them an unfair advantage, they can fall back on the belief that they simply worked hard and anyone could get to that point, too, with hard work (Cech, 2013). Meritocracy is engrained in the broader United States culture and is prevalent in engineering, particularly in the belief that engineering should be 'hard' and that its hardness contributes to its prestige and status. This belief in hardness and difficulty is described as three-pronged by Stevens et al. (2007): "engineers work harder than other people" and "working very hard is a key measure of the worth of an engineer" thus engineers "deserve more material gain" (p. 9). Accordingly, meritocracy connects to *relationship to the environment* and underlies the other dimensions.

All three ideologies work together to protect existing power structures in engineering. Sociotechnical dualism siphons off all *social* concerns (like social justice and equity) and sets them aside in pursuit of objective, technical knowledge. Depoliticization further isolates social concerns with a prevailing belief that *social* and *political* concerns do not belong in engineering. Finally, should any *social* concerns break through or remain after the first two ideologies, meritocracy provides an explanation for any perceived social inequities – rather than power structures and biased systems being responsible for inequities, individuals can believe that the existing systems are fair, and that success can be earned through hard work.

2.2.4 Engineering Culture and Equity, Access, and Inclusion

As the discussion of these ideologies suggests, collectively they embody the ways in which engineering culture is heavily influenced by white, male, heteronormative norms (Cech & Rothwell, 2018; Cronin & Roger, 1999; Godfrey, 2015; Lewis et al., 1998; Tonso, 1996). These norms, in turn, establish power structures that implicitly (and sometimes explicitly) exclude people from underrepresented groups, creating barriers that are often metaphorically referred to as a chilly climate (Lichtenstein et al., 2015). This chilly climate can be as subtle as negative interpersonal relationships and as overt as favoritism and sexual harassment (Lichtenstein et al., 2015). Other indications of a chilly climate include “subtle and overt denigration of skills, attribution of attainment to affirmative action policies, and avoidance of eye contact” (Lichtenstein et al., 2015, p. 321). Importantly, the chilly climate can be particularly present in the classroom, so intentionally creating inclusive classroom spaces and drawing on “pedagogies of engagement” (e.g., cooperative learning, problem-based and project-based learning) are essential to combating the chilly climate (Lichtenstein et al., 2015, p. 323).

Moreover, globally, women and students from underrepresented minority groups face additional challenges and barriers to persistence beyond the barriers classified under the chilly climate. In the U.S., for example, research shows that the lack of role models and a lack of effective advising can impede progress in engineering for women and underrepresented minorities (Lichtenstein et al., 2015). Financial obstacles and work or family obligations can also impact retention of underrepresented students in STEM (Lichtenstein et al., 2015).

Similar findings about gender disparities in engineering education and industry have emerged from other countries (Jawitz et al., 2000, 2005; Male et al., 2018). In Australia, for example, Male et al. (2018) investigated the gender inclusivity of engineering workplaces through interviews with 13 students, building on a previous phase of the study which surveyed 160 students. The authors found that masculine cultures are present in the engineering workplace and made several recommendations for changing the highly masculine culture in the engineering workplace in Australia. In South Africa, Jawitz, Case, and Ahmed (2005) conducted focus groups and interviews with a total of 19 students after they completed a six-week period of vacation work. The authors found that gender and racial issues impacted undergraduate students’ experiences in the workplace. Namely, students who do not identify as white and do not identify as male often reported negative experiences in the workplace that affected their learning and feelings of self-worth (Jawitz et al., 2005). However, these gendered patterns in engineering are not universal across national contexts. For example, Atiq et al. (2018) highlights Malaysia, wherein women represent a near parity percentage of the workforce (Atiq et al., 2018; MWFCD and UNDP, 2014). The fact that significant gender disparities in engineering education and industry are not universal emphasizes the ways in which national cultures shape engineering experiences and further points to the fact that gendering engineering as male is not a universal norm.

Because of the chilly climate and additional barriers faced by women and underrepresented groups in STEM, engineering culture is a factor in student attrition, especially amongst underrepresented groups (Godfrey, 2015; Lichtenstein et al., 2015). Thus, much previous work on engineering culture is motivated, either implicitly or explicitly, by a desire to change the culture in order to increase equity and representation in engineering.

What we know about culture is captured during relatively stable times, and while engineering culture work often aims to spark large-scale changes to engineering culture, the culture has proved highly resistant to change. Research conducted during a crisis that has prompted rapid changes to ‘normal’ ways of operating facilitates the further investigate into why engineering culture is so resistant to change. Moreover, it allows us to discover whether the disruptions caused by the pandemic resulted in any enduring changes.

2.3 Benefits of Researching During Times of Stress: Opportunity of Researching COVID-19

Research on disasters shows us that extreme events – including the COVID-19 pandemic – can help illuminate underlying structural challenges and inequalities as well as tacit beliefs that motivate decisions. Previous research has investigated how higher education institutions have responded to crises, like natural disasters (Schuh & Santos Laanan, 2006), war and conflict (Czerniewicz et al., 2019; SchWeber, 2008), and the H1N1 influenza virus (Santibañez et al., 2009; Van et al., 2010).

First, scholars have examined how higher education institutions have responded to natural disasters from a student affairs perspective. For example, Schuh and Santos Laanan (2006) examined the forced transitions in higher education caused by Hurricane Katrina and Hurricane Rita. They profiled a hypothetical student and examined the challenges that student would face because of the forced transition, including housing and financial issues. The authors targeted a student affairs audience and emphasized that “the fragile lives of students must be a priority in terms of reducing the stress of an unexpected adjustment and forced transition” (Schuh & Santos Laanan, 2006, p. 102).

Second, scholars have investigated how higher education institutions have responded to war and conflict, offering lessons of resilience and examining of tensions in continuing the academic enterprise during times of war and conflict. For example, SchWeber (2008) investigated both a natural disaster (Hurricane Katrina) and a war (2006 war between Lebanon and Israel), offering lessons on resilience in higher education through a crisis. SchWeber (2008) focused on how institutions can respond to crises in a way that maintains students’ access to education. SchWeber (2008) offerd four principles for maintaining academic programs through crisis: 1) “adapt to the situation and problem solve”, 2) “expand upon existing resources”, 3) “quickly make and implement decisions”, and 4) “manage effectively in uncertain and unexpected situations” (p. 41). Similarly, Czerniewicz, Trotter, and Haupt (2019) examined the impact of widespread student protests in South Africa. In 2015 and 2016, the #FeesMustFall student protests called for free decolonial quality education, and the protests resulted in the closure of many South African higher education campuses for periods of days or weeks during the protests (Czerniewicz et al., 2019). Blended learning provided an opportunity to continue students' education during the protests, but was also highly controversial as the protests aimed to disrupt the academic enterprise (Czerniewicz et al., 2019). The authors examined tensions around the protests and shifting to blended or online learning from the perspective of academics, including concerns that blended learning would exacerbate inequality amongst the "socio-economically diverse student body" (Czerniewicz et al., 2019, p. 18).

Third, scholars investigated how responses to the H1N1 pandemic in 2009 highlighted a general lack of preparedness for pandemic disasters, both at a national level and within higher education specifically. Broadly, Santibañez et al. (2009) highlighted shortcomings in the United States' preparedness for future influenza pandemics, providing insights that are particularly stark in light of the realities of the COVID-19 pandemic. Further, they emphasized that vulnerable populations are at risk to experience disproportionate impacts from future pandemics. While Santibañez et al. (2019) did not focus on higher education, their findings emphasize, from a public health perspective, the heightened risk that vulnerable populations would face in an influenza pandemic. Alternatively, Van et al. (2010) situated their work within higher education and examined the responses of students and faculty in Australia to the H1N1 pandemic in 2009. The authors found that students and faculty did not perceive much risk associated with the virus; nearly 75 percent of students and faculty reported making no changes to the way they lived their life because of the virus (Van et al., 2010). The authors attributed this dampened risk perception to the mildness of H1N1. The authors suggested that universities invest in more effective health communication as well as online teaching resources (Van et al., 2010).

The studies discussed above help us understand how higher education institutions have responded to previous crises and how these crises have revealed underlying structural challenges and inequalities as well as tacit beliefs that motivate decisions. Universities often responded to previous crises by shifting classes online (Czerniewicz et al., 2019; Gelles, Lord, Hoople, Chen, & Meija, 2020; SchWeber, 2008), cancelling classes (Czerniewicz et al., 2019), or sending students to other institutions until the university was able to recover (SchWeber, 2008). Moreover, most of the studies discussed above emphasized equity concerns related to changing the mode of education in response to a crisis.

One additional study, Swartz, Gachago, and Belford (2018), more deeply explored these equity concerns, emphasizing the importance of care and compassion during times of crisis. Swartz, Gachago, and Belford (2018) reflected on the ethics of their teaching practices during the 2015 and 2016 student protests in South Africa. Specifically, they used an ethics of care framework to reflect on the ethics of continuing to teach despite protests that aimed to disrupt the academic enterprise; the ethics of asking students to continue engaging in academic work while simultaneously participating in protests of the academic system; and the ethics of shifting to online learning, when some students may not have the necessary resources to engage in online leaning (Swartz et al., 2018). Swartz, Gachago, and Belford (2018) acknowledged that the decision to continue teaching through blended or online outlets was a political act, emphasizing the importance of "reflecting on the ethics and politics of what we are doing unless we want to reproduce [the] hegemonic systems of oppression our students fight so hard against" (p. 62). Understanding the extent to which responding with care and compassion aligns with existing beliefs about engineering allows us to think and talk about engineering culture differently. If core beliefs in engineering run counter to responding to a crisis with care and compassion, perhaps those core beliefs are flawed.

2.4 Current Related Work Around COVID-19

The COVID-19 pandemic differs from previous localized disruptions to higher education because it is a long-term, ongoing, global disaster that prompted widespread mandates for online or remote learning around the world. COVID-19 thus provides an ideal opportunity to open new avenues for conversation about equity and accessibility in engineering by investigating dimensions of engineering culture during a crisis. Current work around the COVID-19 crisis has focused largely on student and faculty experiences, but it has not yet pushed beyond those immediate issues to look at the ways that existing belief systems impacted decision making and whether those belief systems remain resistant to change.

2.4.1 Funded Engineering Education COVID-19 Studies

In the U.S., the National Science Foundation (NSF) awarded a small number of RAPID grants to engineering education related COVID-19 studies immediately following the outbreak in March 2020. Table 2-4 lists the COVID-19 related RAPID awards granted by the Division of Engineering Education and Centers (EEC) of NSF during 2020. Table 2-5 lists the engineering education, COVID-19 related RAPID awards granted by the Division of Undergraduate Education (DUE) of NSF during 2020. These studies can be categorized as focusing on diversity & inclusion, student-centered concerns, faculty-centered concerns, online learning, and K-12 education.

Table 2-4: NSF EEC RAPID COVID-19 Education-Related Funded Projects in 2020

Project Title	**Category**	**Award Number and Link**
Approaches to online implementation and social support in undergraduate engineering courses	Online Learning, Faculty-Centered Concerns	2030083
Assessing the reactionary response of high school engineering teachers to COVID-19	K-12 Education	2033445
Engineering student mental wellness during the COVID-19 pandemic	Student-Centered Concerns	2029206
Faculty adaptability and community engagement when teaching in a crisis	Faculty-Centered Concerns	2027471
Impact of the COVID-19 pandemic on electrical and computer engineering programs at minority serving institutions served by the Inclusive Engineering Consortium	Diversity & Inclusion	2031717
The impact of COVID-19 on broadening participation in engineering at HBCUs	Diversity & Inclusion, Student-Centered Concerns, Faculty-Centered Concerns	2031221
Understanding the impact of abrupt changes to instructional methods on underrepresented engineering students	Diversity & Inclusion, Student-Centered Concerns	2029564
Using SenseMaker to investigate complex dynamics in social systems to inform agile, real-time policy responses in times of crisis	Student-Centered Concerns, Faculty-Centered Concerns	2028452

Table 2-5: NSF DUE RAPID COVID-19 Education-Related Funded Projects in 2020

Project Title	Category	Award Number and Link
Addressing equity when STEM teaching and learning go remote	Diversity & Inclusion	2029642
Collaborative proposal: Effects of institutional responses to the COVID-19 pandemic on undergraduate faculty and students across STEM disciplines	Student-Centered Concerns, Faculty-Centered Concerns	2029754
Exploring impacts of the COVID-19 pandemic on undergraduate STEM education by student gender, race/ethnicity, and socioeconomic status	Diversity & Inclusion	2028341
Impacts of unprecedented shift to online learning on students' cognitive load and readiness for self-directed learning	Student-Centered Concerns	2027637
Investigating effects of the disruptive shift to online courses on identity formation and self-efficacy of students and faculty in a first-year engineering course	Student-Centered Concerns, Faculty-Centered Concerns	2027506
Measuring the impact of the COVID-19 pandemic on STEM student engagement and learning in online learning environments	Student-Centered Concerns	2028224
Mitigating the potential negative impacts of involuntary online engineering courses to diverse students? Sense of belonging	Diversity & Inclusion, Student Centered Concerns, Online Learning	2037605

2.4.2 Published Engineering Education COVID-19 Studies

As Tables 2-4 and 2-5 show, these funded studies are dominated by a focus on impacts – seven of 15 include the term "impact" in the title, while two others use "effects." Only one, award number 2028452, explicitly focuses on the complex dynamics of the social system with an eye toward policy, and none address the deeper issues of the underlying culture. The work published to date from these and other COVID-related studies reflects this pattern, focusing largely on the impacts of the pandemic on students and faculty. A review of work in each category is provided below. Note, however, that COVID-related research continues to emerge with new work being published monthly if not weekly; hence the review here necessarily excludes work published after the submission of this dissertation in February 2022.

Student-Centered Concerns

Published studies have investigated student centered concerns, like student responses and experiences during the pandemic. These student-centered studies largely focus on students' health and wellbeing, which are inherently linked to engineering culture. A culture of stress and anxiety in engineering, which can impact students' health and wellness, has been identified by researchers (Jensen & Cross, 2018).

First, Danowitz and Beddoes (2020) investigated the effects of COVID-19 on engineering students' stress in the United States using a large-scale survey (N=670) of negative life events and disruptions caused by COVID-19. The authors argue that students already experience stress related to the engineering curriculum and that COVID-19 has added additional stressors. The authors found that some populations, namely Latinx individuals and international students, experienced more stress than the baseline population (Danowitz & Beddoes, 2020a). On the other hand, other populations – including women (race not indicated), Asian Americans (gender not indicated), African Americans (gender not indicated), and veterans (gender and race not indicated) – experienced the same or even less stress than the baseline population (Danowitz & Beddoes, 2020a). The study also emphasizes that different groups of students are more or less likely to be affected by different types of events, highlighting the need to understand the intersectional impacts of COVID-19 (Danowitz & Beddoes, 2020a). Overall, this study emphasizes the need to understand and prioritize engineering students' mental health and wellness.

Second, Miller and Jensen (2020) and Atman (2020) introduced student-centered techniques to show care for students and help them mitigate stress. Miller and Jensen (2020) discuss incorporating mindfulness activities into the end of each synchronous session of their upper-level engineering courses. They found that the activities were beneficial to students and communicated care, even if students chose not to participate in the activities (Miller & Jensen, 2020). Atman (2020) had students complete a check-in at the beginning of each synchronous class, indicating how they were feeling "in terms of hope/despair, stress/calm, and energy level" (p. 1). She also organized and facilitated a student group that met out of class called "Sketch & Kvetch," where participants talked about how they were doing and shared a sketch that they had prepared for the group (Atman, 2020). Atman found that both of the reflective activities had a positive impact on students.

Third, Jensen (2021) argues that higher education was facing a mental health crisis amongst its students prior to the onset of the pandemic. Further, she argues that "dramatic changes" were made to instruction in response to the pandemic, demonstrating "our ability to redesign engineering education to promote community and student physical health" (Jensen, 2021, p. 43). Jensen (2021) questions why engineering education can be redesigned around physical health and hasn't yet been redesigned around mental health. Lastly, Jensen (2021) argues that "shifting the culture in engineering," specifically the high workload, celebration of poor self-care, and meritocracy of difficulty, "is a first and necessary step towards addressing the mental health crisis" (p. 47).

Finally, Qadir and Al-Fuqaha (2020) provide suggestions that students can use to improve their learning in the online environment. They surveyed the literature for techniques that students can use to thrive in an outcome-based education (Qadir & Al-Fuqaha, 2020). They offer seven steps that engineering students can employ as they continue learning during COVID-19: "begin with the end in mind, upgrade your metacognitive skills, aim for holistic learning, become coachable, take ownership of learning, focus on developing authentic skills, and become a lifelong learner" (Qadir & Al-Fuqaha, 2020, pp. 3–4).

Faculty-Centered Concerns

Studies have also investigated faculty-centered concerns, like academic integrity, assessment, and course design. Gamage, de Silva, and Gunawardhana (2020) review methods of ensuring academic integrity in online environments. They discuss common approaches to assessment pre-pandemic and during the pandemic, as well as the academic integrity concerns that come along with each approach. The authors also review common reasons that students take shortcuts, including pressure for performance, lack of time, motivation, and interest, and cultural background. Concerns about cheating are common in literature relating to the ethics of online learning (Swartz et al., 2018), so it is not surprising that academic integrity is a concern in pandemic-induced online learning settings.

Next, Sheppard (2020) used storytelling as a method to report on her experiences responding to COVID-19 and the racial justice movement that began in June 2020. Rather than focusing on the ins and outs of online learning, Sheppard (2020) focuses on the importance of educators in higher education "being a teaching community that works together and promotes respectful relationships between all members to support personal and intellectual growth and flourishing" (Sheppard, 2020, p. 2). She identifies failings of her engineering education teaching community to “identify our own biases and passivity” as well as to be an “all-inclusive community” (Sheppard, 2020, p. 5).

Finally, Gelles et al. (2020) conducted a qualitative case study within an integrated engineering department at a single site in the United States in order to investigate how 11 students adapted to remote learning during COVID-19. Gelles et al. (2020) focuses on illustrating how engineering faculty can support students during remote learning and how students adapted to the crisis. Gelles et al. (2020) findings focused on characterizing challenges with and approaches to remote learning, finding that students faced significant challenges and used self-discipline strategies to overcome them. Gelles et al. (2020) also emphasized the importance of faculty members communicating compassion and being flexible in course requirements and assignments. They frame their study as counter to traditional engineering pedagogy and emphasize the value of permanently shifting towards a culture of care and compassion in engineering education (Gelles, Lord, Hoople, Chen, & Meija, 2020).

2.5 Present Study

Most research into engineering culture aims to increase equity by sparking large-scale changes, but the culture has proved highly resistant to such changes. However, COVID-19 prompted rapid shifts to remote learning and forced at least a small degree of change in the engineering education enterprise. While understanding cultural change is not the explicit goal of this study, this study enables future work to investigate cultural change.

This study aims to capture a snapshot of teaching and learning practices during COVID-19 at a single period within the unfolding pandemic, understanding how classroom-level practices changed during COVID-19 and mapping those practices onto Godfrey and Parker’s (2010) dimensions of engineering culture. As the world recovers from the COVID-19 pandemic, we can then compare accounts of engineering culture *before, during,* and *after* in order to understand if COVID-19 prompted lasting changes to engineering culture. Further, future work can examine if those changes, whether temporary or lasting, led to more equity and accessibility engineering.

3 Methods

The purposes of this study are to 1) understand what facets of engineering culture were salient in students' interpretations of their classroom experiences during the COVID-19 pandemic and 2) investigate how salient facets of culture differed across national contexts in order to 3) understand what an exploration of engineering culture during a disaster tells us about the culture itself. Accordingly, using the dimensions of engineering culture identified by Godfrey and Parker (2010) as a framework, this study is designed to investigate the following research questions:

RQ 1: How do the dimensions of engineering culture emerge in students' constructions of their experiences during the pandemic?

RQ 2: How did the presence of the dimensions of engineering culture vary across sites?

Drawing on a constructivist paradigm, I conducted a comparative case study focused on mechanical engineering students' perceptions of their experiences taking courses during the COVID-19 pandemic. A case is defined here as the collective perspective of mechanical engineering students at a given institution about their experiences taking courses during the pandemic. Interviews with key informants and university communications at each site provide context for each case.

