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The impact of emergency remote learning on students in engineering and computer science in the United States: An analysis of four universities

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Abstract

Background: In Spring 2020, the COVID-19 pandemic sent universities into emergency remote education. The pandemic has been disruptive but offers the opportunity to learn about ways to support students in other situations where abrupt changes to teaching and learning are necessary.

Purpose/Hypothesis: We described the responses of engineering and computer science students to a series of prompts about their experiences with remote learning.

Design/Method: Data about students' remote learning experiences were collected from undergraduate engineering and computer science students at four different universities through an end of semester survey. Descriptive statistics were calculated, and qualitative responses were analyzed using qualitative content analysis through the lenses of master narrative theory and socio-cultural theory.

Results: Student responses revealed how their individual circumstances combined to reduce motivation, create home environments detrimental to completing schoolwork, and increase stress. Many students described negative impacts of remote learning, but some students found positive aspects of the situation. The majority of students did not indicate a change in their desire or plans to pursue engineering or computer science majors.

Conclusions: There was wide variation in how students experienced the disruption to university learning during Spring 2020. Implications of this paper can help not only in cases where emergency remote learning is needed in the future, but also as universities seek to return to "normal" operations in 2022 and beyond.

Key Words

COVID-19, remote learning, equity, multi-institution, undergraduate, qualitative methods, engineering, computer science

1. Introduction

The first positive COVID-19 case was diagnosed in the United States on January 20, 2020. By mid-March 2020, universities began an abrupt switch to remote learning. This emergency switch to remote learning was both unprecedented and urgent. And it left colleges and universities with little time for deliberation or data collection as they made and remade policies and strategies to handle unanticipated stresses on the higher education system (Hodges et al., 2020; Williamson et al., 2020). For example, students, faculty, and others working in crucial student support areas were sometimes given less than 24 hours to shift to a completely remote learning environment (Sahu, 2020). Faculty members were simultaneously experiencing stress and anxiety caused by the pandemic, using new teaching strategies, and doing their best to demonstrate care and concern for students (Johnson et al., 2020). Campus information technology offices, teaching and learning centers, and libraries had to rapidly shift their operations to meet the new needs of thousands of remote students and instructors (Espino-Díaz et al., 2020). Campuses around the world indicated challenges in communicating with students and staff in ways that were clear and effective, as well as meeting the specific teaching and learning needs associated with specific fields of study, such as laboratory courses (Marinoni et al., 2020). The difficulties caused by the pandemic reached every facet of life, including health and safety, economics, and politics, and thus profoundly affected all students (Marinoni et al., 2020; Williamson et al., 2020).

Through its widespread impacts the pandemic exacerbated existing inequities in U.S. society. For example, Black and Hispanic people experienced higher rates of death and unemployment (Louis-Jean et al., 2020). It is highly likely that existing inequities and injustices

in higher education also became more pronounced (Barr et al., 2020). Here we examine the impact on engineering and computer science students at four universities.

Some of the negative impacts of the emergency switch to remote learning on engineering students were documented in a recent study by the American Society for Engineering Education (ASEE, 2020). This study reported that some students received incompletes for their grade in laboratory-based classes that were canceled. For courses that continued, about half of the students in the ASEE study had to use personal funds to buy equipment to participate in their courses remotely. Further, students struggled with the remote learning environment because inadequate internet bandwidth prohibited their remote participation. These students also indicated problems with motivation and concerns about the job market as a result of the pandemic.

Another study reported similar negative impacts on student motivation, social connectivity with professors and peers, student finances, and activities that promote physical and mental well-being (Gonzalez-Ramirez et al., 2021). These immediate negative impacts may have long-term consequences for students. It is also possible that the challenges associated with remote learning and the pandemic as a whole have changed how engineering and computer science students view the role of engineers and their desire to remain in engineering and computer science.

The COVID-19 pandemic was not the first time that educational systems were severely disrupted. In 2005, Hurricane Katrina impacted at least 30 institutions of higher education and disrupted the education of more than 50,000 university students (Gill et al., 2007). These disruptions ranged from canceling classes for a few days to the cancelation of the entire academic year (Gill et al., 2007). From 2010 to 2011, the Canterbury earthquakes resulted in

widespread damage to schools and universities in New Zealand (Mackey et al., 2012). In 2003, Hong Kong and China closed schools when the deadly SARS virus hit (Lau, 2003; Zeng et al., 2005). Since natural and human-made disasters will continue to occur, it is critical to better understand the difficulties that instructors, students, and schools have faced and develop solid systems for rapidly deployable quality remote learning.

1.1 Purpose

In this study, we examined how engineering and computer science students were impacted by the emergency switch to remote learning, how sources of stress were systematically or distinctively experienced, how university context influenced student stress, and how the challenges of Spring 2020 impacted students' views about their engineering and computer science majors. Specifically, we collected data in Spring 2020 from engineering and computer science students at four universities. While different terms were used by these universities for different types of learning, in this manuscript we use the term “remote” to reference any kind of learning that was not delivered in-person. To understand the experiences and sources of stress affecting students related to the emergency switch to remote learning, we first present a summary of the impact of COVID-19 on learning more broadly and then situate our study in socio-cultural and master narrative theories (Lemke, 2001; McLean & Syed, 2015). From this information, we provide recommendations for how to address future similar situations.