To address my research questions and achieve theoretical and literal replication (Yin, 2018), I selected two large public institutions based on institution size, mechanical engineering program size, mechanical engineering curriculum, and national context. Between September and November 2020, I interviewed 10 to 11 mechanical engineering students at each site who were enrolled in second- or third-year mechanical engineering courses in March 2020. This criterion ensured that participants were enrolled in at least one 'middle years' course in the semester that the pandemic first impacted and could thus reflect on that experience during the interview (Lord & Chen, 2014). Additionally, in order to contextualize each case, I interviewed 1 to 2 key informants at each site and collected university communications related to the COVID-19 pandemic. I used deductive, inductive, and pattern coding, guided by Miles, Huberman, and Saldaña (2019), to condense the data and present findings within and across cases.

Section 3.1 describes the underlining worldview that guides my research. Sections 3.2-3.5 describe the details of my research design, data collection plan, and data analysis plan. Finally, Section 3.6 discusses the measures taken to ensure the quality of this research and Section 3.7 discusses the strengths and limitations of my research design.

3.1 Epistemology

Table 3-1 summarizes the epistemology, research focus, and methodology that inform and make up my research design.

Table 3-1: Summary of Research Design Components

Research Design Component	**My Approach**	**Description**
Epistemology	Constructivism	Participants' perspectives are trusted as their own reality; aims to identify consensus among multiple perspectives.
Research Focus	The influence of cultural beliefs and values in engineering on classroom-level responses during COVID-19	RQ 1: How do the dimensions of engineering culture emerge in students' constructions of their experiences during the pandemic? RQ 2: How did the presence of the dimensions of engineering culture vary across sites?
Methodology	Case study using: • Interviews • A priori/Inductive Analysis	Case studies are often informed by theory and use multiple sources of evidence to contextualize each case. Case studies are in-depth studies of a contemporary phenomenon.

Epistemologically, I adopt a constructivist worldview. Research conducted with a constructivist worldview aims to understand people's experiences by investigating individual reconstructions of the experience and identifying the consensus of those experiences (Guba &

Lincoln, 1994). Constructivist research does not aim to identify "facts" or an "objective reality" (Patton, 2002, p. 98). Rather, it aims to find consensus among "informed and sophisticated constructors" (Patton, 2002, p. 98). This study centers on making meaning from students' experiences. Students' self-reported experiences are taken as "real" (Patton, 2002, p. 98). While their perceptions should not be assumed to be more or less true than the perceptions of other stakeholder groups (e.g., faculty, administrators), this study centers student voices by design, and trusts and values students' perceptions and constructions of their own experiences. Even though other stakeholders may have different constructions of their experiences, in this study, students' constructions of their experiences are centered.

3.1.1 Theoretical Framework

Godfrey and Parker's (2010) six dimensions of engineering culture serve as the theoretical framework for this study. First, using these dimensions as a framework aligns with the purpose of Godfrey and Parker's work: "to develop a conceptual framework of cultural dimensions that has the potential to guide the understanding of culture in the context of engineering education" (Godfrey & Parker, 2010, p. 5). Importantly, Godfrey and Parker (2010) developed the dimensions by studying undergraduate engineering education at a four-year university, and my work studies this same setting. Next, other existing ways of conceptualizing engineering culture, like the ideologies of engineering culture, are embedded in the dimensions. Using the dimensions as my framework still allows me to explore concepts like *meritocracy* and *sociotechnical dualism* in the data.

In this study, the theoretical framework serves two purposes. First, it informed the development of the interview protocol. I intentionally designed questions to elicit responses around the dimensions. Second, it informed the data analysis process. In the first round of coding the data, I used the dimensions of engineering culture as an a priori framework in order to identify which dimensions of engineering culture are reflected in students' perceptions and experiences. The second round of coding identified emergent themes and subcodes within and beyond the existing dimensions. Cross-case analysis was then used to compare the themes that emerged in each case in order to identify commonalities and differences across the two study sites.

3.2 Research Design

Table 3-2 gives an overview of my research design, which I discuss and justify throughout the remainder of this chapter. I conducted a comparative case study of mechanical engineering students' experiences taking courses during the COVID-19 pandemic at two large, public universities. I recruited student participants at each institution and interviewed them about their experiences. These interviews were analyzed first by using a priori coding techniques, guided by Godfrey's dimensions of engineering culture, and second by using inductive coding techniques to identify themes not captured by the theoretical framework.

Table 3-2: Overview of Research Design

Element of Research Design:	**My Approach:**
Case Development	• Mechanical engineering students' experiences taking courses during the COVID-19 pandemic at two large, public universities.
Site Selection	• Literal replication factors include English-language instruction; large comprehensive universities with strong engineering programs; middle year mechanical engineering courses; mechanical engineering program size; and curriculum status. • Theoretical replication factors include nation; national and local responses to COVID-19; and demographic characteristics of the student body.
Recruitment Strategies	• Identify site coordinator for each site who could distribute recruitment email and link to screening survey to second- and third-year mechanical engineering students. • Schedule interviews with participants who completed screening survey.
Data Collection Approaches	• Conducted semi-structured interviews with students. • Conducted semi-structured interviews with key informants.
Data Analysis Techniques	• A priori coding using six dimensions of engineering culture. • Inductive coding to identify subcodes within the existing dimensions and, as needed, new codes to characterize additional beliefs that emerge. • Follow Miles, Huberman, and Saldaña's (2019) approach to iteratively condense, cluster, and display data.

3.2.1 Comparative Case Study

Case study is defined as "an empirical method that investigates a contemporary phenomenon ("the case") in depth and within its real-world contexts, especially when the boundaries between phenomenon and context may not be clearly defined" (Yin, 2018, p. 15). A comparative case study examines and makes comparisons between two cases. Accordingly, comparative case study is a particularly well-suited approach for this study because this study investigates a contemporary phenomenon (Yin, 2018) (i.e., how engineering culture influenced mechanical engineering departments' responses to COVID-19) within the context of a broad set of real-world events (e.g., the COVID-19 pandemic, the Black Lives Matter movement in the U.S., prior #FeesMustFall student protests in South Africa) (Yin, 2018). Further, Yin (2018) argues that case study research "comprises an all-encompassing mode of inquiry," not limited to solely a data collection tactic or design feature (p. 15). Accordingly, a comparative case study approach allows me to collect and analyze a variety of data sources as I develop a description of each case. Finally, comparative case study supports the use of guiding frameworks and can be used to develop or confirm theory (Yin, 2018). Thus, a multiple case study approach supports my use of Godfrey's six dimensions of engineering culture as a theoretical framework.

3.2.2 Overview of the Study

To answer the research questions, I implemented a four-phase research process, shown in Figure 3-1. Phase 1 is the data collection phase, wherein I conducted interviews with students and key informants. In Phase 2, I used Miles, Huberman, and Saldaña (2019) as a guide to conduct deductive and inductive coding in order to develop a codebook and condense the data for each case. I then used pattern coding to identify salient themes within each case. In Phase 3, I looked across cases to identify collective themes, and in Phase 4, I drew conclusions about the findings and used data display techniques to summarize the findings.

Figure 3-1: Graphical Depiction of Study Phases

3.2.3 Case Development

In this study, a case is defined as the collective perspective of mechanical engineering students at a given institution about their experiences taking courses during the pandemic. Importantly individual students are not each their own case; rather, students are considered *subunits* of each case. These case and subunit definitions are summarized in Figure 3-2.

Mechanical engineering was chosen as the discipline of focus in order to reduce variables associated with differences in engineering subdisciplines and curricula and because mechanical engineering is a common discipline across most engineering programs. Choosing to focus on mechanical engineering allowed me to investigate how the dimensions of engineering culture impacted student experiences without having too broad a scope (multiple engineering disciplines) or too narrow a scope (one student's experience).

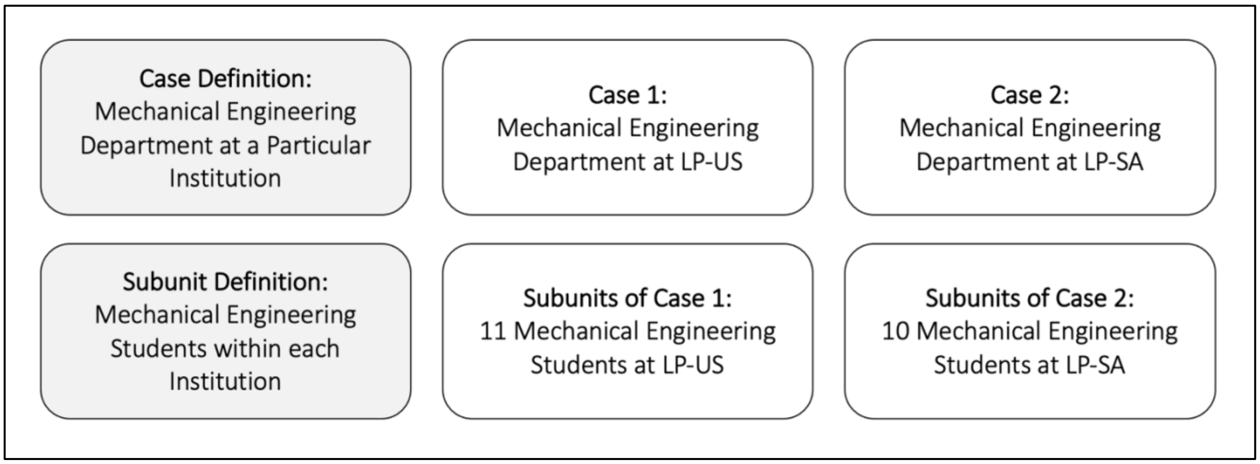

Figure 3-2: Definition of Case and Subunits

Each case includes two data sources, as detailed in Table 3-3. Given my study's focus on investigating student experiences during the pandemic and interpreting their experiences through the dimensions of engineering culture, semi-structured interviews with students are the primary source of data. However, I acknowledge that student perspectives can vary from faculty perspectives, so I conducted interviews with key informants (i.e., mechanical engineering faculty) in order to gather necessary context about faculty perspectives on each site's response to COVID-19.

Table 3-3: Case Data Sources

Data Source	Quantity	Description
Student Interviews (*primary data source)	10 - 11 per site	Semi-structured interviews guided by dimensions of engineering culture to gather participants' experiences taking courses during COVID-19
Key Informant Interviews	1 - 2 per site	Semi-structured interviews to provide context and a triangulation method for student interviews

3.2.4 Site Selection

Yin (2018) argues that multiple case study should be viewed similarly to conducting multiple experiments (i.e., replication), rather than viewing multiple case studies as similar to multiple respondents to a survey. In the multiple experiment analogy, each case study is a unique "experiment" where multiple cases allow for replication. In contrast, cases should be selected such that they predict similar results (literal replication) or predict different results for a predictable reason (theoretical replication). This approach allows for *analytic generalizability*, wherein the research expands and generalizes theories (Yin, 2018). Statistical generalizations – extrapolating to a population – is not the goal of case study research.

Two sites were then selected for this study. While this study was limited to sites where I had access to potential collaborators, I aimed to select sites with a sufficient number of comparable variables in order to ensure the two sites could be compared, yet enough differences to explore the potential impact of national context. LP-US is a large public university in the mid-Atlantic region of the U.S. LP-SA is a large public university in South Africa. Several factors were considered when selecting these sites, some aimed at literal replication (Yin, 2018) and some aimed at theoretical replication (Yin, 2018), as summarized in Table 3-4 and discussed below.

Table 3-4: Literal and Theoretical Replication Variables

Variables aimed at Literal Replication	Variables aimed at Theoretical Replication
Virtual Learning during COVID-19	Nation

Variables aimed at Literal Replication	Variables aimed at Theoretical Replication
Middle-year ME Courses	National and Local Response to COVID-19
Public, Comprehensive University	Demographic Characteristics
University Size	Dominant Mode of Instruction
ME Program Size	

Literal Replication

There are several shared characteristics between each site that aim for literal replication in order to make comparisons between both cases useful and meaningful. First, both universities are public and comprehensive with strong reputations as research universities and both offer engineering and non-engineering degrees. Second, both universities shifted to remote learning in March and April 2020 as a result of COVID-19, sending residential students home. Moreover, both have similar middle-year mechanical engineering curricula. Third, both programs are large: the LP-US program has around 1200 students and the LP-SA program has around 800 students. When contextualized with the total undergraduate enrollment at each university, each mechanical engineering program educates the same share of students – 4%. Finally, both universities are relatively large: LP-US has around 30,000 undergraduate students and LP-SA has around 20,000 undergraduate students.

Theoretical Replication

In addition to shared characteristics aimed at literal replication, there are important differences between the two sites aimed at theoretical replication that can illuminate meaningful differences between both cases. First, each site represents a different national context and a different national response to COVID-19. The U.S. adopted a state-by-state national approach rather than a single coherent national strategy in responding to COVID-19, resulting in wide variations across the country in how states and institutions responded. In contrast, South Africa adopted a more unified, top-down national approach, where the government declared a "national state of disaster, banned international travel, closed schools, restricted gatherings, and promoted social distancing and hand hygiene" ("The South African Response to the Pandemic," 2020, p. 1). As a result, the U.S. institution allowed individual instructors to determine the mode of instruction in the second half of 2020 (e.g., asynchronous, synchronous, face-to-face) while the South African institution required all courses be asynchronous throughout the response, with the exception of a handful of senior-level laboratory courses.

Second, the demographics of each university are different, reflective of different demographics in each country (see Table 3-5). At LP-US, the majority of students are white at 62%, which is on par with the national demographics in the U.S. At LP-SA, the majority of students are Black at 45%, which includes students who identify as Black South African, colored, Indian, Chinese, and Asian. However, the percentage of Black students at LP-SA is significantly lower than the national demographics in South Africa.

Table 3-5: Racial Demographic Characteristics of Countries and Sites

United States				**South Africa**		
Demographic Category	Country (% population)	LP-US (% undergraduate students)		**Demographic Category**	Country (% population)	LP-SA (% student population)
White	60%	62%		Black (incl. Black South African, colored, Indian, Chinese, Asian)	91%	45%
Hispanic or Latino	18%	7%		White	9%	22%
Black or African American	12%	5%		Another Race	1%	18%
Asian	5%	11%		International Students	n/a	15%
International Students	n/a	3%				
Other	5%	12%				

Source: (*Census 2011: Census in Brief*, 2012; *Transformation Report - 2018*, 2018; The Office of Analytics & Institutional Effectiveness, 2020; U.S. Department of Commerce: Economics and Statistics Administration, 2011)

Mechanical Engineering Departments

While researchers often treat engineering as a monolith, a number of studies have identified cultural and epistemological differences among engineering subdisciplines (Agrawal et al., 2018; Becher, 1981; Groen, 2017). To bound the study and limit variation introduced by discipline, I chose to focus on a single department at both institutions. Mechanical engineering was chosen because it is commonly regarded as a versatile engineering discipline and because it is a common and prominent discipline across most engineering programs. Together with civil engineering, mechanical engineering is one of the oldest engineering disciplines and is the archetypal engineering design field. In order to investigate dimensions of engineering culture, participants need to be actively engaging in those discipline specific courses. Further, students taking second- and third-year courses were chosen because the majority of core, discipline specific courses are taught in the second and third year (see Table 3-6). The choice of *taking* second- and third-year courses, as opposed to requiring that students be in their second or third year, was intentional. This choice ensured that participants were enrolled in those core, discipline specific courses, and allowed for flexibility for students who were not following the traditional timeline (e.g., a transfer student from a community college or a fourth-year student planning to take five years).

Nearly all the second- and third-year mechanical engineering classes are common across both universities, as shown in Table 3-6. The majority of technical, major specific courses at both universities are taught during the second and third years. Additionally, second-year students at both universities take several math/science courses, and second- and third-year students at both universities take a handful of design and electrical engineering courses.

Table 3-6: Middle Year Courses at LP-US and LP-SA

Course Topic (general names to maintain site anonymity)	**LP-US**		**LP-SA**	
	Year 2	**Year 3**	**Year 2**	**Year 3**
Math/Science Courses				
Calculus (final course in sequence)	X		X	
Differential Equations	X		X	
Programming	X			X
Statistics	X		*n/a*	
Mechanical Engineering Courses				
Statics	X		*Year 1 Equivalent*	
Dynamics / System Dynamics	X	X	X	X
Deformable Bodies	X		X	
Thermal Fluids / Thermodynamics	X	X	X	X
Material Engineering		X	X	
Controls or Vibrations		X		X
Heat & Mass Transfer		X	*Year 4 Equivalent*	
Electrical Engineering Courses				
Electrical Engineering	X		X	
Electronics / Energy Conservation		X		X
Design / Lab Courses				
Design & Economics	X		*n/a*	
Manufacturing Lab / Machine Design	X		X	
Mechanical Design		X		X
Professionalism	*Year 4 Equivalent*			X

3.3 Recruitment Strategies and Participants

The recruitment strategies used in this study along with a description of the sample are described below.

3.3.1 Recruitment

In order to construct each of the two cases, I recruited students who were enrolled in second- or third-year mechanical engineering courses during March 2020 at the selected sites; note that even though interviews occurred between September 2020 and November 2020, the selection criteria remained taking second- or third-year mechanical engineering courses during March 2020. Existing professional contacts at each site were leveraged in order to identify site coordinators (an academic faculty member or administrative staff member in mechanical engineering) at each site. Identifying site coordinators was important because it allowed me to access proper human subject research approvals at each site. Moreover, site coordinators were able to distribute or facilitate the distribution of the recruitment email, and students were more likely to respond to an email sent from a known contact. Recruitment for the data that is used in this study occurred between September 2020 and November 2020 at both sites.

Student Recruitment

Students were recruited through the distribution of a recruitment email, which contained a link to a screening survey wherein students could indicate their interest in participating in an interview. In the recruitment email, students were informed that they would be compensated with a $20 gift card for their participation in the study. The screening survey (Appendix A) asked students which mechanical engineering courses they had taken in Spring 2020, their perceived level of difficulty in taking remote courses, and their email address. The screening survey served multiple purposes. First, it allowed me to confirm that students had taken second- or third- year mechanical engineering courses in March 2020. Second, it allowed me to confirm that students were willing to participate in an interview and gave me a way to contact them. Third, it allowed me to select students from across perceived levels of difficulty to ensure I had a balanced sample. After reviewing responses, I invited the selected students to review the consent form and sign up for an interview. I did not collect any demographic information until after the interview, so I was not able to recruit based on gender, race/ethnicity, or other identity-based factors. I waited to collect demographic information so as not to activate stereotypes prior to data collection (Steele, 2010).

My goal was to recruit 12 student participants from each site. Recruitment at LP-US and LP-SA began in September 2020. At LP-US, 28 students completed the screening survey, 14 students were contacted for interviews, and 11 students completed interviews. At LP-SA, 18 students completed the screening survey, 12 students were contacted for interviews, 11 students completed interviews, and 10 interviews were successfully transcribed. The audio for the final interview was too poor in quality, due to a poor internet connection during the interview, to transcribe.

Table 3-7 give insight into how student participants were selected for the study. The table shows how many respondents to the screening survey were invited to participate in interviews at each site, how many of those invited completed an interview (that is included in this study), and their perceived level of difficulty taking courses to date during the pandemic. When I had more than 12 participants respond to the screening survey, I sent out interview invitations evenly across perceived difficulty level. However, if I had 12 or less respondents, I invited them all to complete an interview regardless of difficulty level.

Table 3-7: Student Participant Selection – Perceived Difficulty Level

Site	**Perceived Difficulty Level**							
	1 – It wasn't ideal, but I did fine.		2 – It was a little tough, but overall I managed.		3 – I did okay with some things, but not with others.		4 – Honestly, it was pretty rough around.	
	Invite	**Interview**	**Invite**	**Interview**	**Invite**	**Interview**	**Invite**	**Interview**
LP-US	7	2	13	4	8	2	9	3
LP-SA	2	2	6	6	3	2	2	0

Table 3-8 provides a demographic breakdown for the student participants in the study by gender, race/ethnicity, disability status, and year in university. Students completed a demographic survey after participating in an interview. The demographic survey was open-ended and asked participants to identify their gender, race/ethnicity, ability status, level of access to the internet, and year in university at the time of interview. Recall that the selection criteria required students to be enrolled in second- or third-year courses in March 2020. At LP-US, some participants were in their 5th year at the time of interview but were still enrolled in second- or third-year courses in March 2020. Additionally, note that demographic information is provided in aggregate in order to protect participants' identities.

Table 3-8: Student Participant Demographics

Site	**Gender**		**Race / Ethnicity**			**Disability Status**		**Year in University**				**Total**
	Male	Female	White	Black	South Asian	Yes	No	2nd	3rd	4th	5th	
LP-US	9	2	9	0	2	3	8	1	2	4	4	11
LP-SA	4	6	2	8	0	1	9	5	5	0	0	10

Key Informant Recruitment

Key informants were recruited differently than students because emails from department personnel could have created a pressure to participate. In order to avoid any perceptions of pressure to participate in the research, the recruitment email was sent by a member of the research team. Key informants needed to have direct knowledge of second- and third-year mechanical engineering courses and the broader departments' transition to remote teaching. Faculty teaching second- and third-year courses were recruited to be key informants, as they could provide a balancing perspective to the students. One key informant was recruited from LP-US and two key informants were recruited from LP-SA.

All mechanical engineering faculty who were listed as teaching at least one second- or third-year mechanical engineering course on the respective university's public timetable were contacted. Similar to the student recruitment email, faculty were asked to respond to a short screening survey (Appendix A). The screening survey asked faculty which Mechanical engineering courses they had taught in Spring 2020, their perceived level of difficulty in teaching remote courses, and their email address.

My goal was to recruit at least two key informants at each site. At LP-US, one faculty member completed the screening survey and went on to complete an interview. At LP-SA, three faculty members completed the screening survey, all were contacted for interviews, and two completed interviews in October and November 2020.

3.3.2 Sample

Table 3-9 provides a summary of the data collected at each site for the analyses in this study. Eleven students from LP-US participated in the study and 10 students from LP-SA participated. Because of the challenges associated with recruiting key informants, I used the LP-US key informant interview from the pilot round of data collection to develop the LP-US case. All LP-US student participants were interviewed in September and October 2020, and all LP-SA participants were interviewed in October and November 2020.

Table 3-9: Summary of Data Collected

	Student Interviews	**Key Informant Interviews**
LP-US	11	1
LP-SA	10	2
Total	21	3

3.3.3 Participant Protection

Several measures were taken to ensure participants understood the practices in place to protect them. Participants were sent an electronic consent form survey when they were contacted to schedule an interview, so they had ample time to review the study procedures. When participants joined the interview Zoom meeting, they were asked if they had any questions about the consent form. Participants were then emailed their compensation and reminded that they were free to stop participating at any time without penalty (i.e., they could keep the gift card). Participants were also reminded that they could contact the researcher after the interview to delete some or all of their data. After the interview, transcripts were anonymized to remove names and any other information that could identify the participant or the site. Further, demographic information is reported in aggregate so that participants from particularly small groups are not identifiable.

3.4 Data Collection

Two forms of data are being collected for each case in this study: student interview data and key informant interview data. The development of these interview protocols is discussed below.

3.4.1 Interviewing and Interview Protocols

This study uses qualitative interviews as the primary data collection tool. Interviews are common and important sources of evidence in case study research because they collect first-hand accounts and can suggest explanations of the key events and phenomenon under investigation (Yin, 2018). Moreover, interviews align with my epistemology and allow me to gather rich descriptions of the phenomena from the perspective of those experiencing it. In this study, interviews were semi-structured and lasted about one hour. All interviews were conducted via Zoom. Most participants joined with their video on, but some participants kept their video off or called into the meeting via phone. I developed two interview protocols, one for students and one for key informants. These protocols can be found in Appendix B and Appendix C, respectively.

Godfrey's dimensions of engineering culture and Schein & Schein's (2017) conceptualization of culture were used to develop the interview protocol in order to ensure that the interviews appropriately captured the key dimensions of culture. Table 3-10 details the influence of my theoretical framework and research questions on the interview protocol.

Table 3-10: Student Interview Questions and Anticipated Contribution of Data

Interview Questions and Prompts	**Theoretical Influence**	**Research Question**
1. Can you walk me through from when the announcement was made that we'd be transitioning to remote/online teaching & learning until now? What has gone well? What has not gone well? **Prompts:** - 1a: What changed and what do you think of those changes? - 1b: Why do you think those things changed / didn't change? Feel free to speculate. - 1g: Did anything surprise you about how any of your classes went? If yes, what surprised you? Why? If not, why were you not surprised?	- Constructivist Worldview	RQ 1, 2
1c: How did the remote portion of the semester compare to your beliefs about how engineering classes should be taught?	- An engineering way of doing	RQ 1, 2
1d: Did the level of difficulty or workload change in any of your classes?	- An engineering way of doing	RQ 1, 2
1e: Did your instructors address the transition online? Why do you think they did/didn't?	- An engineering way of doing	RQ 1, 2
1f: Did your instructors talk about the pandemic at all during the semester? Why do you think they did/didn't? How do you feel about that choice?	- An engineering way of doing	RQ 1, 2
2. Can you talk a bit more about what went well in your classes and what didn't go well? **Prompts:** - 2a: What were the main differences between the class(es) that went well and the class(es) that didn't go well? - 2b: What are your thoughts about how the instructor(s) managed the remote portion of the course overall? 2c: What were the main differences between instructional practices that were effective and ineffective?	- Constructivist Worldview	RQ 1, 2
2d: Can you tell me a bit more about how your instructors approached tests/quizzes exams? **Prompts:** - Did it seem like cheating was a concern? - Why do you think they were worried about cheating? Do you think they should have been concerned about cheating?	-An engineering way of thinking -An engineering way of doing	RQ 1, 2
3. Are there any instructional practices that your professors adopted during this time online that you want them to continue after the pandemic? Any instructional practices you'd be happy to leave behind?	- An engineering way of doing - Resilience	RQ 1, 2

Interview Questions and Prompts	Theoretical Influence	Research Question
4. Did you take any non-engineering courses? If not, are you able to compare your experience to the experience of those in non-engineering departments? **Prompts:** - What similarities and/or differences did you notice between your engineering and non-engineering courses? - Why do you think those things are similar or different? - Why were your engineering classes different? Is it something about engineering? Is any of this specific to engineering? Why?	- An engineering way of thinking - An engineering way of doing - General beliefs and values unique to engineering	RQ 1, 2
5. How prepared do you feel for what you want to do next? Did these online courses impact how prepared you feel?	- Being an engineer - Relationship to the environment	RQ 1, 2
6. What kind of factors do you think your *instructors/lecturers* considered when making the choices they did about moving their classes online?	- An engineering way of thinking - An engineering way of doing	RQ 1, 2
6a. What kind of factors do you think your *department* considered?	- Relationship to environment	RQ 1, 2
6b. What kind of factors do you think your *university* considered?	- Relationship to environment	RQ 1, 2
7. Are there any factors that you wish your instructors/department/university had considered?	- Relationship to environment	RQ 1, 2
8. What do you want your faculty / instructors to know about how this pandemic impacted you as a student?	- Opportunity to share more personal details	RQ 1, 2
9. Anything else that is important for me to capture about your experience?	- Catch-all for additional insights.	RQ 1, 2

Schein & Schein (2017) describe three levels of culture: artifacts, espoused beliefs and values, and basic underlying assumptions. In order to access deeper levels of culture, like espoused beliefs and values and basic underlying assumptions, I continuously probed about *why* my participants believed what they believe and made the decisions that they did. For example, I asked participants how their instructors adapted their assessments, which often received artifact-level responses. Participants often mention test taking tools like their Learning Management System and video conferencing. Then, I ask participants why they think their professors gave exams in that manner. This question probes deeper into underlying assumptions. Sometimes, participants would identify incongruencies between the professors' practices and their perceptions of what was appropriate. I'd then ask participants what they thought about the professor's approach – was it warranted? These answers helped me get closer to the basic underlying assumptions. Participants talked about their beliefs about the purpose of education and the role of cheating. I rely on these probing "why" questions along with Godfrey's existing framework to uncover the hidden layers of engineering culture.

The key informant protocol is based on the student interview protocol. This protocol asks similar questions but changes the phrasing to be appropriate for the participant. For example, key informants were asked to walk through their decision-making process for moving their courses online, and they were asked to reflect on how students responded to the changes online. They were also asked to provide context about their approach, their department's approach, and their university's approach to remote learning. Because the key informant interviews are only used to contextualize the findings and because the interview protocol is based on the student interview protocol, I do not provide a mapping of the key informant interview questions to the theoretical influence and research questions.

I piloted the protocols in May and June 2020 by interviewing four students and one key informant at LP-US. These interviews were analyzed at a high level (i.e., reading transcripts and memos to identify initial themes and assess the interview protocol), and the interview protocol was then refined in order elicit broader, more narrative-like responses and reflections on participants' department, institutions, and decision-making processes. The refined protocol also prompted students to make more comparisons between their engineering and non-engineering classes and invited participants to discuss the broader engineering and university systems.

3.4.2 Ethics Review

This study was reviewed and approved by the Virginia Tech Institutional Review Board (VT-IRB #20-414) and by the appropriate university ethics boards for individual sites prior to data collection. Participant confidentiality and anonymity was maintained using practices approved by IRB: anonymizing sites, assigning pseudonyms to participants, removing potentially identifying information from transcripts, storing identifying information separately from participant data, and storing all data on password-protected computers. Interviews were audio-recorded as long as participants granted verbal permission at the beginning of the interview. The audio recordings were transcribed verbatim for analysis.

3.5 Data Analysis

My analysis process follows Miles, Huberman, and Saldaña's (2019) approach to qualitative analysis and is summarized in Figure 3-3. The data condensation and pattern coding phases were conducted within-case, followed by a cross-case analysis. Then, I used data display techniques to summarize my findings within and across cases. Figure 3-3 also summarizes the quality measures that I employed in this study, which are discussed further in section 3.6.

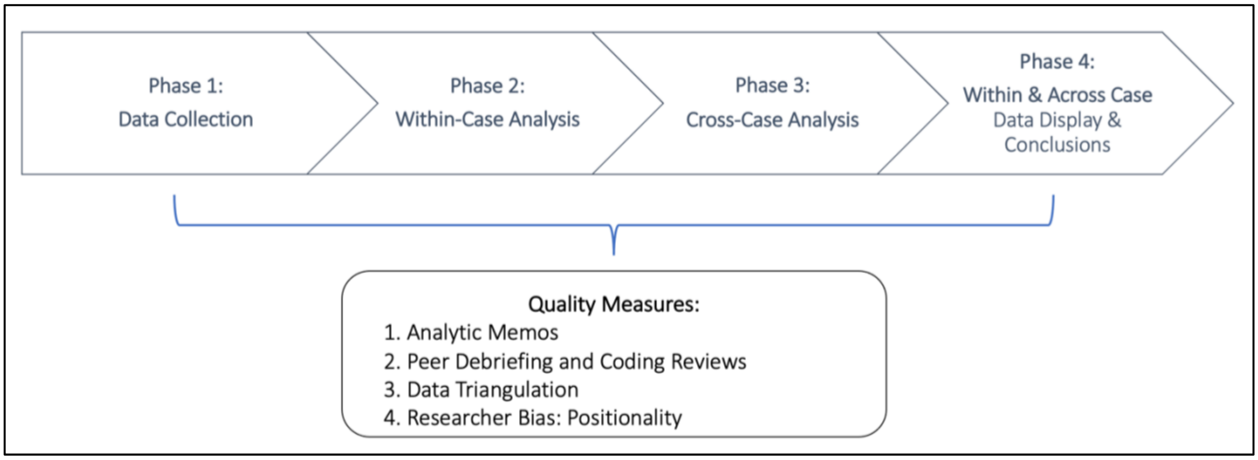

Figure 3-3: Analysis Overview

3.5.1 Within-Case Analysis

I began by analyzing each case separately. This within case analysis followed an iterative four-step process, as shown in Figure 3-4, that combines deductive and inductive coding.

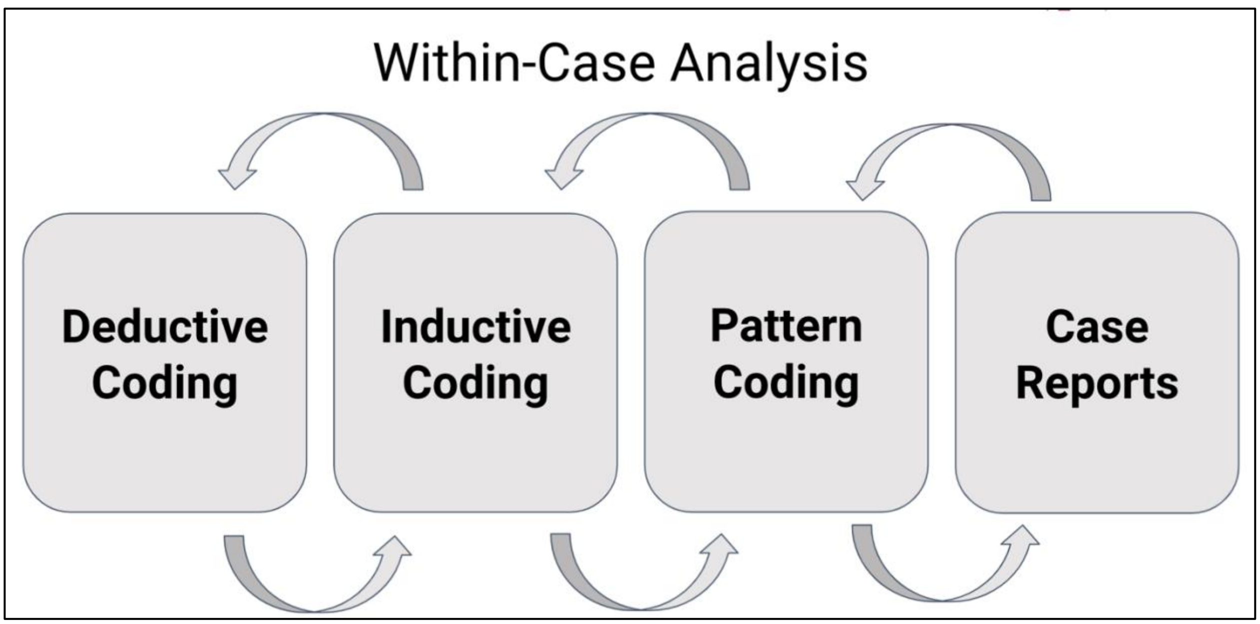

Figure 3-4: Within-Case Analysis

The combination of deductive and inductive coding supported my analysis in a number of ways. Using deductive codes developed from the theoretical framework allowed me to answer my research questions, anchoring my analysis in the framework and leveraging Godfrey's extensive ethnographic work. Then, the inductive analysis allowed me to identify subcodes within each dimension, as well as any insights not captured via the theoretical framework in the first round of coding.

Deductive Coding: A Priori Codes

For each case, I started by deductively coding each interview using the dimensions of engineering culture as a priori codes (shown in Table 3-11). I read through each interview, pulling each paragraph of text into an excel sheet and applied an a priori code. During this first round, I added an initial in vivo subcode to each excerpt in order to capture the general idea discussed in that excerpt. There were 590 unique in vivo subcodes applied during this round of coding. In order to avoid losing context as I split excerpts, I assigned each excerpt an ID number. That way, I could go back to the excerpts before or after and find the context, if needed. I also removed identifying information and added details in brackets to excerpts in order to capture the topic.

Table 3-11: Initial Codebook based on Godfrey's (2015) Cultural Dimensions

Code	**Definition**
An engineering way of thinking	Kinds of knowledge that are valued; practice vs. theory
An engineering way of doing	How teaching and learning should be done; hardness, rigor, cheating
Being an engineer	Identity and enculturation into engineering
Acceptance of difference	Tendency to privilege homogeneity; fitting in; norm within engineering
Relationships	The 'right' way to relate to others in engineering; importance of friends and peers
Relationship to the environment	Broader institutional, professional, and national context
Other	Other

Inductive Coding and Pattern Coding

To refine my first round of coding, I looked at each dimension individually. First, I pulled all of the excerpts that had been coded as a given dimension into an excel sheet and then went through each dimensions separately. I started by sorting each dimension's codes alphabetically by initial in vivo subcode. Then, I pulled each unique in vivo subcode into a separate document and looked for themes across in vivo subcodes. Through this process, I refined the large number of unique subcodes into a smaller amount of subcodes.

I then returned to the data and recoded the excerpts based on the refined list of subcodes. If an excerpt fit into a refined subcode, I added that subcode to that line of data. If, on the other hand, I no longer agreed that an excerpt belonged in that dimension, I moved it to the dimension it belonged to or added it to the "other" tab of my spreadsheet. Table 3-12 shows the example of LP-US, where the total number of subcodes at the end of deductive coding was 509, while the total number of subcodes after inductive coding was 107.

Table 3-12: Example of Number of Subcodes by Round of Coding and Dimension for LP-US

	Deductive Coding		**Inductive Coding**		**Pattern Coding**
	No. Subcodes	No. Excerpts	No. Subcodes	No. Excerpts	No. Themes
An Engineering Way of Doing	290	469	17	399	5
An Engineering Way of Thinking	42	57	28	42	4
Being an Engineer	56	65	5	9	4
Acceptance of Difference	53	77	29	66	3
Relationships	76	111	10	91	5
Relationship to the Environment	73	104	18	109	5
Total	590	883	107	716	26

Next, I used pattern coding to further refine the remaining subcodes into a smaller number of meaningful themes. Pattern coding is a method for condensing large amounts of data and codes into a "smaller number of analytic units (e.g., categories, themes, concepts)" (Miles et al., 2019, p. 79). After condensing the data into the a priori dimensions during the deductive phase and reducing the number of subcodes in the inductive phase, I conducted pattern coding in order to refine my analysis into more meaningful categories, explanations, relationships, or theoretical constructs (Miles et al., 2019). Once I had gone through each excerpt and assigned it a new subcode in the inductive phase, I resorted my spreadsheet alphabetically by subcode. I looked for overlap between subcodes in order to identify broader, overarching themes. As shown in Table 3-12, the subcodes were reduced into five or fewer themes for each dimension, leaving 26 themes overall.

At this point, I looked at all of the themes across all dimensions in order to identify if themes were unique within dimensions. Through this process, identified that while some themes were unique to a given dimension, other themes spanned multiple dimensions. This realization led me to switch from reporting the data by dimension to reporting the data by theme. In order to determine which themes were most salient in the data, I constructed a table with the unique themes and counted how many interviews each theme appeared in. These themes could be unique to a single dimension or could span multiple dimensions. If a theme appeared in 75% or more interviews, I considered it a salient theme and included it in the results section.

Case Report

Developing the case report for each case was an iterative process. First, I used information gleaned from the interviews about how each institution responded to the pandemic in conjunction with publicly available communications from each university about the response to write the site description and response summary for each case. Additionally, I used insight from the key informants to construct the site description for each case. I looked across sources of information to identify the key features of the site and key features of the pandemic response for each case. The case report for each case reflects all of these sources of information.

Data Display

Once I determined the larger patterns and themes within my data, I use data display techniques to summarize my findings within and across cases. Specifically, I use matrices and networks, drawing on guidance in Miles, Huberman, and Saldaña (2019). Matrices, or tables, make data easily viewable in one place, allow for detailed analysis, and “set the stage for later cross-case analysis” (Miles et al., 2019, p. 105). Networks are a “collection of *nodes* or binds connected by *links* or lines that display streams of participant actions, events, and processes” and can be particularly useful in displaying the storyline of events over time and showing complex relationships between variables (Miles et al., 2019, p. 109).

I used tables (i.e., matricies) to display salient themes and provide definitions and frequencies of those themes. Additionally, I constructed a concept map (i.e., network) for each site based on the themes and subcodes found through pattern coding. This concept map, provided in Chapter 4, show how the themes and subcodes interact and relate to one another.