1.2 Challenges of Remote Learning during the COVID-19 Pandemic

In Spring 2020, the worldwide COVID-19 outbreak forced instructors and students to transition rapidly to remote teaching and learning (Hamilton et al., 2020; Lake & Dusseault, 2020); this rapid shift created the challenge of providing students with high-quality remote

learning experiences. Because most K-12 schools, colleges, and universities suspended face-to-face teaching to protect students, instructors, and community members, the quick shift to remote learning was the only solution for carrying out the desired curriculum. Unlike existing online courses in higher education, this transition required instructors to deliver course content intended for face-to-face instruction remotely (Hodges et al., 2020). Instructors had to modify their instructional strategies, assessments, and ways of communication without any training and very little time to make the necessary changes (Gillis & Krull, 2020).

While there is an increasing body of literature around the emergency shift and remote teaching practices, at the time we designed this study there was little literature to guide this change, and little still had been published while we analyzed our data. Furthermore, much of what was published during our writing process is focused on international or global contexts (e.g., Bozkurt, Aras et al., 2020; Mukhtar et al., 2020; Petronzi & Petronzi, 2020; Williamson et al., 2020). While thinking about the global impacts of the emergency shift to remote learning is important, research situated in contexts beyond the United States may or may not apply to our study, due to the wide range of sociocultural contexts and master narratives that informed educational shifts globally (Bozkurt, Aras et al., 2020).

To navigate this emergency switch to remote learning, instructors began applying innovative remote pedagogical approaches and rapidly designing more collaborative learning environments (Favale et al., 2020). As part of the shift, the use of products that could help remote teaching and learning, such as Google Classroom, Google Jam Board, Zoom, and other platforms for Massive Open Online Courses, significantly increased (Basilaia & Kvavadze, 2020).

Particularly due to the differences between pre-pandemic online learning and remote learning during the pandemic (Williamson et al., 2020), instructors and students faced a variety of difficulties while teaching and learning remotely. Both students and instructors struggled with technical problems, such as a lack of high-speed internet access, devices, or competencies in using new software needed for remote learning (Gonzalez-Ramirez et al., 2021). The remote context made it even more difficult to engage students because students may have had more distractions while learning at home (e.g., taking care of pets or other family members, household chores). These distractions may have been heightened during COVID-19, as students may have been required to take on additional caregiver, employment, or other responsibilities in response to the pandemic (Gillis & Krull, 2020). Therefore, remote classes during the emergency shift to online learning may have required more self-motivation for some students.

Moreover, students could have a hard time focusing on their studies as they faced other big changes due to COVID-19, such as family, health, or financial problems (Dhawan, 2020; Gonzalez-Ramirez et al., 2021). Indeed, Adnan and Anwar (2020) found that 72% of higher education students experienced less motivation for remote learning than conventional in-person learning. The quality of remote learning also depended on institutions' level of preparedness for remote learning, learning management systems, and instructors 'competence in using remote learning tools (Parkes et al., 2015).

According to a report from the National Center for Education Statistics (NCES, 2021), 94% of students (ages 3 to 18) had internet access around the time of the switch to emergency remote learning. However, 6% of these students had access only through smartphones, which are inappropriate for teaching or learning. The NCES report revealed significant differences in resources for remote learning among students of different racial/ethnic identities. While only

about 3% of white students could access the internet exclusively with smartphones during the emergency shift, this was true for 11% of Black and 10% of Hispanic students. While these data focus on younger students, they exemplify the inequities in access that did not disappear for undergraduate students once they were no longer K-12 students, especially if they were living with their parents after their universities shut down.

Student experiences in higher education are never uniform, as they are influenced by numerous, interacting factors. Even though many in higher education have been working to mitigate existing inequities around social identities and socio-economic status, too often higher education replicates and/or amplifies these societally-embedded inequities rooted in structures of oppression, such as systemic racism (Rollock, 2018). In the case of COVID-19, when institutions of higher education shifted to remote learning, some students were left experiencing homelessness and food-insecurity, living in unsupportive or toxic situations, and lacking the technology to access not only their courses but also other vital networks of support (Day et al., 2021; Goldrick-Rab, 2020; Gonzalez-Ramirez et al., 2021).

1.3 Theoretical Framework

To help us understand the specific challenges students faced, our research was informed by the intersection of socio-cultural and master narrative theories. Socio-cultural theory informed our entire research process, from initial research question development through data analysis. During the data analysis we also used master narrative theory to strengthen the theoretical grounding. Socio-cultural and master narrative theories are both deeply relevant in the context of the emergency shift to remote learning, as changes related to COVID-19 added layers of social and cultural assumptions and norms to the pre-existing norms that already create inequitable learning environments for students (Eisenhart & Allen, 2020; Lemke, 2001).

According to socio-cultural theory, each individual's social and cultural experiences influence their everyday interactions, including their learning (Lemke, 2001). A socio-cultural lens requires researchers to think of STEM, STEM education, and research on STEM education as activities that are conducted within both institutional and cultural frameworks (Eisenhart & Allen, 2020; Lemke, 2001). As such, the beliefs and practices of instructors, institutional and societal norms, and students' lived experiences all influence how students learn (Lemke, 2001).