3.5.2 Cross-Case Analysis

Once I completed each case report and identified the most salient findings for each case, I conducted a cross-case analysis to identify commonalities and differences across the two study sites, allowing me to answer my second research question. I compared the site description, response summary, and salient themes in order to identify the common features across both sites and the differences. Common features pointed to aspects of engineering culture that are common across national contexts, and differences can pointed to aspects of engineering culture that vary by national context. Once I determined the larger patterns and themes within each case, I used a data display technique, specifically matrices, to summarize findings across cases (Miles et al., 2014). I used tables, or matrices, to display the key similarities and differences across cases in order to clearly and simply compare across cases.

3.6 Ensuring Quality

In order to enhance the quality of this study, I utilized a range of strategies aimed at reliability[3] and trustworthiness[4]. To produce reliable research whose procedures could be replicated, I provide descriptions of the data collection and analysis procedures. Moreover, I include a detailed description of the qualitative codebook development. To produce trustworthy results, I use analytic memos, peer debriefing, data triangulation, and reflexivity. These techniques align with common techniques in case study. For example, to achieve construct validity as defined by Yin (2018), I use peer debriefing and data triangulation. More detailed descriptions of these techniques are provided below.

3.6.1 Analytic Memos

This study uses analytic memos, which capture my insights, potential themes, and connections between themes and my theoretical framework, in order to ensure that my insights and interpretations were not lost over time and help develop findings. I wrote memos after interviews, capturing what stood out to me about the interview and noting any themes I was noticing across interviews. Additionally, I transcribed some of the interviews myself, and kept memos of themes and connections to the theoretical framework. I continued to memo throughout the data analysis process in order to capture emerging themes and connections between

[3] "Demonstrating that the operations of a study – such as the data collection procedures – can be repeated, with the same results" (Yin, 2018, p. 42)

[4] "How we can determine whether we have accurately described the settings and events [and] participants' perspectives" (Leydens et al., 2004, p. 67)

interviews and sites. These analytic memos help boost the credibility, dependability, and trustworthiness of this study.

3.6.2 Peer Debriefing and Coding Reviews

Peer debriefing involves asking researchers who are familiar with the phenomenon being explored but not directly involved in the given project to review the findings (Borrego et al., 2009; Creswell & Miller, 2000). A peer reviewer "provides support, plays devil's advocate, challenges the researchers' assumptions, pushes the researcher to the next step methodologically, and asks hard questions about methods and interpretations" (Creswell & Miller, 2000, p. 129). This process of peer debriefing and coding reviews helps establish trustworthiness and credibility. Additionally, peer debriefing allowed me to practice reflexivity by viewing the data through the lens of other researchers.

In this study, I involved peer researchers (i.e., members of my research group and peers familiar with engineering culture research) throughout the data analysis process, asking them to review my codebook, review a subset of coding, and review my overall findings. First, I conducted two coding review sessions with a group of peer researchers and an experienced researcher during the early stages of data analysis. In these sessions, I brought to the group nine excerpts whose codes I was unsure about. Individual group members reviewed each excerpt and applied a dimension code. Then, the group went excerpt by excerpt and discussed their coding decisions. Additionally, the group gave feedback on the overall categories and their fit with the data. Feedback from these sessions led to further iterations of the data analysis process.

Once the deductive round of coding had been completed, an experienced researcher reviewed 40 excerpts that spanned dimensions and subcodes. Excerpts for the experienced research to review were selected because I was unsure about the codes I applied. The feedback gleaned from this coding review led me to revise my coding and improved my thinking around which excerpts fit in which dimensions and subcode. Additionally, the experienced researcher reviewed all of the excerpts selected for publication in this dissertation to ensure consistency between excerpts and the final themes they were coded as.

Once the pattern coding had been completed and a final codebook had been developed, I conducted two final coding review sessions with peer researchers whose research is related to this dissertation. Excerpts that had been selected for inclusion in the findings chapter were presented to each researcher to review. Each researcher was given the final codebook and asked to code 10 excerpts from each case. Then, the peer researcher and I discussed each excerpt and each code. In the case of disagreements, we negotiated to consensus.

3.6.3 Data Triangulation

Because this study relies primarily on student perspectives, an important quality measure is identifying and incorporating the perspectives of faculty. I interviewed one to two faculty members at each site who had taught courses that some participants took. These interviews allowed me to triangulate the findings from the student interviews and identify consistencies or inconsistencies between the two perspectives. In order to triangulate findings between the two perspectives, I first completed my analysis of student interviews, deriving salient themes. Then, I read through each key informant transcript and looked for discussions related to the salient themes. I noted where their perspectives confirmed students' constructions of their experiences as well as where their perspectives challenged students' constructions. These areas of confirmation and challenge are noted in the findings and discussion sections. This check helped boost the credibility and trustworthiness of the student perspective captured in this research.

3.6.4 Researcher Bias

My beliefs and experiences influenced and biased my decisions about the study. I operate from the view that all research is influenced by human biases and subjectivity. The problems we choose to study, questions we ask, and methods we use are all influenced by our personal beliefs and experiences. From this perspective, my approach to the study is undoubtably biased. However, being aware of our biases and working to mitigate them allows us to produce quality research that is viewed as reliable (Walker et al., 2013). Having biases and being subjective is not detrimental to research and can be beneficial if channeled properly because biases "enable researchers to be alert to themes in common with the broader human experience" (Ahern, 1999, p. 408). Thus, I argue that my biases and personal experiences are strengths, and I offer discussions about two key practices that help researchers mitigate their biases: positionality and reflexivity.

Positionality Statement

I am a white, cisgender, able-bodied woman who grew up in a mid-sized city in Western Colorado. I attended an engineering-focused undergraduate institution, but I majored in Applied Mathematics & Statistics, not engineering. When I momentarily switched to an engineering major during my second year, I experienced middle-year engineering courses that were designed to weed out students. I found the experience so miserable that I returned to the math department, where I felt my success was more valued by instructors.

I have personally experienced the rigidity of engineering: who does and does not count as an engineer. I have experienced not being engineering *enough* multiple times throughout my undergraduate and graduate education, despite attending an engineering undergraduate institution and pursuing a graduate degree in engineering education. I have been positioned outside of engineering by rigid beliefs of what counts as engineering: applied math does not count, statistics does not count, engineering education does not count. My higher education experiences and my experience navigating my own engineering identity (or lack thereof) shaped my interests in engineering culture.

I believe that research should be used to document and challenge the power-laden structures that we operate in. Further, I believe that people's personal experiences and stories are valid sources of data, and that qualitative methods that elicit these stories are valid ways of knowing. I share the experience of undergoing an engineering-focused curriculum as well as the experience of being a student during COVID-19 with my participants, but I do not share their experience taking mechanical engineering courses nor do I share their experience of being a mechanical engineering undergraduate student during the pandemic.

In this research, I am both an insider and an outsider (Berger, 2013). I share the experience of undergoing an engineering-focused curriculum with my participants, but I do not share their experience of taking mechanical engineering courses. I share the experience of living through and being a student during the COVID-19 pandemic, but I was a graduate student, not an undergraduate mechanical engineering student taking several major specific courses. I had to balance using my experiences to aid my interpretation of the data while not letting my experiences control how I interpret the data. Additionally, I had to recognize that there were several experiences that I didn't share with my participants and understand that I was unable to fully understand the experiences that my participants describe.

3.7 Strengths and Limitations

The strengths of this study lie in the choices made to aim for theoretical and literal replication, the richness of the qualitative data, and the ability to study a phenomenon as it happens. First, choosing two cases with a number of similar and different traits allows me to aim for theoretical and literal replication within the scope of a dissertation. Next, collecting qualitative interview data enabled me to provide rich descriptions of the phenomena under investigation that cannot be captured in large-scale quantitative studies. Finally, conducting interviews during the pandemic as students were navigating the phenomenon under investigation allowed me to capture unique data and perspectives that cannot be replicated after the pandemic ends.

Despite the strengths, my research methods have limitations. One limitation of my comparative case study design is only having two cases. This limitation is largely due to resource and time constraints. Yin (2018) recommends 6-10 cases in a multi-case design and having six or more cases would allow me to make stronger recommendations. Having two cases allows me to make comparisons between cases but limits my ability to draw broad conclusions about the impact of the pandemic on engineering culture. Moreover, only having one case in each country limits the extent to which I can attribute differences between cases to national context. To mitigate this limitation, I chose universities that have similar profiles. While only including one case in each country limits generalizability, the similarities and differences identified between national contexts can be useful, especially where they confirm findings from other studies. Further, studying how a single event – the pandemic – impacted education in two countries can open up useful comparisons between the influence of national context and the influence of a broader engineering culture.

Another limitation is that I am mostly reliant on interview data from students and less reliant on other sources of data. Although I utilized triangulation measures to help address this limitation, my sample represents primarily the student perspective. While this approach aligns with a constructivist paradigm, students' construction of their experiences may not align with the perspectives of other stakeholders (e.g., faculty, administrators) or outside observers. Accordingly, the results should be interpreted as students' perspectives of their experiences during the pandemic.

Finally, this study only captures public, comprehensive universities and only captures a single engineering discipline. While the results can be transferred to other contexts, they should not be generalized.

4 Findings

This chapter answers this study's two research questions:

RQ 1: How do the dimensions of engineering culture emerge in students' constructions of their experiences during the pandemic?

RQ 2: How did the presence of the dimensions of engineering culture vary across sites?

In order to answer these questions, I first provide a contextual site description for each case (Sections 4.1.1 and 4.2.1) in order to situate the findings and provide context about each university's response to the pandemic. In Sections 4.1.2 and 4.2.2, I describe the findings for RQ 1 for each case, respectively, presenting the most salient themes from each case. In Sections 4.1.3 and 4.2.3, I directly answer RQ 1 by discussing how those salient themes intersect with Godfrey & Parker's (2010) dimensions of engineering culture. Lastly, in Section 4.3, I compare across cases in order to answer RQ 2.

4.1 Case Descriptions

4.1.1 LP-US Case Description

LP-US is a large public land-grant research university located in the mid-Atlantic region of the United States. LP-US enrolls around 30,000 undergraduate students, about 10,000 of whom are enrolled in the College of Engineering. The university is classified as an R1 doctoral university, indicating very high research activity. As is typical at R1 doctoral universities, tenure-track faculty in the mechanical engineering department are expected to develop and run a strong externally sponsored research program. The mechanical engineering department is one of the largest departments in the university, with approximately 70 faculty members and 1200 undergraduate students.

National Context

When the COVID-19 pandemic began in the United States, the country was in the midst of a presidential election campaign. The pandemic began in March, presidential primaries and caucuses occurred in the spring and summer months, and the presidential election occurred in November 2020, after the interviews for this study were conducted. Moreover, the country faced significant tensions over racial injustice during the summer of 2020 as a result of the murder of George Floyd, Ahmaud Arbery, and Breonna Taylor. Several protests of racial injustice occurred across the country and were met with significant retaliation from police forces. The racial discrimination in the country and the resulting tensions have led researchers to coin racism the second pandemic (Addo, 2020). Additionally, the country faced a split response to the pandemic. Initially, many grade schools, universities, and companies throughout the country closed non-essential in-person operations, sending students and many parents home. However, different states and localities approached closures differently, with some schools and companies reopening within a few months and others staying closed to in-person education much longer. Accordingly, many students and adults worked from home for at least some portion of time, and many parents (including faculty) had to devote significant time to child-care and to supporting primary and secondary students in virtual learning. The country also faced a split response with respect to mask mandates. While many individuals adopted masking practices in compliance with university, city, and state-wide mandates, many other individuals refused to comply with mask mandates. Participants in this study were experiencing a contentious presidential election, a period of heightened awareness around racism and racial injustice, and tensions around responses to the COVID-19 pandemic.

LP-US Response to the COVID-19 Pandemic

When the COVID-19 pandemic began spreading in the United States in early March 2020, universities across the country responded. At LP-US, in-person courses and activities continued until the start of spring break. Classes were supposed to resume the Monday after spring break, but on Wednesday of spring break week, the university informed the community that spring break would be extended an additional week. As at most U.S. universities, students were instructed to not return to campus after the extended spring break. Further, students who lived in on-campus housing in March 2020 were not allowed to return to their residences on campus. At this institution, nearly all first-year students live on-campus. Additionally, some on-campus housing is reserved for second-, third-, and fourth-year students. With few exceptions, all of these on-campus students had to find a new place to live for the rest of the Spring 2020 semester. On Friday of the first week of spring break the university sent a message to students informing them of this decision about on-campus housing and offering a $1000 rebate. All students who live in university-owned housing are also required to purchase dining plans from the university. Financially, the only refunds the university offered were to students who lived on-campus. No refunds of tuition or fees were given, in any semester, nor were reductions given.

The university mandated that all courses transition to online and remote instruction. At LP-US, the initial response to COVID-19 was largely dictated by the university and instructors were given strict instructions about which course formats were allowed. Instructors were given an extra week of spring break in order to prepare for the transition online. In the spring (January to May) 2020 semester, individual instructors could choose whether to offer their courses synchronously (i.e., live meetings online) or asynchronously (i.e., posting content online with no live sessions). In the spring 2020 semester, the university extended the deadline to drop a course without penalty to mid-April and offered grading options that students could take in lieu of the traditional A-F grading system. Undergraduate students could opt-in to a credit/non-credit grading system. Opting in or out of the new grading system had no impact on students' academic progress or financial aid status. There were no alternative grading options available beyond the Spring 2020 semester.

However, by the Fall (August to December) 2020 semester, when students were interviewed, instructors were allowed to choose among in-person, virtual synchronous, or virtual asynchronous offerings. For the participants in this sample, the vast majority of their courses were offered online in the Fall 2020 semester with the exception of some in-person offerings for laboratory courses. Some students appreciated having in-person opportunities while others were frustrated and felt the university should have offered only online courses.

In Fall 2020, the university began offering more COVID testing and developed a case reporting dashboard. It also implemented strict rules around student gatherings, threatening disciplinary action (e.g., academic suspension or expulsion) if students violated the rules. The threatened action, however, changed over the course of the semester.

Student Perspectives of LP-US Response

While the focus of this study is on students' perceptions of their experiences in engineering courses, it is useful to contextualize those perceptions within their responses to the university as a whole. As students recounted their experience during the initial transition online in March 2020, they recalled feelings of challenge and frustration with the university's response, particularly with respect to the transition online, communication, finances, and new policies. First, students recalled challenges that they faced when *transitioning online*, including challenges navigating remote learning and finding places to work. Students had to navigate changes in their course formats while also navigating uncertainty and changes to daily life. Additionally, some students, especially those who had to move out of their on-campus residences, faced challenges finding a place to work.

Second, several students felt that the *communication* from the university was poor or lacking. The university primarily communicated through mass emails and social media posts. One student compared the process of the university developing a plan to being "blindfolded and tossed around the circle. And then they whip the blindfold off, they're like, Online classes now!" Other students wished that the university had asked for input from the community rather than making unilateral decisions.

Third, students felt that the university considered *finances* in their response to the pandemic, and some expressed frustration about the university's handling of finances, like tuition and fees. Some students discussed making decisions based on their finances about whether to take a semester off of school because the university was not lowering tuition or fees. Moreover, some students felt frustrated that they were paying the price of an in-person experience yet taking all of their courses remotely.

Lastly, in Fall 2020, the university implemented new parking rules which required students to have a university parking pass to park on campus between 7am and 10pm. Prior to the pandemic, permits had been required from 7am to 5pm (in most areas). These changes to parking added to challenges that student faced in collaborating with their peers. The added cost of coming to campus made it even more challenging to work with their peers.

Course-Level Response to COVID-19

All courses at LP-US shifted to a virtual format during the spring 2020 semester and most courses maintained a virtual format in fall 2020. This shift to a virtual format led to a variety of responses at the course-level in lecture-styles and assignment / assessment structures. The common types of course-level responses, which are gleaned from both the key informant interview and the student interviews, are discussed below.

First, instructors had to adapt to losing a week of instruction time due to the extended spring break in spring 2020. There was a range of responses among instructors to this loss of time. Some instructors tried to condense the existing content into the shorter time frame, while others decided to cut a week of content to adjust. Additionally, some instructors kept the same assignments and assessments as before, while others removed an assignment and/or assessment.

Second, instructors had to choose between offering their courses synchronously or asynchronously. The data for this study captured both styles of response. For instructors who offered their courses synchronously, they most often kept as much the same as possible. If the course was lecture-based before the pandemic, they continued to give the same lectures, only online. For instructors who offered their courses asynchronously, they often posted lecture recordings and kept the rest of the courses structure the same.

Overall, students reported that their professors generally kept as much the same as possible. Generally, instructors' lecture style as well as their assignment and assessment schedules stayed the same. Rules around assignments and assessments were adapted for the virtual environment.

4.1.2 LP-SA Case Description

LP-SA is a public research university in South Africa. LP-SA enrolls around 18,000 undergraduate students. The university is classified as a public research institution, indicating very high research activity. As is typical at R1 doctoral universities, tenure-track academic staff in the mechanical engineering department are expected to develop and run a strong externally sponsored research program. The Mechanical engineering department has approximately 30 faculty members, who span research and lecturer appointments, and 800 undergraduate students.

National Context

South Africa responded to the COVID-19 pandemic by declaring a national state of disaster and implementing travel restrictions, school closures, and lockdowns. According to news sources, the country remained in some form of lockdown through the completion of interviews for this study. Importantly, the country had faced widespread student protests of increases to student fees at South African Universities in 2015 and 2016. The protests intended to disrupt in-person teaching and some instructors opted to move their courses online during the protests. These protests heightened awareness of inequities related to access to higher education and also primed faculty to teach online. Across the South African participants, students seemed aware of the larger context in which the university was responding to the pandemic. One participant described why the university was so aware of difference:

> South Africa is very diverse, and I mean it's called the Rainbow Nation. So, that fact that we are diverse and the fact in South Africa they, the poverty line's just, it's just wow. A lot of students come from very disadvantaged backgrounds. And for me, I wouldn't even call myself as a student who comes from a disadvantaged background, because I know how the poor the standard of living are from some of my colleagues. Um the fact that they came to campus and all they came with were like their clothes. There was no books. They have like um this um funding called [removed] that paid for almost everything else. And it was just because of that and because of the large amount of students that don't have that financial back-, backing from home, um the university knew that have to take care of these students.
>
> Um as well as we had this thing called FeesMustFall a couple of years ago where it was just very violent. If you search like on, like just search the internet, hashtag FeesMustFall [University Name], you'll see a lot of things about that. It was just, it was just intense. Um, so they're coming from a system whereby students have been complaining about "Hey [University], you're very expensive, you don't cater to the needs of people who are uh, come from just a bunch of backgrounds. Please do something about it."
>
> Um and so this year they, you know, when they were making their plans, they said, "Hey, we have to think about this as well." So, that's probably why. [38M-37]

Participants from South Africa recognized the role that previous protests had on preparing the university to more equitably respond to the pandemic. Key informants confirmed that student protests played a role in priming the university to respond to the pandemic.

LP-SA Response to the COVID-19 Pandemic

When the COVID-19 pandemic began, South Africa took a strong-handed approach to its response. As documented by Landa, Zhou, & Marongwe (2021):

> On 15 March 2020, the South African president declared a national state of disaster under the Disaster Management Act of 2002. On 26 March 2020, national lockdown, which included measures stipulated in guidelines for education in emergencies, was implemented in South Africa. The presidential declaration and subsequent lockdown came at a time when some of the universities in South Africa were already struggling either to commence the academic year, or to make up for time lost due to persistent student protests relating to several student demands. However, disaster management now entailed that all schools and institutions of higher education were forced to close immediately for extended periods, necessitating alternative ways of ensuring access to education. (p. 167)

At LP-SA, students were sent home at the start of lockdown, and residential students had to move out of on-campus spaces. Students were only required to pay for the number of days that they lived on-campus. Additionally, funding assistance was made available to students who met certain requirements (typically family income limits). All instruction shifted online, and the university paused formal online instruction for four weeks to give students and faculty time to adapt and prepare for online instruction.

The university took several measures to ensure that online learning was accessible to students. In a message sent by the university to students, they assured students that their online workload would be lighter than their workload in-person, they could access lectures on their own time (i.e., all lectures were asynchronous), and they would have access to their course convenors and tutors. Key informants confirmed that a priority of the university was to ensure students with limited connectivity could access course materials. Moreover, the university ensured that every student had a laptop, and laptops were delivered directly to students. Lastly, the university worked with local cellular companies to ensure that students would have access to data with which they could complete their courses. Students who had ample internet access were encouraged to opt out of receiving data so the data could be distributed to other students in need.