Master narrative theory, a related theory, specifically states that there are dominant cultural norms, or master narratives (McLean & Syed, 2015). Additionally, there are alternative narratives, which are norms that are dominant within sub-cultures that do not fit the dominant norms (McLean & Syed, 2015). Master narratives provide norms for how to be a good or successful member of society, as envisioned by the dominant culture (McLean & Syed, 2015). While these norms can be useful in creating a coherent society, they can also be harmful, as they are often exclusionary for those whose experience is not represented by the master narrative of a given situation (McLean & Syed, 2015). Furthermore, it is usually challenging for individuals to follow paths that are not part of a master narrative (McLean & Syed, 2015). Alternative narratives, while potentially helpful to those with identities beyond master narratives, can be similarly confining (Bradford & Syed, 2019).

Because everything happens situated within a socio-cultural context (Eisenhart & Allen, 2020), students' experiences during the emergency switch to remote learning were influenced by their own socio-cultural context, as well as the master narratives used by decision-makers. Due to the unprecedented nature of this shift, there were not specific research-based master narratives we could draw from when we developed our study and analyzed our data. However, we used socio-cultural theory to help us understand how different students experienced the emergency

shift online through different social and cultural contexts. Master narratives that had been developed in relation to COVID-19 by the time we were writing our paper were focused on narratives relating to medical and epidemiological facets of the epidemic, such as plague originating in Asia and European methods of fighting plague is the only successful way to end disease (e.g., Törrönen, 2021; Varlık, 2020). We were unable to find published master narratives relating to education.

Despite the lack of master narratives specifically related to students' experiences during COVID-19, we argue that assumptions made at the university level about students' internet access, home environment, and other factors that facilitate remote work were all master narratives that institutions relied upon during the switch to remote learning. Specifically, we identified three major implicit assumptions that created master narratives: 1) students had internet access and a computer sufficient for synchronous video conferencing, 2) students had a home environment that was safe, had sufficient space, and lacked distractions that would interfere with their participation in coursework, and 3) students had the self-directed learning skills to learn independently without frequent contact with their instructors or other students.

Our arguments are supported by the studies that discuss how students who did not have access to both appropriate computers and high-speed internet service, as well as those whose living situations were not conducive to at-home learning, were put in situations that led to inequitable access to learning (Gonzalez-Ramirez et al., 2021; Iyer & Chapman, 2021). Even when students could access content through alternative means, such as a smartphone, iPad on a cellular network, or wireless internet broadcast outside a library, they would have experienced bigger barriers to learning than students who could easily work from computers in a private room (Gonzalez-Ramirez et al., 2021). While we do not claim to have identified all master narratives

in higher education during the early stages of the COVID-19 pandemic, we identified these major master narratives by considering the situation from a socio-cultural lens (i.e., what are the different ways peoples' lived experiences are influencing this situation) and based on critical evaluation of our own and others' experiences during the emergency shift. Our experiences included university emails, feedback from students and conversations with colleagues, as well as reading literature about computer and internet access. We critically evaluated the narratives we identified with the emerging body of literature about students' experiences, continued communications with our universities and colleagues, and the themes present in our data analysis.

Students' socio-cultural environment and its alignment with the master narratives influenced students' experiences. To counter inequities, both socio-cultural theory and master narrative theory explain the importance of incorporating alternative narratives and experiences related to barriers to access into planning and decision-making (McLean & Syed, 2015). Specifically, these theories explain the importance of interrogating assumptions made about learning by those in power, as people in power within academia are those who have succeeded within the previous 'status quo.' Therefore, they are likely to be predominantly people whose experiences are described by dominant socio-cultural experiences and master narratives within the academy (Eisenhart & Allen, 2020; McLean & Syed, 2015).

1.4 Current Study and Research Questions

To understand how the assumptions about students' experiences, and access to technology influenced their learning we examined students' responses to an end of semester survey. In our data collection and analyses we specifically focused on how students' socio-cultural contexts affected their remote learning experiences. Our focus allowed us to connect each individual

student's responses to the larger socio-cultural contexts and master narratives that influenced the emergency shift to remote learning. These data not only help explain what students experienced during the emergency shift to remote learning, they may help in creating more effective teaching environments in similar future situations. In this paper we address the following research questions:

1) What personal and course-based elements of student experiences did students report as sources of stress?
2) How did students perceive socio-cultural influences and elements of the master narrative in how their personal identities or circumstances affected their learning, and how the entire situation affected their performance?
3) How did the pandemic affect student views about and plans for careers in engineering or computer science?

2. Methods

To address our research questions, we collected survey data from engineering and computer science students at four universities in the United States. The research team, which included the authors and several individuals listed in the acknowledgements, was already working together to study the development, implementation, and evaluation of course activities intended to teach engineering and computer science students about diversity, equity and inclusion topics in required undergraduate courses (Atadero et al., 2018). When the universities began switching to remote learning the research team was immediately interested to learn how this switch would impact students with different circumstances. Because the research team was already working together, had already had most of the study procedures vetted by IRB, and had

already planned an end of semester survey, we were able to quickly collect data about student experiences during the emergency switch.

2.1 Setting and Participants

Of the four universities involved (see Table 1 for university characteristics), Universities A and D are large, very high research activity (R1) land-grant universities (A, $n = 93$, and D, $n = 353$). University B is a private, high research activity (R2) liberal arts university located in a metropolitan setting in the Rocky Mountain region ($n = 35$). University C is a public, non-residential, larger master granting (M1) university also in a metropolitan setting in the Rocky Mountain region ($n = 33$). We note that while all of the universities are predominately white, there is a wide range in the races and ethnicities reported across the universities, as well as a wide range in the number of students participating at each university (see Table 2). Also, Table 3 reports students' gender identities by university. A comparison of the demographics at each of the four universities and participants showed that the sample adequately represented engineering or computer science undergraduates at each university. Detailed demographics can be found in Supplementary Tables 2–5.

The survey response rates for our study were 66.4% for University A, 81.4% for University B, 51% for University C, and 72.9% for University D. These response rates represent the percentage of respondents who consented to participate in our study.

Table 1: The four universities in our study

University	Location	Number of undergraduates	University demographics	Student/Faculty ratio
A	Mid-sized City	25,903	22% Students of Color, 21% First Generation, 21%	16:1

			Pell Grant eligible, 52% Women	
B	Large City	5,765	22% Students of Color, 54% Women	11:1
C	Large City	19,258	44.7% Students of Color, 49.1% First Generation, 31.5% Pell Grant eligible, 54% Women	18:1
D	Small City	22,504	15% Students of Color, 46% Women	20:1

Table 2: Student reported race and ethnicity by university

	A	B	C	D	Total
American Indian (Alaskan Native)	4	0	0	5	9
Asian	8	11	6	22	47
Black or African American	1	2	1	13	17
Hispanic, Latino, or Spanish	9	6	7	10	32
Middle Eastern or North African	2	1	1	17	21
Native Hawaiian or Other Pacific Islander	3	0	1	2	6
White	81	30	15	298	424
Prefer not to respond	2	0	4	2	8

A race, ethnicity, or origin not listed	2	0	1	2	5
Total	112	50	36	371	569

Table 3: Student reported gender by university

	A	B	C	D	Total
Woman/Female	25	16	5	79	125
Genderqueer					0
Man/Male	65	19	26	242	352
Nonbinary/Third Gender	1		1		2
Transgender					0
Prefer not to respond	2		1	28	31
I don't understand the question					0
Non-serious responses				4	4
Total	93	35	33	353	514

2.1.1 Courses Involved

The data for this study were collected from engineering and computer science courses across the four universities. Specifically, we collected data from 12 engineering courses at University A, two engineering courses and two computer science courses at University B, two computer science courses at University C, and six engineering courses at University D. All of

these courses were intended for students majoring in an engineering, computer science, or a related discipline (i.e., none were courses for non-majors completing distributional requirements.) These courses had instructors who had already agreed to participate in the aforementioned ongoing diversity, equity and inclusion study. The survey took approximately 20 minutes for students to complete. Although not reported here, the survey contained items related to thirteen constructs of interest to the larger project. Specifically, the survey also included 73 closed-ended items covering constructs such as student attitudes toward diversity in engineering and student likelihood to enact inclusive behaviors (Rambo-Hernandez et al., 2021) as well as engineering self-efficacy, outcome expectations, interest, and intentions to pursue engineering (Lent et al., 2005). Some courses were implementing new curriculum related to the study, and others were participating in baseline data collection. Students were given course credit for completing the surveys and were given the option to have their data used for research purposes. The study was deemed exempt from institutional review at Universities A, B, and C, and University D's Institutional Review Board reviewed and approved the study.

2.2 Data Collection Context and Approach

The four universities began announcing emergency remote learning the week of March 16, 2020. Given the need to collect data as the pandemic unfolded, the research team met virtually multiple times starting on March 20th to create and revise prompts about student experiences. Institutional Review Boards began reviewing the prompts about two weeks later. The researchers involved represented all four universities and spanned academic roles including faculty, administrator, research scientist, and graduate student. The four authors of this paper are a subset of this larger team, and include a STEM education research scientist, an education research associate professor, a STEM education graduate student, and an engineering associate

professor. Each research team member, except for the graduate student, had at least 10 years of experience performing STEM education research.

The positionality of the researchers may have influenced our study through the research questions we chose to explore and the preconceptions we brought to our analyses. The different groundings of the researchers (STEM, education, and engineering) and different university backgrounds may have helped us think about the situation differently. Our different lived experiences also helped us consider the range of experiences our students might be having. For example, one of the authors lived rurally and relied upon public internet access at the local library at the start of the pandemic, while other authors had young children participating in remote schooling. These experiences made the research team more aware of some of the different challenges our students could be experiencing. However, we were also aware that we were interpreting student responses through the lenses of our own experiences. These included experiencing the pandemic as faculty, researchers, or graduate students rather than as undergraduate students. We worked to address this influence of our positionality through meeting regularly through the analysis process and considering potential other interpretations.