Students and key informants recognized the need for making online learning accessible. Both groups of stakeholders cited how some students did not have ample access to internet and some had challenging situations at home. One key informant noted that instructors were asked to not assign more than 30 hours of work per week for students, across courses, because of issues students were facing with connectivity and home environment. As a result, the key informant reported cutting content from their courses. Lastly, the key informant recognized that international students who returned to their home countries were not given the same access to laptops and data as students residing in South Africa.

Student Perspectives of LP-SA Response

Again, while the focus of this study is on students' perceptions of their experiences in engineering courses, it is useful to contextualize those perceptions within their responses to the university as a whole. At LP-SA, students did not share the same frustrations with university-wide communication or finances that students at LP-US shared. Nearly every student discussed the support that the university provided in terms of laptop and data. While students faced challenges communicating effectively with lecturers, they were understanding and empathetic towards the challenges that their instructors faced during the pandemic. Students at LP-SA were generally understanding and appreciative of the university response to the pandemic.

Course-Level Response to the COVID-19 Pandemic

At LP-SA, all courses shifted to an asynchronous online model at the start of the pandemic, and the university was still operating under this model when this study was conducted. Accordingly, no live, synchronous lectures were held. Students often referred to learning through "You-Tube" videos. Some students reported that live help or tutorial sessions were held, but all formal instruction was delivered asynchronously.

Students received and submitted work through the university's Learning Management System. Assessments were also administered through the university's Learning Management system. In many of their courses, students were given flexibility on when they wrote their exams, which they believed was a result of their lecturer's awareness of challenges they may face in their home environment, like access to internet and a quiet study environment.

4.2 Salient Themes

In alignment with the aim of this study to understand what facets of engineering culture were salient in students' interpretations of their classroom experiences, I have chosen to organize my findings around the most salient themes that emerged from the data. These salient themes, shown in Table 4.1, were selected because they emerged in 75% or more interviews (i.e., at least 9 interviews). Table 4.1 also display the dimension(s) that aligned with each theme as well as the definition of each. theme. The salient themes in each case align with and map to the dimensions of engineering culture, but they also integrate and cross dimensions. Simply mapping one theme onto one dimension was not possible, as many of the themes are connected to and influence multiple aspects of engineering culture. For example, the theme *hardness* – which represents a core belief that engineering must be hard – reflects how engineering is taught and learned (i.e., an engineering way of doing), but also impacts the kinds of relationships that are formed in engineering (i.e., relationships).

As seen in Tables 4.1, the themes identified for LP-US and LP-SA are largely similar with a few key differences. First, for LP-SA, *seeking help* emerged as a salient theme, but did not appear in enough LP-US interviews to qualify as a salient theme. Second, for LP-US, *job market* emerged as a salient theme, but did not appear in enough LP-SA interviews to qualify as a salient theme. Lastly, in LP-US, *scientific way of thinking* emerged as a salient theme but did not appear in LP-SA results. The full codebooks for each site, including themes that did not qualify as salient themes, are provided in Appendix D.

Table 4-1: Salient Themes for LP-US and LP-SA

Theme	**Dimension(s)**	**Definition** (excerpts about…)	**LP-US Salience** (Participants of 11)	**LP-SA Salience** (Participants of 10)
Intrinsic Hardness	- An Engineering Way of Doing - Relationships	… the tendency of engineering courses to be hard (i.e., difficult), and the value placed on hardness	11	10
Differential Access to Resources	- Acceptance of Difference	… the impact students access to resources (e.g., internet, home environment) on students experience in engineering	9	10
Application & Design	- An Engineering Way of Doing - An Engineering Way of Thinking - Relationships	… the role of application and design (e.g., hands-on experiences, real-world examples) in engineering	9	10
Seeking Help	- An Engineering Way of Doing - Relationships	… the role of help (e.g., assistance) in engineering, including discussions of sources of help and challenges receiving help	**n/a**	10
Job Market	- Relationship to Environment - Relationships	… the impact and influence of the job market (e.g., desired jobs, perceptions of available jobs, perceptions of needed skills) on engineering	9	**n/a**
Scientific Way of Thinking	- An Engineering Way of Thinking	… a way of thinking based in logic and the scientific method	8	**n/a**

The following sections describe these themes in detail, beginning with those that were salient across both sites, and then discussing those that emerged only at one site or the other.

4.2.1 Intrinsic Hardness

Godfrey (2015) found that a belief in hardness – that is that "anything worthwhile is hard" and that hardness conveys "worth and status" (p. 442) – was a basic assumption at their institution of study. In this study, the term hardness refers to the level of difficulty – in assignments, assessments, and the course structure in general – that students encountered in their engineering courses. Moreover, students at both sites felt that hardness was central to their education as an engineer. The term *hardness* is common across engineering culture literature, and students in this study repeatedly used the term *hard* to describe their experiences in engineering courses.

Sources of Hardness

Students at both sites expected their courses to be hard. One LP-SA participant described that "engineering courses aren't easy" and knew to expect "to work hard" [37M-12]. Students expected to encounter challenging courses and content and described how the difficulty could result from several sources: 1) course content, 2) workload, 3) assessments, and 4) remote learning.

Course Content

First, students discussed how hardness resulted from their course content. That is, the material covered in the course could be difficult and challenging. However, students expected their course work to be difficult and challenging. For example, one LP-SA participant reflected that they knew their second-year courses "were going to be a step up from the first year" so they used the first weeks of the pandemic when instructional plans had yet to be solidified to "go over the course work" from their first year and "solidify all [their] knowledge in everything" [38-7]. While students acknowledged that hardness can come from course content, they spent more time discussing other sources of hardness.

Workload

Second, students discussed how hardness resulted from their heavy workload. That is, the amount of work that students are expected to complete can make their experience hard and challenging. For example, one LP-US student reflected that the workload during the pandemic felt "unrealistic at times," saying that they spent "every waking moment on [their] computer, just doing homework and trying to keep up with everything that was being thrown at us" [12F-19]. But at LP-US, participants also explained that the workload they students faced varied by course and instructor, while at LP-SA, students received consistent messaging that they should expect the workload to be high.

With respect to their experiences before and after the shift to online learning, at LP-US, some participants felt that their workload decreased while others felt that it increased. The workload varied by course and instructor, as one LP-US student described:

> I'm really not sure [if the workload changed]. Because in the spring, obviously we missed like a week of class, so some of the professors just said, OK, we're not going to cover these topics and then some of the professors […] for example, for my deforms class […] It was just, at the time it was hard. The professor was like, well, we're going to have to catch up, so we're doing like three homework sets a week until we caught up. So that kind of sucked. [15M-29]

Another LP-US student described a situation where his professor gave optional assignments in lieu of increasing or decreasing the required workload. Altogether, LP-US students drew connections between the high workload and the hardness that they experienced during the pandemic. As one student summarized, "I may not always have the ability to […] work on an assignment at certain times because all the other classes build up against each other. And you can't really take a break from one to do another since, if you do, you'll get stuck up even more" [14M-55].

Students at LP-SA received mixed messages around their expected workload. According to a key informant, the university set expectations to limit the workload to 30 hours a week. But the curriculum was set up such that students should work 50 to 60 hours a week, according to the key informant, so cutting that much content was challenging. Accordingly, some students reported classes that lowered the workload, while other students found that the workload stayed the same despite the university-wide expectation. Students even reported losing a week of a scheduled vacation shortly before the interviews took place because that time was needed to deliver content:

> We recently had a vacation, a university vacation. So, it was supposed to be two weeks. Everyone got two weeks except for engineering students. We got one week. So, they explained that to qualify for certain courses, we need to put in minimum require-, a minimum of certain hours and stuff like that. And they said to do this, we can only afford to have vacation of one week, [not] two weeks. So yeah, all our other friends who don't do engineering were on vacation for an extra week. And I was back at school. [32F-16]

Moreover, this student went on to describe the messaging that they received from instructors about how much they were expected to work. The student reported that the instructor expected students to work more than their peers in other degree programs:

> In the beginning, like when we were receiving e-mails about how we were going to go [online], some lecturers would just mention things like, "You must understand that this is a science and engineering degree, and you're supposed to put this many hours a week, so you shouldn't be complaining about the lecture content or the lecture materials, because this is what you'd be doing if you were on campus." So, they strived to continue like that even if we're online. So, they would just say things along those lines where you can tell that they don't really, they're not trying to be, I guess, considerate about the situation. [32F-13]

Altogether, the amount of work that students were expected to complete contributed to hardness that they experienced in their courses. Students at LP-US found that whether their workload increased varied by class and instructor: workload increased in some classes, stayed the same in some classes, and decreased in some classes. Students at LP-SA also found that their workload varied by instructor and was complicated by university-wide expectations about how much students should work.

Assessment

Third, students discussed how hardness can result from assessment, including kinds of questions asked, format, and time constraints. Sometimes, students found that the questions asked on an assessment did not align with the content that was taught, which contributed to the hardness of the course. For example, one LP-SA student reflected on a course where they were "doing things like note taking, studying, all of that" but the tests were "different than the examples in the notes" [32F-25]. The student reflected that the course wasn't "supposed to be this hard," but the lack of alignment between their lecture notes and the tests made it "really hard" [32F-25]. At LP-US, a student shared a similar experience where their instructor made an exam significantly harder in order to compensate for students completing the exam remotely. The student shared that "the test went from taking a half an hour to taking, you know, fifteen to twenty hours working with two other group members" [6M-25]. Another LP-US student had a similar experience, describing a situation where the professor made the exam open book and open note – meaning that students were allowed to use their textbook, notes, and sometimes other resources (i.e., internet search) – but significantly increased the difficulty. The student said:

> The professors were like "All right. Well, got to remake my exam now, because like I'm not going to not make it open book, like, OK, guess what? It's open book/open notes. This exam is going to be awful. Good luck. Because I know you can look up anything, so the test is...." This is one of the ways one of my professors put it. He was like, "There's a few different ways you can take tests. And the last one was it's like open book/open notes and use any resources you can because the test is going to be so hard that God Himself couldn't pass it." [8M-21]

Altogether, hardness could come from the kinds of questions asked on an exam. Additionally, in response to remote learning during the pandemic, students reported that some instructors opted to make the content on their assessments harder.

Next, students found that the format of the exam could add to the difficulty. At both sites, some assessments had tight time limits (i.e., minutes to hours), while other assessments had more lenient time constraints (i.e., days). In most cases, students at both sites reported receiving additional time on assessments in order to compensate for the online environment, but some felt it still wasn't enough time. For example, one LP-SA student reflected that receiving an extra "5, 10, or 15 minutes for taking pictures, uploading, and all that" wasn't enough, saying "I feel like there is never enough time for anything really" [35F-19].

Remote Learning

Fourth, students reported that hardness resulted from the remote nature of instruction due to the pandemic itself; that is, while many of the factors noted above are sources of hardness in themselves, experiencing them in a pandemic had an amplifying effect. Importantly, the self-directed nature of remote asynchronous learning posed both challenges and benefits. One LP-SA student discussed the challenges of trying to learn engineering concepts without the ability to seek help in person. This student talked about how "concept based" engineering is and how challenging it is to "teach yourself concepts" because it is not easy find explanations of the concepts online [33M-7]. On the other hand, another LP-SA student appreciated the flexibility that came with asynchronous learning, including the ability to "work on your own time, pause if you're not focused, [and] go back [and] rewind" [33M-34].

Lastly, hardness can be a cumulative effect across multiple courses and multiple sources of hardness. Students experienced engineering as hard because each course is challenging in terms of material, high in terms of volume, and difficult in terms of assessment. Moreover, because of remote learning during the pandemic, students reported having less access to teaching support to get help. Thus, the sources of hardness described here do not exist in isolation, but rather combined to make the overall experience hard and challenging. This cumulative hardness could lead students to experience overwork and burnout as they tried to keep up with the workload. Hardness will continue to appear as a central theme that is embedded in other salient themes.

4.2.2 Differential Access to Resources

Differential access to resources captures the level of access that students themselves had or that students observed others having to physical resources, primarily related to home environment and internet access, and how that access impacted students' experiences taking courses during the pandemic. Most participants recognized the importance of physical and digital resources, whether they lacked access themselves or saw the impacts of others' lack of access. That is, some students faced significant challenges engaging in classes and coursework because of their home environment and/or internet access. Other students demonstrated an awareness that others were facing challenges related to their home environment and internet access, though they did not face those challenges themselves.

Home Environment

At both LP-US and LP-SA, all students living on-campus (with few exceptions) were forced to move out of their residence hall at the start of the pandemic. As a result, students had to find a new place to live and study. One LP-US student recalled the stress of finding a new place to live, saying that they "don't have the most reliable internet at home" and made the "panic decision to move in" with their partner [12F-2]. They described how the "non-academic stresses […] made things a lot harder" [12F-4]. Another LP-US student described traveling home to their parents' house and struggling to work in the crowded home, which was full of their siblings and family friends. Eventually, they made the decision to return to the university town but described feeling "isolation" because "none of [their] friends" were in town [9F-48]. These stories capture the added difficulties that some students faced during the pandemic at both sites. Since the universities were shut down, students had to adapt and find other places to live and study. But not all students had access to another place to live that was conducive to going to class and studying.

Internet Access

While students in both contexts experienced challenges related to home environment, a key difference between LP-US and LP-SA emerged related to the steps taken by each university to ensure that students had the resources they needed to successfully engage in remote learning. LP-US did not have any widespread programs available to deliver laptops or internet access to students, while LP-SA did. Students at LP-US discussed challenges they and others faced with accessing reliable internet, while students at LP-SA discussed the steps the university took to ensure they could engage in coursework remotely. Importantly, LP-US students experienced several courses with synchronous, video-conferencing lectures while at LP-SA, all instruction was delivered asynchronously.

At LP-US, participants described instances where they believed differences in access to physical resources – specifically internet – were ignored in the classroom. Students described instances where access to these resources could or did impact their ability to engage in class (including attendance, taking exams, and submitting assignments). For example, one participant described how the infrastructure of the university's town was not "built to have this many people online" [12F-13b]. The student went on to say that their "professors don't always think about" those differences in internet access. Another student worried about losing points on an exam if their internet dropped. The exam was scheduled to be proctored with an anti-cheating lockdown software that recorded students while taking the exam and prohibited access to any other sites or windows. If the internet connection was lost, the student could be accused of cheating. This student explained that they "just switched to a new internet in [their] apartment and Zoom occasionally will drop here and there" [11M-44]. They worried that their internet would drop during the exam, making it look like "Oh, this guy's cheating" [11M-44]. They worried that losing their internet during the exam might cause them to fail the class, which they couldn't "afford" [11M-44]. This student later described losing points on a presentation because of problems with their internet:

> For [a lab course], we had a presentation a couple weeks ago, and they're taking off points for Zoom not working, which is stupid. Like, I don't understand what they're trying to do there. [11M-48]

Unfortunately, this student's description of being penalized for a lack of stable internet access was not uncommon at LP-US. Another participant recounted the story of a friend, who was staying with them at their parent's house, losing internet during an exam due to a power outage. The friend had to submit the notice from the utility company to the professor in order to avoid failing the exam. The participant described:

> I will say that like, during finals week, anyway, my friend for one of his finals, he had to be on Zoom. And if they disconnected from zoom, the professor was going to assume they were cheating and fail him. And that was an issue because my—There was an accident outside my parents' house and our power went out. So, then I was scrambling, he was scrambling like missing time on his final exam, I was scrambling trying to get my phone—While being out of the camera in case Zoom came up. I was trying to hotspot for him on my phone. Without having power so he could get back on zoom. And we ended up having to like—I had to get the notice from the utility company for my parents, so that he could send it to him and prove that the power did in fact go out. So, like, on one hand, I think some professors took it too far. It was like, he should not have been threatened to fail that exam because the power went out. But then like, maybe some professors weren't taking it seriously enough, because I definitely know kids who are just blowing off everything and probably didn't learn a single thing after class one went online and still passed. [12F-3]

Altogether, at LP-US, internet access impacted students' experiences, and there were no widespread programs to ensure that all students had the internet access they needed to be successful, like there were at LP-SA. The key informant at LP-US confirmed that internet connectivity issues were a concern for a number of students. The key informant described being flexible with students, especially with tests and quizzes, and working with students on a case-by-case basis to respond to internet issues. Importantly, the purpose of this study is to investigate student experiences, so the results presented in this section around students' access to resources and their resulting experiences reflect students' constructions of their own experiences. The perspectives of other stakeholders may vary; that is, faculty may or may not have intended to create an environment of rigidity and/or project unwillingness to acknowledge or account for differential access to the internet and other resources, but the students in this study still experienced the resulting policies in those ways.

At LP-SA, in contrast, the university paused instruction until they could deliver a laptop to each student who needed one. Additionally, LP-SA secured a fixed amount of cellular data for each student so they could connect to the classroom management system regardless of their access to Wi-Fi. As one LP-SA student described, the university was "obviously considering what each student is going through because not everybody's fortunate enough to have Wi-Fi, to have a laptop, to have resources in general" [37M-26]. This student went on to describe that "during the period before online learning, the university did try to reach out to anybody who didn't have a laptop" or "access to the internet" [37M-26]. The student felt that the university "really did consider our respective position in the country" and tried to "take into consideration as many people as they could to help them receive laptops and data" so that students could "actually learn and actually participate in lecturers and tests" [37M-26]. One student experienced not having a laptop or a smartphone at the start of the pandemic, which was "really stressful" [36M-1]. The student went on to explain:

> And well, then obviously like the university got me a laptop, which also was good that I was able to get Wi-Fi. Yeah, once I was connected, I think things looked good. I didn't really struggle that much with online learning per se. I think I'm a person who, I don't know, I adapted very well and quickly. [36M-1].

One key informant at LP-SA confirmed that ensuring students could access content despite low bandwidth was a key priority of the university. While more measures were taken at a university level at LP-SA to ensure access, students at LP-SA generally reported greater disparities in access than at LP-US. Importantly, at LP-SA, students and key informants noted that while the university secured resources for domestic students, they were unable to secure the same resources for international students who returned to their home country. One student observed that for students outside of South Africa, "they couldn't get laptops or data and basically had to take a leave of absence because of the situation" [36M-28].

4.2.3 Application & Design

Application captures students' experiences and beliefs around the hands-on, application-based aspects of engineering. One of the core beliefs that emerged in this study is the centrality of application and design to engineering education. When the pandemic first hit, both LP-US and LP-SA shifted all instruction to a virtual format, including laboratory sections (called *practicals* at LP-SA). While many students at both institutions appreciated the work that instructors put in to shifting practicals online, they also felt that they were missing out on an important part of their education. One LP-SA participant described that they were a very hands-on person and liked being able to "go into the lab and physically do it" [34F-42]. They found it "frustrating" to lose the "real-life association" and not be able to "see it, how it feels, [or] how it works" [34F-42]. LP-SA students also reported that their courses shifted to covering more theoretical and conceptual material. As one student summarized, "we only write theory tests right now and we don't do any SolidWorks; we don't do anything practical" [36M-20]. Another student discussed that their education was "more concept based" during remote learning and they could no longer "walk up around in the labs and see the actual machinery and its purpose" [33M-8]. Students at

LP-SA perceived practicals to play a key role in their education and noticed a shift to more conceptual content rather than practical, hands-on content.

A LP-US student who had transferred from a community college expressed similar frustration at the lack of in-person laboratory sessions. This student expressed that "the facilities and resources" of LP-US were a key reason that they were paying "the inflated prices that we have for college education these days," so it was a "huge detriment" to lose access to the physical facilities and resources [8M-27]. Students at LP-US not only perceived hands-on learning as important to their education but saw it as one of the key reasons they paid for their education at LP-US. The key informant at LP-US also discussed the drawback of not having hands-on examples and demos in class. This key informant discussed plans to pivot and use equipment that allowed for at home hands-on assignments.

Altogether, these excerpts exemplify a common belief that students held about how engineering should be taught: engineering programs should include in-person design and hands-on experiences. Without these design experiences, students, especially LP-US students, felt that the value of the degree was diminished.