With this study, we focused on capturing the range of student experiences (both within and across the four universities in our study), to assess the validity of the master narratives and to determine whether COVID-19 would have a differential impact on students' future career plans. The student experiences captured were: (a) characteristics of how students engaged with the course, such as the stability of students' internet access, typical delivery of the course, and method of access to the course, (b) sources of student stress, which included personal and course based components, (c) consequences of the remote format, including financial burden, privacy concerns, impacts on learning, and feelings of inclusion (or lack thereof) in the course, and (d)

the impacts of COVID-19 and remote learning on students' future plans as engineers or computing professionals. Experiences a-c provided information about how students' socio-cultural context aligned with master narratives and influenced their learning. Experience d provided information about how the emergency shift combined with students' socio-cultural contexts to impact their future plans. We modified the data collection tools as needed for students in engineering courses and students in computer science courses. For example, when asking students about their future plans, we asked of engineering students: *Did the shift to online learning impact your desire to be an engineer?* But for students in computer science courses, we asked: *Did the shift to online learning impact your desire to work in the computing sciences?* The exact text of each survey item is included in the titles of Tables 6–11.

2.3 Data Analysis

To address our research questions, we analyzed the data using descriptive statistics (e.g., quality of internet access, characteristics of students' learning and living environments) and then performed a qualitative content analysis (QCA) of students' open-ended responses. We performed our QCA following the methods of Mayring (2000), Graneheim and Lundman (2004), Elo & Kyngäs (2008), Mayring (2015), and Graneheim et al., (2017). Because confidentiality of the universities is impossible to ensure while providing university characteristics and the NSF grant numbers that supported this study, to protect students' privacy and maintain data confidentiality we do not break down the student responses by demographics. Furthermore, to help protect student identity we also do not provide the university that the student attended in the example quotes. While social identities (as indicated by demographics) are important in influencing student experiences, we determined that protecting student privacy and data confidentiality was more important than providing specific information about student

demographic characteristics. This is particularly true for students with marginalized identities, who are both most identifiable and most vulnerable in data sets such as ours.

2.3.1 Phase 1

To understand how students' socially-situated experiences influenced their stress levels, we examined the descriptive statistics from five survey prompts. The first prompt asked about their change in stress level relative to the mid-semester change to online courses and had five response options (See Figure 1 for the prompt and response options). The next two prompts asked students what personal and what course related factors affected their stress level. We provided students with an extensive checklist where they could select multiple options. We also provided an open-response option for students to describe any sources of stress not listed. The complete lists of items are shown in Tables 4 and 5. Finally, the last two prompts asked students about how included they felt by their instructor and their classmates (See Figure 2 for the specific prompts and response options).

2.3.2 Phase 2

To gain a finer grained understanding of students' experiences we used QCA to synthesize the student responses to six open-ended survey prompts. Specifically, we focused our analysis on how students perceived the social cultural influences and elements of the master narratives.

QCA allows for a systematic analysis of qualitative data to describe key themes that describe participants' experiences and is particularly helpful for analyzing the frequency of responses that share specific themes in large data sets such as ours (among the 514 participants, the number of responses to an individual open-ended prompt ranged from 75-494) (Elo & Kyngäs, 2008; Mayring, 2015). QCA also allows for analysis of descriptive, latent, and

interpretive content (Graneheim et al., 2017; Mayring, 2015). While QCA is often described as a qualitative method, such as by Elo and Kyngäs (2008) and Graneheim and Lundman (2004), Mayring (2015) argues that QCA is actually a mixed-method approach, bridging between qualitative and quantitative methods. Mayring (2015) makes this argument because QCA combines the qualitative step of assigning categories to text passages with the quantification of these frequencies.

One of the strengths of QCA for our study is that QCA creates space for an abductive research approach, in which the researchers move back and forth between inductive and deductive coding to discover underlying patterns in the data (Graneheim et al., 2017). Abductive coding was important in our study, as the emergency shift to remote learning was a novel event. While there was little existing research to on which to base deductive codes, as part of the collective experience ourselves, we, as researchers, could also not approach our analysis purely inductively.

In abductive QCA, researchers follow three steps: a) preparation, b) organizing, and c) reporting (Elo & Kyngäs, 2008). As part of our data organizing, we defined our unit of analysis as each student's response to a single prompt (see captions for Tables 6-11 for specific prompts), which was usually a few words to a few sentences long. Because student responses were self-contained, yet fairly short, this gave us a unit of analysis big enough to maintain contextual meaning, but small enough that we did not lose important information, meeting the criteria set by Elo & Kyngäs (2008) for a unit of analysis in QCA.

Following Elo & Kyngäs' (2008) steps for QCA, for each survey prompt we developed a categorization matrix that included both our deductive categories and space to create additional categories through inductive coding. Survey prompts in Figures 1 and 2 and Tables 4 and 5

answer Research Question 1, those in Tables 6 and 7 answer Research Question 2, and those in Tables 8-11 answer Research Question 3. For the two survey prompts related to Research Question 3, we split the answers into two groups prior to coding: students who said their views or desire had changed and those who said their views or desire had not changed. Henceforth, we refer to each set of responses relating to a specific set of codes as a response set.