4.2.4 Seeking Help (LP-SA Only)

The difficulty and hardness of engineering often drives students to seek help with their coursework. The necessity of help along with common methods of seeking and receiving help emerged as a salient theme at LP-SA. While this theme appeared in a few LP-US interviews, it did not appear in enough interviews to qualify as a salient theme. Thus, this section will focus solely on results from LP-SA.

Students acknowledged the need to seek and receive help and discussed several challenges that they faced in seeking and receiving help during the pandemic. Students found that some methods of getting help became less prevalent or less useful during the pandemic, like help from tutors, lecturers, tutorials, and peers. For example, one student described how it was challenging to communicate with and get responses from tutors and lecturers and described long delay times in receiving responses. Other students also acknowledged the challenges that their lecturers and tutors were facing during the pandemic and expressed understanding for the communication challenges. One student said, “I realized that lecturers were also human, too; they’re also going through these struggles, especially during this time” [38M-3]. This student went on to describe how this realization discouraged him from seeking help from his lecturer and led him to seek out other sources of help. In addition to facing more challenges seeking help from tutors and lecturers, students also encountered more challenges seeking help from their peers. Students described how they used to rely on help and support from their peers before the pandemic, even referring to engineering as a “team sport” [311F-24]. This student went on to describe how before the pandemic they “worked together quite a bit” with peers, but in the “online learning” environment, “being so isolated and striving to communicate with other people” had an impact. This student went on to explain:

> That lack of accessible communication [with peers] definitely was quite difficult. ’Cause obviously everybody is working at their own pace, working through the content at different times. So, I found that I was often, because I was working in the mornings and afternoons, I was getting to the content before my friends. So, if I had questions to chat to them about, they couldn’t help me. And then I don’t know, the lecturers weren’t amazing at answering questions. I found it more helpful to talk to my friends about the content. And they also said that they like looked on online sources. [311F-25]

Other students who had less of an established group of friends going into the pandemic struggled to get help from peers. One student described “tapping on random people” in the learning management system and asking them to form a peer group to “see if we can help each other ourselves” [35F-5]. Other students found it daunting to reach out to random peers:

> Despite knowing that how small our class is compared to others and even having that, having met most of the people of the group, it is still really daunting to just be like, “Hi,

> can you help me?" I'm not going to lie. It's a bit.... You just don't know how people are going to respond. You don't know if they're going to be kind or if they're going to be rude. And it's just, it's weird. It's weird to get my head around. [34F-25]

Again, while getting help was important, some students found that their peers were no longer an accessible source of help.

While some sources of help became less prevalent and less useful, other existing methods of getting help became more useful during the pandemic, like utilizing question and answer forums within learning management systems, utilizing online resources like YouTube, and utilizing class group chats. One student described realizing "it's engineering, like people make many videos on it" and seeking out videos online that explained the concepts [38M-3]. Another student found that online question and answer forums for individual courses were utilized more and thus became more helpful than they were before the pandemic. They especially liked the feature to "post questions anonymously" because "sometimes you get nervous to ask questions when you don't understand" [32F-36].

Overall, needing help remained a core part of students' engineering experience at LP-SA, but where that help came from shifted during the pandemic. Many students faced challenges communicating individually with their peers, tutors, and lecturers, and accordingly sought out other sources of help, including group question and answer forums and online videos.

4.2.5 Job Market (LP-US Only)

Students at LP-US discussed connections between their education and the job market. In this category, the job market encompasses students' next step after graduation, including engineering industry and graduate school. First, students discussed the ways in which their motivation to do well in school was linked to their perceptions of the job market. For example, one student discussed how their desire to go to graduate school and awareness of admissions criteria motivated them to keep their GPA up during the pandemic.

Second, students discussed building relationships and networking with industry professionals. Two students noted feeling they missed out on opportunities to network with individuals who could help them get to the next step. For example, one student discussed "frustration" at navigating his university's virtual job fair. The student felt they "weren't really making the same connection as before" when the job fair happened in-person [7M-53].

Third, students discussed their perceptions of the landscape of the job market, including the types of jobs that were available and their concerns about the job market. Some students were able to find internships during the pandemic and believed that their internship experience would give them an advantage when searching for jobs. For example, one student said that their internship gave them a "leg up because a lot of people didn't get internships" the prior semester [11M-108]. Other students, though, were concerned about their ability to find a job. One student worried that he wouldn't be as competitive as other engineers who graduated before the pandemic began, saying "who's going to hire somebody who graduate during this time over another student who got the degree before this when they could do lab classes in person [and] when they had that hands-on experience" [8M-9]. This same student considered finding a job instead of returning for his senior year:

These excerpts demonstrate the typical assumption that universities exists to prepare students for jobs and to help them be competitive for those jobs. They also highlight the role that students perceive hands-on application plays in their preparation for work. Without application-based, hands-on work, students worried about their ability to find a job and transition into the workplace.

4.2.6 Scientific Way of Thinking *(LP-US Only)*

Lastly, LP-US students demonstrated a scientific, positivistic, logic-driven way of thinking that showed a preference for efficiency and organization. This scientific way of thinking emerged especially as students discussed university and national responses to the pandemic. One student discussed a New York Times article that he read, which drew connections between the 1918 flu and the modern-day seasonal flu. This student said, “We had an opportunity to not have a second flu, like seasonal flu, and we absolutely blew it” [10M-31]. Additionally, some participants were critical of their peers behavior, which they felt ignored scientists’ recommendations. For example, one student said:

> I feel this semester people are starting to take the virus and everything less seriously because it's past the peak or per se. Because all these people are going downtown, partying and doing all this crazy stuff. I'm like why? Do you uh – I'm guessing there is a lack of brain cells somewhere because people apparently just don't care. Which I don't understand, they're like oh yeah, there is no virus. It's fine, like there is – it's good to go, and I'm just sitting here thinking to myself it's – that's not how this works. That's literally why this all started in the first place because people didn't think it was a big deal, and now we're here. [14M-35]

As shown by the excerpts above, the students in this study displayed a scientific way of thinking when discussing the pandemic. Further, some students expressed frustration at a lack of efficiency and organization in their virtual courses. As one student noted: “Like the organization of how the class is setup is really kind of important. And I think a lot of professors don't do it well” [4M-105]. Overall, a scientific way of thinking coupled with a preference for organization and efficiency are traits that have been found to be common in engineering.

4.3 Summary of LP-US and LP-SA Case

Intrinsic hardness was a key guiding belief among students and in students’ perceptions of what faculty valued at both sites. Students perceived that this belief in hardness impacted decisions about course format and assessment and drove concerns about cheating. Intrinsic hardness coupled with the remote environment heightened students' awareness of the importance of access to physical resources (like internet) in student success and awareness of differential levels of access to those resources. However, the majority of students in this sample did not identify barriers beyond physical resources and socioeconomic status. Students generally felt that their programs must be hard and difficult in order to prepare them for work.

Application and design were also key guiding beliefs among students at both sites. Students believed that their engineering education needed to include hands-on application work, particularly in laboratories. When this hands-on work shifted online, students felt that they were missing out on a key element of their education. At LP-US in particular, some students felt as though they were not getting their money's worth, and others felt concerned for their preparation for work. At LP-SA, students noticed that arrangements were made for the senior engineering students to complete their practicals in person, so they felt more confident that they would eventually partake in in-person application work.

Figure 4.1 summarizes the findings from LP-US and LP-SA. Three themes were seen by students as central to their understanding of engineering and what an engineering education should entail: 1) Intrinsic Hardness, 2) Application and Design, and 3) Scientific Way of Thinking. Intrinsic hardness stemmed from four key sources: 1) assessment, 2) workload, 3) course content, and 4) remote learning. At LP-SA, this hardness led students to seek out help from lecturers, peers, question and answer forums, and online media. At LP-US, students interpreted the hardness of their engineering education along with their hands-on application and design experiences to be central in preparing them for the job market.

Figure 4.1 also demonstrates how the salient themes from this study map onto Godfrey & Parker's dimensions of engineering culture. Salient themes are shown in circles and sub-themes are shown in squares.

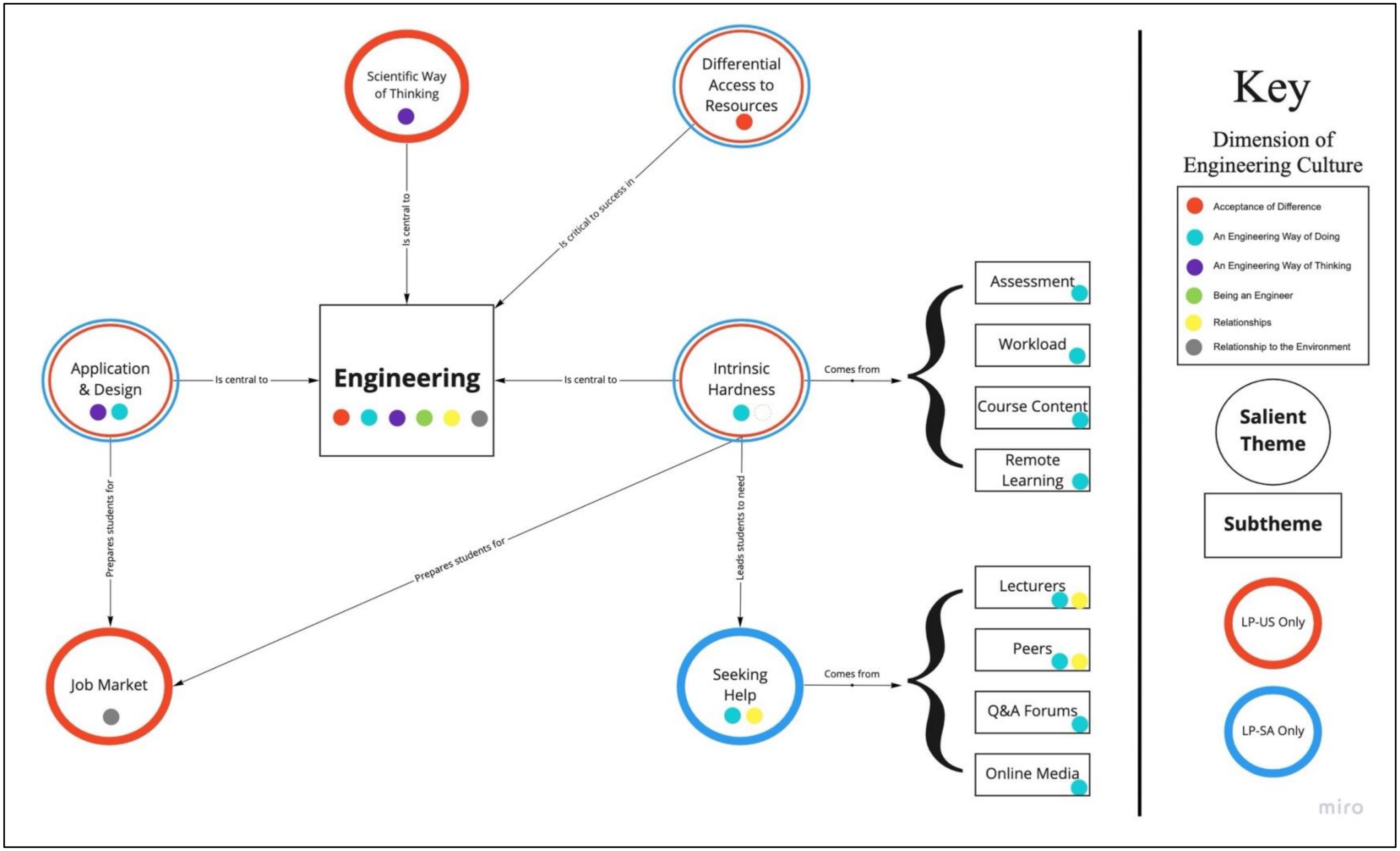

Figure 4-1: Concept Map of Theme and Subcode Interactions at LP-US and LP-SA

4.4 Comparing Between Cases

Because the data revealed strong similarities in students' experiences across cases, the results were organized by theme and similarities within each case was discussed within each theme. However, several potential differences among the cases also emerged in the data, especially pertaining to which themes were salient and how each salient theme emerged in each case. The key similarities between cases are captured in Table 4.2 and the key differences between cases are captured in Table 4.3.

As shown in Table 4.2, the key similarities between cases emerged primarily with respect to three themes: 1) Intrinsic Hardness, 2) Differential Access to Resources, and 3) Application and Design. First, students from both sites reported that their courses were still *hard* and difficult during the pandemic. Moreover, at both sites the belief in hardness was upheld by both students and instructors; both parties expected engineering courses to be hard. At both sites, hardness resulted primarily from assessments, workload, course content, and remote learning. Second, students at both sites acknowledged and experienced *difference* related to their home environment and internet access. This resource related form of difference was the only salient form of difference that emerged at either site. Third, students at both sites reported that *application, design, and hands-on learning* was central to their engineering education. Students felt that in-person laboratory sessions were critical to their development as engineers and expressed frustration at losing out on those in person experiences.

Table 4-2: Key Similarities in Cases by Theme

Theme	Similarities Between LP-US and LP-SA
Intrinsic Hardness	• Students reported that their courses were still hard and difficult. • Hardness resulted from assessments, workload, course content, and remote learning. • Students reported explicit expectations of hardness from instructors.

Theme	Similarities Between LP-US and LP-SA
Differential Access to Resources	• Students acknowledged and experienced difference related to home environment and internet access.
Application and Design	• Students discussed the centrality of application, design, and hands-on learning to their engineering education. • Students expressed frustration about losing out on in-person laboratories and practicals
Seeking Help	*N/A*
Job Market	*N/A*
Scientific Way of Thinking	*N/A*

While key similarities emerged between sites, key differences exist as well. As shown in Table 4.3, the key differences between cases emerged with respect to five themes: 1) Seeking Help, 2) Differential Access to Resources, 3) Application and Design, 4) Job Market, and 5) Scientific Way of Thinking. First, help only emerged as a salient theme at LP-SA. Students discussed the importance of seeking out help in their engineering education but struggled to find help in the same ways they did before the pandemic. Students found it challenging to get help from lecturers in the same ways as before, and students without a strong, existing peer network struggled to find help from peers. Second, LP-SA took more steps as an institution (i.e., distributing laptops, offering data, mandating asynchronous lectures, offering flexibility with deadlines) to ensure that students had access to the resources that they needed to be successful. Moreover, students at LP-US reported a lack of understanding and flexibility from instructors related to internet access while students at LP-SA experienced more understanding, especially at a systemic level. Third, the key difference in application and design between sites was the delivery style during the time period when students were interviewed. At LP-US, students had the option of attending some laboratory sessions in-person while at LP-SA, all practicals were virtual. Fourth, job market only emerged as a salient theme at LP-US. Students reported that hardness and application and design both played a key role in preparing them for the job market. Further, students linked their motivation to do well in their current courses to their post-graduation goals. Lastly, students shared their perspective of the impacts of the pandemic on the job market, including concerns about finding internships and jobs. Fifth, a scientific way of thinking only emerged as a salient theme at LP-US. Students displayed a scientific way of thinking, based on logic and the scientific method, and expressed frustration at other students who did not share their way of thinking and approaching risk during the pandemic.

Table 4-3: Key Differences in Cases by Theme

Theme	Case 1: LP-US	Case 2: LP-SA
Intrinsic Hardness	*N/A*	*N/A*
Differential Access to Resources	• Students reported a lack of understanding and flexibility from instructors related to internet access. The majority of students' courses were conducted synchronously online with students attending live Zoom meetings.	• Students reported university-led efforts to distribute laptops and data to all LP-SA students within South Africa All of students' courses were conducted asynchronously online – a result of an awareness of differential access to resources
Application and Design	• Students had the option of attending some laboratory sessions in-person.	• All practicals were virtual.
Seeking Help	• *Not Salient*	• Students struggled to find help in the same ways they did pre-pandemic. • Students without a strong, existing peer network struggled to find help from peers.
Job Market	• Students reported that hardness and application and design both played a key role in preparing them for work. • Students linked their motivation in their courses to the job market. • Students discussed their perception of the job market during the pandemic.	*Not Salient*
Scientific Way of Thinking	• Students displayed a scientific way of thinking and expressed frustration at other students who did not share similar ways of thinking.	*Not Salient*

5 Discussion

The purposes of this comparative case study were to 1) understand what facets of engineering culture were salient in students' interpretations of their classroom experiences during the COVID-19 pandemic and 2) investigate how salient facets of culture differed across national contexts in order to 3) understand what an exploration of engineering culture during a disaster tells us about the culture itself. To achieve these goals, this study aimed to answer two key research questions:

RQ 1: How do the dimensions of engineering culture emerge in students' constructions of their experiences during the pandemic?

RQ 2: How did the presence of the dimensions of engineering culture vary across sites?

In response to the research questions, I found that three dimensions of engineering culture (*an engineering way of doing*, *an engineering way of thinking*, and *acceptance of difference*) emerged at both sites in students' constructions of their experiences, and two additional dimensions (*relationships* and *relationship to the environment*) only emerged at one site. Moreover, in response to the first research question, I found that some salient themes spanned dimensions. Lastly, I found that the core cultural features to emerge from these data were hardness, application and design, and access to resources. In this discussion, I will address each purpose and answer each research question, in the context of existing literature. Additionally, I will summarize the key impacts of the pandemic on engineering culture.

5.1 Answering RQ 1: Emergence of Dimensions in Students' Construction of Experiences

This study aimed to understand how the dimensions and facets of engineering culture, as defined by Godfrey and Parker (2010) and others, emerged in students' constructions of their experiences during the pandemic. In response to this aim and research question, I found that at both sites, the most prevalent dimension in students' construction of their experiences was *an engineering way of doing*. Students frequently spoke about how teaching and learning were carried out during the pandemic. Other dimensions also emerged at both sites, including *an engineering way of thinking* and *acceptance of difference*, suggesting that these three dimensions were central to students' interpretations of their experiences and beliefs about what it means to be an engineer. At LP-US, *relationship to the environment* emerged and at LP-SA, *relationships* emerged. The emergence of these dimensions as salient at only one site is likely indicative of sample differences. Moreover, many excerpts initially coded as *relationship to the environment* at both sites were used to develop the case report for each site. Importantly, none of the salient themes for either site related to *being an engineer,* which may be reflective of the interview protocol which did not specifically probe for engineering identity. Moreover, I found that some themes spanned multiple dimensions. Because themes spanned dimensions, I will compare how each theme emerged in this study with how each theme emerged in Godfrey (2015) rather than organizing my discussion by dimension.

Intrinsic Hardness

The intrinsic hardness of engineering education has been identified and recognized by several scholars over the past 20 years. Godfrey (2015) reported that the "theme of 'hardness' permeated the conversations of both faculty and students, conveying worth and status, with a devaluing of content or subject areas that were seen as 'easy' or 'soft'" (p. 442). Stevens et al. (2007) refer to hardness as a "meritocracy of difficulty" (p. 1), which they define as "how students' justify their anticipated comfortable futures based on the fact that they perceive their school work to be much more difficult than that of students in other departments" (Stevens et al., 2007, p. 1). In this study, students demonstrated a belief that hardness was a key and necessary element of their engineering education. While students expressed frustration at some forms of hardness – like the logistics behind exams – they expected their coursework to be challenging and they expected to work hard. In addition to Godfrey (2015) and Stevens et al. (2007), Cech (2014) argues that a belief in meritocracy underlies engineering, and within this belief lies the assumption that "those who succeed do so because of their hard work and dedication and those who do not succeed lack such hard work and dedication and thus deserve their disadvantaged status" (p. 49). Accordingly, not only do students believe that engineering should be hard, but they also believe that working hard correlates directly with success. Foor et al. (2007) corroborates this belief in hardness and meritocracy, finding a student-held belief that "challenge and competition are essential to science and weed out classes are necessary to winnow the wheat from the chaff" (p.112).

This consistency with respect to hardness and meritocracy (Cech, 2014; Foor et al., 2007; Godfrey, 2015; Stevens et al., 2007) tells us that expectations and experiences of hardness existed long before the pandemic and endured throughout the pandemic, indicating that hardness is a key and resilient feature of engineering culture. Further, despite the challenges that students faced during the pandemic, specifically challenges related to home environment and internet access, they still believed that their educational experience needed to be hard.