For our abductive analysis, our deductive codes were based upon the limited existing literature about students' experiences with the emergency shift to remote learning, feedback from our own students while we were teaching in this environment, and our theoretical grounding in socio-cultural theory and master narrative theory. The master narratives we observed as we experienced this emergency shift ourselves, especially relating to the equipment and environment required for emergency online learning, were a significant source of inspiration for deductive codes. During our inductive coding we were particularly sensitive to student responses that related to their own socio-cultural experiences, as well as how these experiences interacted with master narratives. Simultaneously, we were sensitive to potential counter examples, codes, and themes that related to our research questions. Our abductive coding process involved developing and refining codes throughout the coding process. As such, the number of codes changed throughout the process. Our final code numbers were 18 relating to students' identity and circumstance (Table 6), 6 relating to the impact on students' learning and performance (Table 7), 23 relating to students' desire to remain in engineering and computer science (Tables 8-9), and 21 related to student's future plans to remain in their field (Tables 10-11).

In our initial coding pass we tested our deductive codes and inductively developed codes that related to the relevant research question for each response set. Then, two co-authors discussed the codes and example responses for the codes and each coded 20% of the responses

for each response set independently. The same two co-authors then discussed and refined codes for each response set as needed, until inter-rater reliability (IRR) reached 80%, using a different set of student responses in each refinement. After IRR reached a minimum of 80% (ranging from 80-100%), they discussed additional discrepancies until agreement was at 100%. These IRR levels meet the guidelines of an IRR of at least 80%, discussed in Merriam (2002). Then, the first author coded the remaining responses within each response set.

Once all the responses for a given set were coded, we synthesized the codes into larger themes. Because different numbers of students answered different open-ended prompts, the number of students who responded to each prompt are listed in the corresponding Tables 6-11. All percentages reported for these tables are based on the number of students within each response set and each student's response was either coded as containing or not containing a theme – it did not matter how many times a student mentioned something within their response related to a given theme.

We completed our QCA process by calculating the percentages of students whose responses fit in a specific theme and developing tables that include descriptions of each theme, example quotes, and the percent of students at each university whose response was classified with that theme, as per Mayring (2015).

In addition to calculating IRR, we followed the guidelines for trustworthiness of QCA described in Elo and Kyngäs (2008). Specifically, we described the analysis in detail, provided tables that link data and results, included authentic quotes in our manuscript, and engaged in continuous dialogue among co-researchers during the analysis process.

3. Results

Overall, we found that students' experiences ranged widely, and their different socio-cultural contexts influenced their experiences. These contexts and experiences did not necessarily align with the master narratives about student experiences during the emergency shift to remote learning. In line with socio-cultural theory, student experiences also varied between universities, as the different universities adopted different norms during the switch to remote learning.

3.1 University and Student Contexts

To provide a general socio-cultural setting for our students' experiences we first describe how students engaged with the course in which they completed the survey in and the stability of their internet. The following percentages in this paragraph describe the percentage of class sessions for the course in which students completed the survey. For example, a 25% synchronous class would have been ¼ synchronous and ¾ asynchronous. At University A, university administration strongly encouraged asynchronous instruction to promote flexibility for students. All courses surveyed at this university were engineering courses. And, on average, students indicated only 26% of their course was delivered synchronously. At University B, most instruction was offered synchronously with instructors recording their class sessions for absent students, as only instructors who had taken specific training could teach asynchronously. Thus, the engineering courses that we surveyed were delivered 100% synchronously, and the computer science courses we surveyed were delivered 56% synchronously. At University C, where all courses surveyed were computer science courses, instructors were allowed to decide how to deliver their course. Even though the university's default delivery was synchronous, students reported attending only 36% of their course was delivered synchronously. At University D, the

decision was left to the instructors, and students at University D indicated courses— all engineering— were delivered 39% synchronously.

Regarding the stability of internet connection, we found only a little more than half of the students from Universities A, C, and D had extremely or very stable internet connections. Compared to the other universities, students at University B appeared to have less stable internet connections, with only one in five students at University B indicating stable or very stable internet connection.

3.2 Research Question 1

To address the first research question, taking the campus context into account, what personal and course-based elements of student experiences were sources of stress, we examined students' responses to four survey prompts: relative to before the midsemester change to online classes, what is your level of stress; which of the following personal situations affected your stress level; which of the following course-related issues affected your stress level; and after the move to the course being online, which of the below best describes how included you felt in the course (Figures 1 and 2, Tables 4 and 5). A comparison of engineering and computer science students at University B, the only university students in both majors, is provided in Supplementary Table 1.

Regardless of university, students largely responded they had more stress than before the change to emergency remote learning. As illustrated in Figure 1, more than half of the students at

each university indicated higher levels of stress than before the change to emergency remote learning.