Differential Access to Resources

In this study, access to resources was the only theme related to *acceptance of difference* that emerged as salient. Throughout my analysis I operationalized "difference" to encompass any challenge or barrier, systemic or individual, that students encountered during the pandemic. Typically, in engineering, difference, along any axis, is not accepted. Godfrey (2015) emphasizes that homogeneity is the norm in engineering, and non-dominant ways of thinking and doing are marginalized. Godfrey and Parker specifically call out difference related to gender, race and ethnicity, and background experiences (Godfrey & Parker, 2010). Other literature points to an intolerance of difference related to sexual orientation (Cech & Rothwell, 2018) and mental health (Danowitz & Beddoes, 2020a, 2020b) in addition to race, gender identity, and background experiences. However, in this study, participants expressed an awareness of difference primarily related to socioeconomic status (i.e., factors that impacted their ability to access a good virtual learning environment). They had experiences in which they felt like differences in home environment and access to internet were not accounted for in the classroom, but should have been, and these instances seemed to perpetuate typical aspects of engineering culture (i.e., meritocracy and hardness). This belief that difference should be accounted for challenges previous dominant beliefs about difference. For example, Foor et al. (2007) found that their participant believed "no changes in the curriculum or pedagogy are necessary to accommodate different ways of learning or knowing" (p. 112).

Participants also reported instances where difference was accommodated, especially with respect to stress and assessments. Most participants demonstrated an awareness of differences that they or their friends were experiencing, but participants did not discuss differences along other axes of oppression, like race, gender, or sexuality. Importantly, differences including race, sexuality, gender, disability, and the intersections of these differences have long impacted student experiences in engineering, but, as Godfrey (2015) found, are often ignored.

Application & Design

Researchers, including Godfrey (2015) and Neumann, Parry, and Becher (2002), have pointed to the centrality of application and design to undergraduate engineering education. Godfrey (2015) found that design and real-world applications were central to students' and faculty's construction of what it means to be an engineer. According to Godfrey (2015), "design seemed to epitomize the essence of what faculty and students believed to be *an engineering way of thinking*" (p. 441). Moreover, Godfrey (2015) found that "the inclusion of design subjects and project-based learning" was a key part of *an engineering way of doing* and distinguished engineering from the "pure" sciences (p. 442). Neumann, Parry, and Becher (2002) argued that engineering is a hard applied discipline and that lab work is a common feature of engineering programs. Nulty & Barrett (1996) support the classification of engineering as a hard applied discipline. Further, Nulty & Barrett (1996) connections between disciplines and Kolb's learning styles, based on the Experiential Learning Model (Kolb, 1981). They classify engineering as characteristic of active experience and abstract conceptualization (Nulty & Barrett, 1996) and emphasize that "it is not only the epistemology of a discipline that influences the learning style, but also the educational processes involved" (p. 341). Thus, the way that students are taught influences their learning styles (i.e., active experience, abstract conceptualization, etc.) (Nulty & Barrett, 1996). This emphasis on application, design, and active experiences from prior literature was confirmed in this study as central to students' perceptions of learning in engineering. Participants in this study also felt that design, and specifically laboratory work, was central to their development as engineers. They further felt that design and laboratory work was a critical piece of the value they received from their tuition dollars. Accordingly, application and design appeared to remain central to students' construction of their engineering experience.

Seeking Help

The theme of *seeking help*, especially from peers, only emerged as salient at one site, but appears in the engineering education literature as a nuanced feature of the discipline. Godfrey (2015) found that "mates" and friendships were critical to both "a sense of belonging in engineering" and students' "academic survival and success," and classified this finding under *relationships* (p. 445). However, competition can take the place of collaborative behavior in some STEM courses and programs (Seymour & Hewitt, 1997; Wolfe et al., 2015), and gender can further complicate which students are most willing to seek out help (Stump et al., 2011; Wolfe et al., 2015). For example, Stump et al. (2011) found that female students reported higher rates of collaboration than their male counterparts, and students who received "B's" reported more collaboration than those who received any other letter grade in their engineering courses. Despite drives to seek out help and barriers to seeking help, strong help-seeking techniques are critical to new graduates' success in the workplace (Ford et al., 2019; Wolfe et al., 2015). For example, research on new engineers in the workplace highlights the importance of developing help-seeking strategies, like talking to others and finding resources, for overcoming challenges, like self-directed learning and teamwork and communication (Ford et al., 2019).

Help-seeking emerged as salient and as an important practice at LP-SA, and gendered patterns were not investigated in this study. The pandemic caused a significant disruption to relationship-building norms, which in turn affected help-seeking behaviors. Students could no longer find peers in-person in their classes to ask questions to or meet up in person to study together. Instead of leaning over to their neighbor in an in-person class, students had to take extra steps to connect with peers, sometimes reaching out to strangers. While these new patterns of peer relationships with respect to help emerged as salient at LP-SA, they did not emerge as salient at LP-US. Participants at LP-US did discuss changes to their peer relationships with respect to getting help, but not enough students to be considered salient. This discrepancy may speak to the strain on help systems at each site – perhaps help systems were more strained in South Africa than in the U.S. because of the asynchronous nature of all instruction. Alternatively, this salience at LP-SA and not LP-US may speak to the differences in year of participants at each site. At LP-SA, the majority of participants were in Year 2 or 3 of their degrees while at LP-US, the majority of participants were in Year 4 or 5. Accordingly, participants at LP-US had more time to build relationships in-person before the start of the pandemic. LP-US participants likely had existing relationships while LP-SA participants had more difficulty forming and maintaining relationships with peers.

Job Market

The theme of job market only emerged as salient at one site: LP-US. Godfrey and Parker (2010) found that the job market (i.e., the engineering profession) was a key piece of the environment that engineering education relates to (i.e., *relationship to the environment*). Godfrey and Parker (2010) found that "it was assumed that the curriculum would not only be monitored, but also shaped by, the needs of the profession," highlighting the perceived connection between engineering education and engineering industry (p. 17). Students at LP-US demonstrated a belief in and awareness of this connection in their interviews. They believed that they should be able to find a job based on the skills they acquire at university. However, they expressed concerns about the availability of jobs and internships as a result of the pandemic.

In addition to the environment aspect of the job market, Matusovich, Streveler, and Miller (2010) found that students described the utility value of their engineering degree in terms of the jobs they could find and money they could earn. That is, a motivator for students pursing an engineering degree is the type of job that the degree positions them for (Matusovich et al., 2010). The findings from this study are consistent with that motivation in that students at LP-US expressed concerns about their preparation for the job market, wondering if their lack of in-person laboratory and design experience would hurt their chances on the job market. These added stresses as a result of the pandemic complicated the relationship that students perceived between themselves and the engineering profession.

Scientific Way of Thinking

Lastly, the theme of scientific way of thinking only emerged as salient at LP-US. In the U.S., students demonstrated a scientific way of thinking, specifically with respect to the national and local response to the pandemic. This tendency towards a scientific way of thinking somewhat aligns with Godfrey and Parker's findings related to *an engineering way of thinking*. Godfrey (2015) identified a tension between the "objectivity of engineering science courses" and the "subjectivity of engineering practice" (p. 441). However, Godfrey and Parker (2010) found four themes to be most prevalent in *an engineering way of thinking*: the role of mathematics, the prevalence of visual communication, problem solving and design, and best not right answers. The prevalence of scientific way of thinking did not emerge as a salient way of thinking in Godfrey and Parker's (2010) study. However, the centering of a scientific way of thinking and more so the desired removal of politics from science that students expressed reflects the ideology of depoliticization (Cech, 2013). Students' belief that the U.S. response to the pandemic should have been divorced from politics reflects a belief that technical knowledge should be apolitical (Cech, 2013).

5.1.1 Comparing Results with Dimensions of Engineering Culture

As described above, there are many areas of overlap between the dimensions of engineering culture (Godfrey & Parker, 2010) and the results in this study. Godfrey and Parker's (2010) framework was chosen for this study because it offered a concrete and practical way to explore engineering culture. On the whole, the findings in this study align to a moderate extent with Godfrey and Parker's (2010) dimensions of engineering culture. Table 5-1 summarizes the themes that emerged as salient in this study *and* in Godfrey and Parker's (2010) and Godfrey's (2015) findings with respect to each dimension. (These themes were identified by generating a list of themes within each dimension from Godfrey and Parker (2010) and Godfrey (2015).)

All but one dimension (*being an engineer*) had common findings across studies, and the majority of themes found by Godfrey and Parker (2010) appeared – either as salient or non-salient – in this study. The themes that emerged in Godfrey and Parker (2010) and not in this study likely did not emerge because of the student-focused nature of this study, the design of the interview protocol, and the remote-learning and pandemic elements of this study. Overall, the dimensions of engineering culture still appear to be a useful starting framework for understanding engineering culture, even from a student perspective and during a crisis. However, researchers should be prepared to make adjustments and identify areas of mismatch between new findings and the findings of Godfrey and Parker (2010), especially when only researching students, researching during a crisis, and researching in national contexts outside of New Zealand. Importantly, Godfrey and Parker's (2010) work, while comprehensive, was developed out of an ethnography of one school of engineering at one university in one country, and thus, by design is not generalizable. Accordingly, researchers must be prepared to translate and adjust the framework to fit their context. Though adjustments may be needed based on the purpose and scope of future studies, the dimensions of engineering culture proved to be a useful a priori framework. Even though some themes spanned dimensions, the dimensions were unique and provided a productive framework for sorting and analyzing the data in this study.

Table 5-1: Alignment of Dimensions of Culture and Salient Themes

Dimension	**Themes that Emerged in Dimensions and were Salient in this Study**
An Engineering Way of Doing	- Shared beliefs and assumptions about how teaching and learning are accomplished - Heavy workload and hardness - Course structure, assessment methods - Cooperative forms of student behavior
An Engineering Way of Thinking	- Identification of the kinds of knowledge that are valued - The contrast between the objectivity of engineering science courses and the subjectivity of engineering practice - Emphasis on contextual learning - Valued knowledge is relevant to real life - Focus on problem solving and design
Being an Engineer	N/A
Acceptance of Difference	- Issues of homogeneity
Relationships	- Unconscious beliefs about appropriate levels of intimacy and formality in relationships - Development of close peer relationships - The importance of mates to academic survival and success
Relationship to the Environment	- Valuing a close relationship with engineering sectors - Assumption that the curriculum would be shaped by the needs of the profession

In addition to identifying common themes across this work and Godfrey and Parker's (2010) work, I also identified challenges with parsing the definitions of *an engineering way of doing*, *an engineering way of thinking*, and *being an engineer*. In order to operationalize the framework, I decided on distinct, mutually exclusive definitions for each dimension, which were drawn from the findings of Godfrey and Parker (2010) and Godfrey (2015). These definitions were provided in section 2.2.2. Once I identified distinct definitions, I was able to apply the framework to the data as a priori codes. However, I found that my peer researchers who contributed to the quality measures in this study arrived at varied interpretations of these dimensions. Specifically, the peer researchers coded more excerpts as *being an engineer* than I did. The peer researchers saw *being an engineer* as the process of becoming an engineer, where I saw *being an engineer* to be specifically related to the process of developing an engineering identity. This resulted in me coding some excerpts as *an engineering way of thinking* or *an* *engineering way of doing,* and the peer researchers coding the same excerpts as *being an engineer*. Once I shared my distinct definitions, the peer researchers reached consensus with my coding. However, these initial varied interpretations point to a difficulty in separating *an engineering way of doing*, *an engineering way of thinking*, and *being an engineer*. While I arrived at distinct definitions that drew on Godfrey and Parker (2010) and Godfrey (2015), other researchers may arrive at different operationalizations of these three dimensions. Ultimately, the challenges highlighted here support the decision to organize the findings by salient theme rather than by dimension. In other words, reporting salient themes rather than reporting findings by dimension and using the framework as a starting point rather than a constant throughout the study made differences in understandings of these three dimensions significantly less important.

5.2 Answering RQ 2: Key Differences Across Sites

In response to the second research question, three themes emerged as salient at only one site, indicating key differences across sites. Moreover, as discussed in Section 4.3, key differences between sites emerged with respect to each salient theme. While the results from LP-US and LP-SA cannot be taken as representative of their respective countries, they do highlight ways in which national politics and national history can shape institutional and departmental policies and climate. Moreover, because the U.S. and South Africa have a similar history in that both countries are English-speaking former British colonies, there are similarities in their educational systems that trace back to the British models. Lastly, these differences may be partially attributable to institutional differences and sample demographics as opposed to other factors.

This national influence can be seen in the theme *scientific way of thinking*. South Africa took a more nationally unified approach to responding to the pandemic than the United States did, which is reflected in the presence of the theme *scientific way of thinking* at LP-US. *Scientific way of thinking* emerged out of students' frustrations with the response to the pandemic in the United States, where the more unified approach in South Africa appeared to not spark frustrations in the same way. Thus, in the U.S., the national response, or lack thereof, spurred students to think about the role of science and engineering in shaping responses to pandemics and spurred frustration that the response was not more rooted in science and a logical way of thinking.

Next, institutional differences can be seen in the theme *differential access to resources*, which had the most poignant variation between sites. LP-SA took significantly more steps as an institution to ensure that students had access to laptops and data, which they needed in order to engage in content remotely. This difference may have been informed, in part, by the student fee protests of 2015 and 2016. The protests may have primed the university to take a more equity minded approach to the response to the pandemic.

In LP-SA's pandemic response, the university acknowledged that inequality persisted despite the steps the university took to increase access. For example, much of the data that students received was limited to the hours of 00:00-5:00 (12:00 AM – 5:00 AM). Students may have faced expectations to share their laptops and/or data with their family members at home. Students may also have returned to home environments that were not conducive to study. As a result, the university set expectations with instructors and made several recommendations to acknowledge and respond to inequalities. For example, the university warned that students will struggle to access video content and encouraged instructors to offer content of the same quality in other formats to ensure that all students can participate. Additionally, the university encouraged faculty to foreground compassion and care in teaching and learning and to be flexible around deadlines. However, requiring that all education be done asynchronously may have impacted the kinds of help that students at LP-SA were able to seek out. For example, asking for help from lecturers or peers during class became impossible, as classes were not held synchronously. Students had to adapt and find other forms of help, like question-and-answer forums. In contrast to LP-SA, LP-US had a stock of about 100 laptops that could be borrowed free of cost by students. Students had to retrieve the laptops from a location on campus. No data was made widely available. The difference in institution-level responses with respect to equitable access to resources is reflective of two key factors: student protests over fees and the cost of a college education in South Africa in the years prior to the pandemic and national conversations about inequity and difference. While both countries continue to grapple with their histories of racial inequity (Mabokela & Mlambo, 2017; Museus et al., 2015), LP-SA took more steps to build equity into their response to the pandemic. The extra steps taken by LP-SA, coupled with the difference in cost of higher education in the U.S. and in South Africa may have also contributed to the difference in how students constructed their experiences related to application and design.

Lastly, institutional and sample differences may have contributed to the salience of *seeking help* at LP-SA and not LP-US. In terms of institutional differences, LP-SA conducted all content delivery asynchronously, so students did not have regular sessions with lecturers in which they could ask for help. At LP-US, most students reported that their courses met synchronously, so they were able to ask for help during lectures or during office hours. In terms of sample differences, participants at LP-US were further along in their degree programs than participants at LP-SA. Recall from Table 3-9 that 8 of 11 participants at LP-US were in their 4^{th} or 5^{th} year at the time of interview while all LP-SA participants were in their 2^{nd} or 3^{rd} year. This difference in degree progress meant participants at LP-US had more time to build peer networks and help seeking strategies in-person before the switch to remote learning. Additionally, this difference in degree progress may have impacted findings related to *application and design*. Participants at LP-US were much closer to graduation than participants at LP-SA, which could account for some of the increased frustration that students at LP-US felt about losing in-person laboratory experiences. Students at LP-US may have felt that they would not get the opportunity for in-person application experiences before they graduated. On the other hand, students at LP-SA noticed the university made it possible for senior students to complete necessary practicals in-person, so participants at LP-SA may have believed that they would receive the necessary in-person practicals before they graduated.

5.3 Disaster and Education: Impacts of the Pandemic

The third purpose of this study is to understand what an investigation of engineering culture during a disaster reveals about the culture itself. In order to address this purpose, I summarize the aspects of engineering culture that changed during the pandemic (Table 5-2) and the aspects that did not change (Table 5-3).

First, at both sites, *intrinsic hardness* remained a core belief that shaped students' understanding of what it means to be an engineering student. Students believed that engineering should be hard and time consuming, even during a pandemic. Thus, through the pandemic, hardness remained a key cultural belief amongst students at both sites. Second, at LP-SA, *seeking help* became harder to access, but remained integral for academic success. Third, at both sites, resources like quiet study environments and internet access remained important for academic success, but these resource factors became more salient as students lost access to university spaces and internet. Fourth, at both sites, students continued to believe that hands-on design experiences were critical to their education, but lost access to in-person design and laboratory experiences. Fifth, at LP-US, students continued to desire jobs in the engineering profession and see the purpose of their education as preparing them for the profession. However, students expressed concerns about the availability of jobs due to the impact of the pandemic on the job market. Lastly, a scientific way of thinking emerged as a prevalent way of thinking amongst students at LP-US, primarily due to the national response to the pandemic.

Table 5-2: Summary of Changes During the Pandemic

Theme	**Changed During Pandemic**	
	LP-US	**LP-SA**
Intrinsic Hardness	N/A	N/a
Seeking Help		Harder to access help
Differential Access to Resources	Internet, home environment became more salient	Internet, home environment became more salient
Application & Design	Lost in-person experiences	Lost in-person experiences
Job Market	Concerns about availability of jobs	
Scientific Way of Thinking	Emerged as a prevalent way of thinking	

Table 5-3: Summary of Consistencies Through the Pandemic

Theme	**Did Not Change During Pandemic**	
	LP-US	**LP-SA**
Intrinsic Hardness	Engineering education should be hard and time consuming	Engineering education should be hard and time consuming
Seeking Help		Help is necessary for academic success
Differential Access to Resources	Resources (like quiet study environments and internet) are necessary for academic success	Resources (like quiet study environments and internet) are necessary for academic success
Application & Design	Hands-on design experiences are critical in training to be an engineer	Hands-on design experiences are critical in training to be an engineer
Job Market	Centrality of engineering profession	
Scientific Way of Thinking	N/A	

The changes in aspects of engineering culture during the pandemic reflect the broader context of the pandemic: remote learning, campus and residence hall closures, job market impacts, and national pandemic response. This finding indicates that when higher education is disrupted – in this case by a global health event – the structural features of that response will impact the ways in which students engage in their education as well as the concerns that are most prevalent for students. For example, shifting to remote learning and closing campuses led to challenges finding appropriate study environments, which led to challenges receiving help and challenges with accessing the necessary resources. Importantly, the changes in aspects of engineering culture were more so related to the broader context of the response. Students continued to believe that hardness, rigor, application, and design were central to their experience, despite disruptions to the ways in which education was carried out.

Accordingly, the consistencies in aspects of engineering culture during the pandemic point to enduring cultural features that remained important despite disruptions: the role of hardness, the role of help, the importance of access to physical resources, the centrality of application, and the centrality of the engineering profession. These features give significant insight into the 'stickiest' and most enduring beliefs in engineering. Moreover, the features that appeared as salient at both sites are particularly 'sticky,' as they emerged as central to engineering in two different national contexts and amongst two different sample demographics. These features – hardness, application and design, and access to resources – appear to be most central to students' construction of engineering. The salience of hardness and application and design aligns with other research that has been conducted in multiple national contexts and over time – as discussed in Section 5.1. The idea that engineering must be hard and must be hands-on appears to be central to students' construction of engineering. The salience of access to resources may have emerged because of the kind of disruption that the pandemic caused – students had to complete their education remotely and needed the physical resources necessary to do so successfully.

The pandemic stripped higher education and specifically engineering programs down to their most central elements, and knowing what remained when everything else (i.e., in-person learning and activities) was taken away gives significant insight into what elements of engineering culture are likely to endure through future change efforts and disruptions. Going forward, researchers and change-makers can specifically expect hardness and application and design to remain central to students' understanding of what it means to be an engineer.