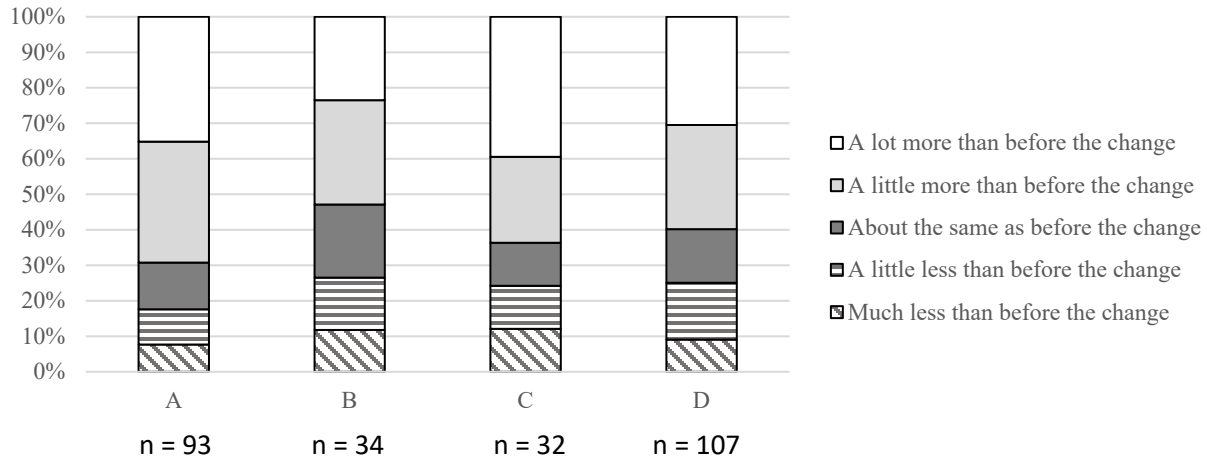

Figure 1: Percentages of student responses by university to the prompt: relative to before the midsemester change to online classes, what is your level of stress?

Table 4 provides students' closed-response answers for the personal situations students reported as influencing their stress levels. We found that students across the four universities experienced a range of challenges. Around half of students at the four universities indicated space issues such as living with multiple people, sharing space with siblings, or suffering from a lack of a consistent place to work. The next two biggest sources of stress were general angst about COVID-19 and the shrinking economy. Students at University B appeared to answer slightly differently, as they indicated they were stressed because of general angst more than space issues.

Table 4 Percentages of student responses by university to the prompt: which of the following personal situations affected your stress level?

	%			
Closed response answers	A	B	C	D

	n = 91	n = 32	n = 29	n = 334
Living with multiple other people	56	63	48	52
Sharing space with siblings	36	25	24	34
Home schooling your children	3	0	10	2
Lack of a consistent place to work	47	38	31	35
Increased workload at your job	14	3	28	12
Loss of a job	15	16	17	16
Personal illness	13	6	21	5
Concerns about my finances	32	56	55	31
Unhealthy living environment with others where I live	13	16	10	8
Caring for ill friends or family	8	16	7	5
Recent death of family member or close friend	3	9	7	5
Living alone	4	6	3	8
General angst about the economy	49	78	38	33
General angst about COVID-19	64	81	45	59
Other, please describe	35	19	34	24

Note: Students were allowed to select more than one response. The percentage was calculated by dividing each answer count by the total number of students who responded; therefore, the percentages do not add up to 100%.

The course-related challenges that students reported as affecting their stress levels are provided in Table 5. For this prompt, which of the following course-related issues affected your stress level, students were allowed to select all choices that applied to them. The two largest sources of stress related to coursework were simply the courses in general and the remote format

of the course. Unreliable internet service was also a source of stress for students at Universities A, B, and D. Also, a higher percentage of the students at University B suffered from limited access to software and unreliable internet than the other three universities.

Table 5: Percentages of student responses by university to the prompt: which of the following course-related issues affected your stress level?

	%			
Closed response answers	A n = 89	B n = 32	C n = 29	D n = 339
Classes in general	75	59	66	80
The online format for class	85	66	59	74
Unreliable internet	26	41	10	31
Insufficient computer here at home	1	0	14	5
Limited access to software (e.g., MATLAB, Solidworks, ANSYS)	14	25	10	12
Limited or no access to textbook	5	9	3	9
Other-- please describe:	14	16	28	15

Note: Students were allowed to select more than one response. The percentage was calculated by dividing each answer count by the total number of students who responded; therefore, the percentages do not add up to 100%.

We also examined a second course-based component — how included students felt by their instructors and classmates following the move to remote courses. Results for these prompts are shown in Figure 2. In thinking about inclusion by their instructor, at three of the universities (A, B, and D), students were pretty equally split between feeling equally included and less included with remote learning as they did in the classroom. However, students at University C

were much more likely to indicate they felt equally included with remote learning as in the classroom.