6 Conclusions and Implications

In conclusion, I conducted a comparative case study of mechanical engineering students' expediencies taking second and third year courses during the COVID-19 pandemic at two large, public institutions. After completing both within- and cross-case analyses of the data, I identified six salient themes across the cases, three of which were salient at both sites and three of which were salient at only one site. My analysis identified the following cultural features that emerged as salient from students' perspectives during the pandemic at both sites: intrinsic hardness, differential access to resources, and application and design. Additionally, my analysis identified the following cultural features that emerged as salient at only one site: seeking help, job market, and scientific way of thinking.

These contributions enhance the field of engineering education because they highlight key cultural beliefs that emerged as or remained salient through a significant disruption to higher education. The pandemic impacted education across the globe. Understanding the beliefs and values that guided students' interpretations of their experiences provides significant insight into the most resilient aspects of engineering culture as well as the aspects that became more salient because of the disaster. By understanding students' experiences during the pandemic, instructors and administrators have additional data to support their decision making through the next educational disruption that they experience. Further, by understanding what elements of engineering culture were most salient during a disaster, we are able to understand the most prominent, underlying, and sticky aspects of the culture – the aspects that endured through one of the most significant disruptions to education in recent history.

6.1 Implications

The results of this study point to key implications for practice as well as key implications for future responses to educational disruptions. These key implications are discussed below.

6.1.1 Key Implications for Practice

There are three key takeaways from this study for instructors and faculty members who teach mechanical engineering. First, students' experiences varied and were highly dependent on individual instructors. Students had different experiences in each class they took, and those experiences primarily depended on their instructor's approach to teaching during the pandemic. Accordingly, these results suggest instructors have the power to directly affect students' experiences of education during a disaster based on how they respond. Additionally, these results suggest that students were empathetic and understanding of challenges that instructors faced, and students benefited most from good communication with instructors.

Second, instructors should consider where the hardness in their courses should come from. As this study highlights, hardness can come from many sources beyond course content, including assessment style, workload, and challenges associated with remote learning. Additionally, students expect their courses to be challenging, but some sources of hardness can be inequitable if students do not have adequate access to resources (e.g., requirements for assessments that do not account for students with limited internet access). As instructors and faculty are designing their courses, they should work to align their content, assessments, and difficulty levels with the learning outcomes of the course. Additionally, instructors can aim to clearly communicate what is intended to be hard (e.g., the questions on an exam) and what is not intended to be a barrier to success (e.g., short submission timeframes, anti-cheating software).

Moreover, while there are practical ways to reflect on where hardness in engineering courses should come from as mentioned above, the pandemic necessitates a moment of reflection on the role of hardness in general. During a global pandemic where, at the time of interviews, nearly 200,000 people in the U.S. and 20,000 people in South Africa had lost their lives to COVID (Ritchie et al., 2020), and where students were faced with significant challenges – moving out of dorms, finding the resources necessary to take classes remotely, family health and concerns, health concerns, financial uncertainty, etc. – they still overwhelmingly felt that not only their *classes* but their *experience* should be hard. While they appreciated flexibility when they felt it was offered, they simultaneously worried about the quality of their education when they experienced flexibility. As an engineering education community, we must reflect on the role of hardness in engineering programs, especially during times of disruption. Where are students picking up on messages that their education must be hard in order to be worth something? Why is extending grace and flexibility synonymous with *easy*? What are the implications of this valuing of hardness on our students' mental health and wellbeing? What are the implications of this valuing of hardness on diversity, equity, and inclusion?

Third, instructors should consider where opportunities exist for better communication and expectation setting with students. For example, instructors may intend to balance flexibility with expectations to cover certain content and students may only perceive the pressure to cover content. In this situation, instructors could open communication with students and explain their desire to offer some flexibility as well as the constraints they face in needing to cover certain content. The data in this study highlights challenges with communication across students and faculty. Striving to clearly communicate not only expectations but intentions can help mitigate misunderstandings between instructors and students.

6.1.2 Key Implications for Remote Learning

The COVID-19 pandemic will not be the last disruption to higher education. Natural disasters (Schuh & Santos Laanan, 2006), public health disasters (Santibañez et al., 2009; Van et al., 2010), protests (Czerniewicz et al., 2019), and war and conflict (SchWeber, 2008) have all disrupted higher education in the past and will likely disrupt higher education in the future. Moreover, remote and online teaching and learning are likely to endure long after the pandemic, whether or not there is an ongoing disruption forcing education online. Accordingly, it is imperative that we learn from this educational disruption and wide-scale shift to remote learning in order to create more equitable remote learning experiences and to better respond to future disruptions. Based on the findings and salient themes from this study, three key implications for future remote learning and disruption response emerged.

The first key implication for future remote learning and disruption response is ensuring an equitable remote experience across students. Assuming remote learning is here to stay in some form, regardless of disruption, universities should prioritize understanding the level of access that students have to necessary resources (e.g., laptops, Wi-Fi / data, quiet and safe study environments). Universities should provide the needed resources to students in order for them to successfully engage in remote learning. LP-SA's response, described in section 4.1.2, is an example of what equitable remote learning can look like. Universities should set expectations with instructors around remote learning (i.e., low bandwidth options only) to account for their students' level of access to resources. Additionally, universities should consider other factors that may limit students from engaging in traditional ways and ensure their mitigation strategies are effective and appropriate.

The second key implication for future remote learning and disruption response is an awareness of the centrality that students place on application and design. While students emphasized the importance of in-person application and design opportunities, it is worth investing in research into how to offer effective hands-on application and design during a disruption that drives students away from campus spaces. Several potential solutions emerged in these data, both for completely remote instruction and phased in-person instruction. The potential remote solutions that emerged in this data are at-home kits and recording the experiment and sharing data with students. The potential solutions for phasing back to in-person application and design include hybrid models (e.g., some students in-person, some students remote) and prioritizing in-person for certain groups of students (e.g., seniors). While this research identified potential solutions, it was not designed to investigate the efficacy of these solutions and thus is not equipped to provide recommendations on which solution is "best." Additional research investigating the efficacy of remote application solutions on students' preparedness would aid in understanding which solutions to invest in going forward.

The third key implication for future remote learning and disruption response is an awareness of the role of help in undergraduate engineering education. As programs strive to prevent cheating during remote instruction, they should not only be aware of the forms of help that are available to students but also be aware of the need for help and aim to facilitate that help in a way that aligns with their academic integrity policies. The frustrations that emerged in this study with respect to getting help related to slow communication between instructors / teaching assistants and students as well as not having enough established relationships with peers to effectively get help. Some students turned to online resources, like YouTube, and participants reported that other students turned to platforms that sell answers to homework and test problems, like Chegg. Programs should understand why students seek out help and aim to offer effective forms of help that align with their academic integrity policies.

Altogether, we must learn from educational disruptions, like COVID-19, in order to design more equitable remote learning experiences and better respond to future disruptions. While this study pointed to the three key implications for response discussed above, it is also critical to conduct additional research aimed at improving remote learning and preparing to respond to future disruptions.

6.2 Future Work

Future work can take several avenues to further investigate engineering culture both during times of disruption as well as during times of stability from the perspective of students and faculty. First, future work can expand on the investigation of culture during times of stress and disruption by examining student experiences during other disruptions (e.g., natural disasters, protests, etc.). This study examined one type of disruption, a pandemic, and future work could examine the impact of other disruptions on experiences and decision making. Second, future work can expand on the investigation of culture across national contexts. This study examined two English-speaking countries, both with histories of British imperialist rule. Future work could examine engineering culture in countries with different imperial and educational histories in order to identify commonalities and differences in engineering culture across national contexts. Third, as the pandemic is ongoing, future work can use the findings in this study to develop a quantitative survey, which can be distributed to large public institutions in the United States and South Africa. A survey would allow an investigation of the generalizability of the findings in this study. Fourth, future work can expand to more engineering disciplines in order to understand how engineering culture varies by discipline. This study examined mechanical engineering during a crisis, and future work could expand to examine more disciplines during times of crisis in order to understand differences in disciplinary cultures. Fifth, future work can further explore the themes that appeared as salient at both sites in order to understand if these themes remain central to students' constructions of engineering beyond the pandemic. Sixth, future work can build on Godfrey and Parker's (2010) dimensions of engineering culture and aim to develop a more generalized framework of engineering culture. Seventh, future work can explore the role that year in school plays in how students construct their experiences as related to the salient themes identified in this study. Eighth, future work can aim to understand the role that contextual factors, like the student fee protests in South Africa, impacted university level responses to other disruptions, specifically with respect to equity. Lastly, future work can investigate how to improve responses to future educational disruptions. This study revealed the key elements of an undergraduate engineering education, according to students, and those key elements could be further investigated in order to equitably and effectively respond to future disruptions.

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Appendix A: Screening Survey

Participants were directed to a Qualtrics survey with the following questions:

Student Screening Survey

1. What Mechanical engineering courses were you enrolled in during March 2020? (Open Response)
2. How would you describe your experience taking these courses? (Multiple Choice)
    a. It wasn't ideal, but I did fine.
    b. It was a little tough, but overall I managed.
    c. I did okay with some things, but not with others.
    d. Honestly, it was pretty rough all around.
3. If you are willing to participate in an interview, please provide an email address we can use to contact you. (Open Response)

Key Informant Screening Survey

1. What Mechanical engineering courses did you teach during March 2020? (Open Response)
2. How would you describe your experience teaching these courses? (Multiple Choice)
    a. It wasn't ideal, but I did fine.
    b. It was a little tough, but overall I managed.
    c. I did okay with some things, but not with others.
    d. Honestly, it was pretty rough all around.
3. If you are willing to participate in an interview, please provide an email address we can use to contact you. (Open Response)

Appendix B: Student Interview Protocols

This study will use semi-structured interviews and address questions such as those below. However, because the interviews are semi-structured, the exact wording and order of the questions may vary slightly, and follow-up questions may be included to elicit additional information around these topics.

Introduction:
Thank you so much for making time for this interview. I know these past few months have been particularly disruptive and challenging. I'm really interested to hear about your experiences since this pandemic hit and hear your perspective about how your instructors, department, and university approached the transition. And I'm interested to know about the decisions you've made since March in regards to being a student.

I want to invite you to **speculate** about why your engineering courses were run the way they were. I welcome you to bring in your observations about your experiences of engineering education. And, if you've had conversations with your friends about their experiences, I welcome you to bring those conversations to this interview as well.

I want to start by having you tell me your story of the last few months.

1. Can you walk me through the spring semester (U.S.) up till now, starting when the announcement was made that we'd be transitioning to remote/online teaching & learning? What went well, what didn't go well?

Let the participant tell an uninterrupted narrative. Take notes for follow-up questions. Potential follow-up questions:

- What changed and what do you think of those changes?
- Why do you think those things changed / didn't change? Feel free to speculate.
- How did the remote portion of the semester compare to your beliefs about / perceptions of how engineering classes are and how engineering classes should be taught?
- Did the level of difficulty or workload change in any of your classes?
- Did your instructors address the transition online? Why do you think they did/didn't?
    - Did your instructors talk about the pandemic at all during the semester? Why do you think they did/didn't? How do you feel about that choice?
- Did anything surprise you about how any of your classes (engineering or non-engineering) went? If yes, what surprised you? Why? If not, why were you not surprised?

The following questions might be covered in the participant's narrative. They can be used as follow-up questions or additional questions if not covered in the narrative.

2. Can you talk a bit more about what went well in your classes and what didn't go well?

- What were the main differences between the class(es) that went well and the class(es) that didn't go well?
- What are your thoughts about how the instructor(s) managed the remote portion of the course overall?

- What were the main differences between instructional practices that were effective and ineffective?
- Can you tell me a bit more about how your instructors approached tests/quizzes/exams?
    - Did it seem like cheating was a concern? Why do you think they were worried about cheating? Do you think they should have been concerned about cheating.

3. Are there any instructional practices that your professors adopted during this time online that you want them to continue after the pandemic? Any instructional practices you'll be happy to leave behind?

4. Did you take any non-engineering courses? If not, are you able to compare your experience to the experience of those in non-engineering departments?
    - What similarities and/or differences did you notice between your engineering and non-engineering courses?
    - Why do you think those things are similar or different?
    - Why were your engineering classes different? Is it something about engineering?
    - Is any of this specific to engineering? Why?

5. How prepared do you feel for what you want to do next? Did these online courses impact how prepared you feel?

This section will focus on understanding why you think that your faculty made the choices they made in adapting your course.

6. What kind of factors do you think your *instructors/lecturers* considered when making the choices they did about moving their classes online? What kind of factors do you think your *department* considered? Your *university*?

7. Are there any factors that you wish your instructors/department/university had considered?

This section will focus on broad, closing questions.

8. What do you want your faculty (your instructors / faculty in your department) to know about how this pandemic impacted you as a student?

9. Anything else that is important for me to capture about your experience?

Appendix C: Key Informant Interview Protocols

This study will use semi-structured interviews and address questions such as those below. However, because the interviews are semi-structured, the exact wording and order of the questions may vary slightly, and follow-up questions may be included to elicit additional information around these topics.

Introduction:
Thank you so much for making time for this interview. I know these past few months have been particularly disruptive and challenging. I'm really interested to hear about your experiences since this pandemic hit and hear your perspective about how you, your department, and your university approached the transition. I'm curious about what decision you had to make when making your classes remote, and how you went about making those decisions. I welcome you to bring in your observations about your students, colleagues, department, and university. Speculations are welcome!

Let's start by having you tell me your story of the last few months.

1. Can you walk me through the spring semester (~Jan – May) up till now, starting when the announcement was made that we'd be transitioning to remote/online teaching & learning? What went well, what didn't go well, and what was challenging?

Let the participant tell an uninterrupted narrative. Take notes for follow-up questions. Potential follow-up questions:

- What changes did you make as an instructor / lecturer? Why? What didn't change? Why?
- Did the level of difficulty or workload change in any of your classes? Why?
- What factors did you consider as you shifted your courses online? Why? *(if appropriate here, if not wait until Question 7)*
- How did the remote portion of the semester compare to your beliefs about how engineering classes should be taught? *(if appropriate here, if not wait until Question 6)*
    - If you think of how engineering classes should be taught, in what ways did the courses you taught align or not align with those beliefs? Why?
- Did anything surprise you about how any of the classes you taught went? If yes, what surprised you? Why? If not, why were you not surprised?
- Did you address the transition online with your students? If so, how? If not, why not?
    - Did you talk about the pandemic during the semester/term? If so, how? Why did you choose to talk about it or not to talk about it? Do you believe it should be talked about?

The following questions might be covered in the participant's narrative. They can be used as follow-up questions or additional questions if not covered in the narrative.

2. Thinking across the courses you taught this year (including all terms since March 2020), were there classes that went well and others that didn't?

- Tell me about the class(es) that went well.
- Tell me about the class(es) that didn't go well.
- What were the main differences between the class(es) that went well and the class(es) that didn't go well?
- Did you find that any of your approaches or practices were effective? Why were they effective?
    - Were any ineffective? Why were they ineffective?

3. How would you say your students responded to the change to remote learning?
Possible prompts:
- What do you think was hard or challenging for students about this change?
- What do you think was easy or less challenging for students about this change?

This section focuses on assessments.
4. Can you tell me a bit about how you approached tests/quizzes/exams?
- Timing, format, lockdown browser?
- Did the level of difficulty of courses factor into your decisions about assessments?
- Did cheating factor into your decision about how to give assessments? Why? Looking back, do you still agree with your approach?

5. Did you (or your department) have concerns about academic dishonesty?
Possible prompts:
- How did you address those concerns in your course? Department? University?
- In your opinion and experience, were those concerns about academic dishonesty warranted? Why or why not?

This section focuses on beliefs about how engineering classes should be taught.
6. Did you teach any non-engineering courses?
(If yes) - What similarities and/or differences did you notice between your approach to engineering and non-engineering courses? Any differences with students?
(If no) - How did the remote portion of the semester compare to your beliefs about how engineering classes should be taught? How did your beliefs about how engineering should be taught influence how you approached your online classes?

This section will focus on broad, closing questions.

7. What factors did you consider when transitioning your courses online? Are there any factors that you wish either you, your department, or your university had considered? Why do you think those factors weren't considered?
Possible Prompts:
- What are your thoughts about how you, your department, and your university managed the shift to remote teaching? What went well? What didn't go well?

8. Are there any instructional practices that you adopted during this time online that you want to continue after the pandemic? Any instructional practices you'll be happy to leave behind?

9. What do you want students to know about how this pandemic impacted you as an instructor/lecturer/faculty member? What do you want your administration to know about how the pandemic impacted you?

10. Anything else that you'd like me to capture about your experience?

Appendix D: Full Codebooks

Table E-1: Full Codebook for LP-US

Theme	Category	Subcodes	Dimension	Number of Participants (out of 11)
Differential Access to Resources	- Awareness of Difference - Treatment of Difference - Experiencing Difference	- Internet - Home Environment - Physical Resources	- Acceptance of Difference	9
Health and Wellness	- Awareness of Difference - Treatment of Difference - Experiencing Difference	- Mental Health - Physical Health - SSD Accommodations	- Acceptance of Difference	5
Apolitical & Decontextualized	- Ways of Learning - Ways of Teaching	- Objective - Apolitical	- An Engineering Way of Thinking - An Engineering Way of Doing	3
Application & Design	- Ways of Learning - Ways of Teaching	- Application - Design - Job Market	- An Engineering Way of Doing - An Engineering Way of Thinking	9
Intrinsic Hardness	- Assessment - Ways of Teaching - Ways of Learning - Peer Relationships - Instructors/TAs	- Burnout - Workload - Overwork - Cheating - Assessment Format - Course Format - Efficiency - Engagement - Help - High Stakes - Inflexible Curriculum - Motivation - Office Hours	- An Engineering Way of Doing - Relationships	11
Scientific Way of Thinking	- Epistemology	- Efficiency - Organization - Structure - Logic - Uncertainty	- An Engineering Way of Thinking	8
Identity	n/a	- Self - Group	- Being an Engineer	3
Engineering Mindsets	n/a	- A desire to help	- Being an Engineer	1
Job Market	- Job Market - Preparedness - Industry Professionals	- Internship - Type of work - Availability of Work	- Relationship to Environment - Relationships	9

Theme	Category	Subcodes	Dimension	Number of Participants (out of 11)
		- Arrogance		
University Environment (*Included in case report)	- Administration - Department - Interactions	- Communication - Finances - Policies & Procedures	- Relationship to Environment	11
Seeking Help	- Peers - Tutors - Lecturers	- Office Hours - Collaboration - Challenges	- An Engineering Way of Doing - Relationships	7

Table E-2: Full Codebook for LP-SA

Theme	**Category**	**Subcodes**	**Dimension**	**Number of Participants (out of 10)**
Differential Access to Resources	- Awareness of Difference - Treatment of Difference - Experiencing Difference	- Internet - Laptop - Data - Home Environment - Physical Resources	- Acceptance of Difference	10
Health and Wellness	- Awareness of Difference - Treatment of Difference - Experiencing Difference	- Mental Health - Physical Health - Accommodations	- Acceptance of Difference - An Engineering Way of Doing	6
Application & Design	- Ways of Learning - Ways of Teaching - Job Market	- Application - Collaboration - Design - Preparedness	- An Engineering Way of Doing - An Engineering Way of Thinking - Relationships	10
Intrinsic Hardness	- Assessment - Ways of Teaching - Ways of Learning	- Burnout - Workload - Overwork - Cheating - Assessment Format - Efficiency - Engagement - Help - High Stakes - Inflexible Curriculum - Motivation - Office Hours	- An Engineering Way of Doing	10
Apolitical	- Ways of Learning - Ways of Teaching	- Objective - Apolitical	- An Engineering Way of Thinking - An Engineering Way of Doing	3
Identity	- n/a	- Self - Group	- Being an Engineer	2
Seeking Help	- Peers - Tutors - Lecturers	- Office Hours - Collaboration - Challenges	- An Engineering Way of Doing - Relationships	10
Communication	- Peers - Tutors - Lecturers - Department - University	- Challenges	- Relationships - Relationship to Environment	7
Empathy	- Professors	n/a	- Relationships	1

Theme	**Category**	**Subcodes**	**Dimension**	**Number of Participants (out of 10)**
Job Market	- n/a	- Application - Preparedness	- Relationship to the Environment - An Engineering Way of Doing - An Engineering Way of Thinking	6