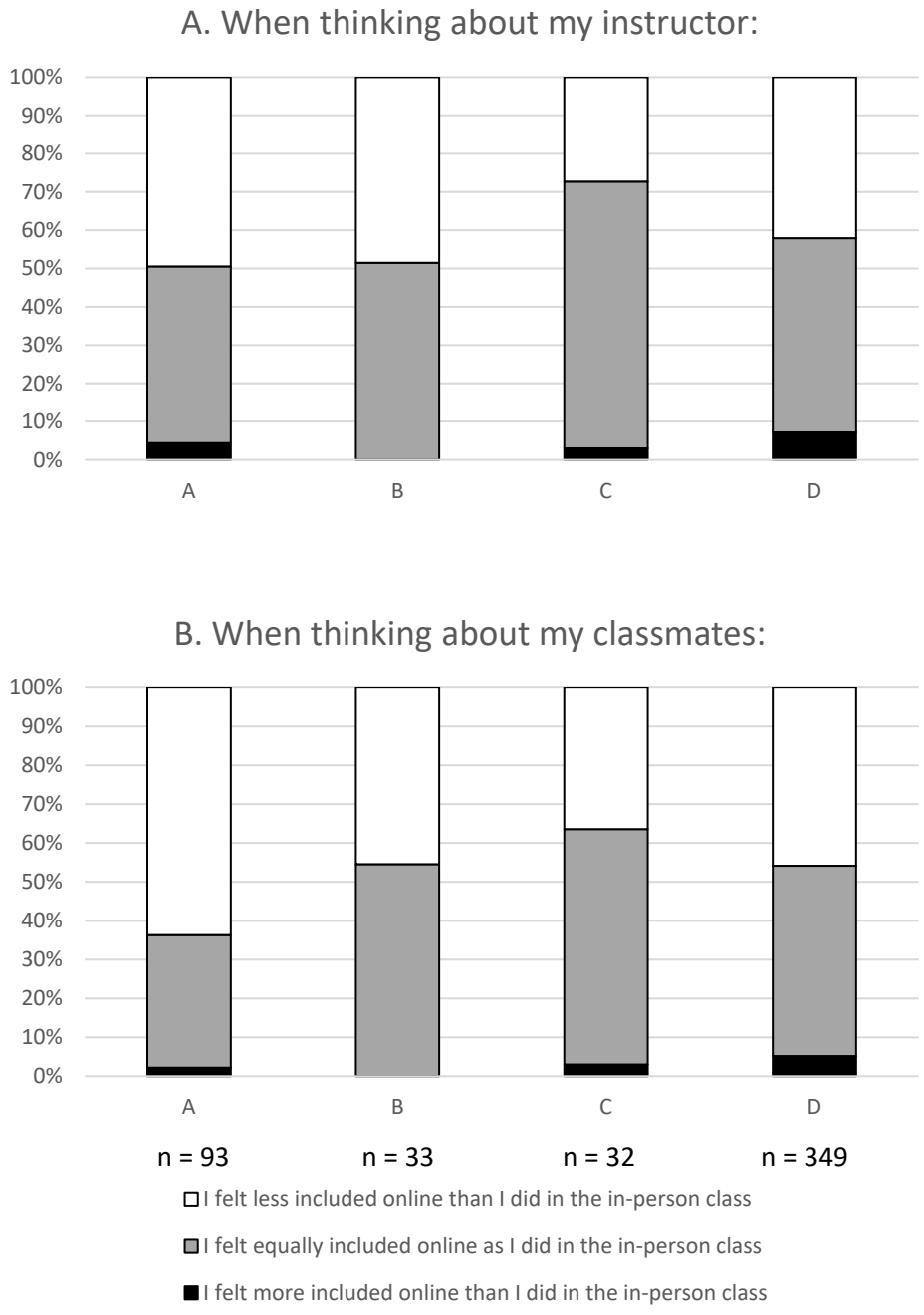

Figure 2: Percentages of student responses by university to the prompt: after the move to the course being online, which of the below best describes how included you felt in the course?

Students responded to this prompt specifically in regards to both their instructor (A) and their classmates (B).

Regarding how much students felt that they were included by classmates in remote courses compared to the in-person courses, students were again rather equally split at Universities B and D between feeling equally included and less included in remote learning comparing to the classroom. However, more students at University A indicated they felt less included by their classmates relative to the in-person class, and at University D, fewer students responded that they felt less included with remote learning as they did when the course met in-person.

3.3 Research Question 2

Data from two survey prompts informed our themes around Research Question 2, how did students perceive social cultural influences and elements of the master narrative in how their identities or circumstances affected their learning, and how the entire situation affected their performance? The first prompt was, "if you are comfortable, please share what aspects of your circumstances or particular identity you think may have affected your performance in the course," while the second prompt was "how did the change in delivery affect your learning and performance in this course." Tables 6 and 7 provide detailed information about student responses for these prompts, including the themes we developed, a description for each theme, example quotes, and percent of student responses by university. In the text we provide some information about the overall percentage of students whose response was categorized as part of a specific theme to give readers some context of frequency; however, these percentages sometimes ranged widely by university.

As shown in Table 6, students predominantly discussed circumstances, rather than identities, that influenced their ability to participate with remote learning. The two most common themes were learning in a remote learning environment (41%) and challenges with their living situation (33%). Table 7 indicates that even though most students reported their learning and performance were negatively impacted, about 1/3 of students' comments indicated a positive outcome or experience or not much change.

3.3.1 Identity and Circumstance

The data for Research Question 2 revealed that students discussed a range of themes in relationship to their socio-cultural situation. Themes spanned personal factors, such as neurodiversity, their living situations, and challenges with the change to remote learning, as well as a range of external factors, such as changes in job status and access to healthcare, and also included identifying that they had no challenges (themes are detailed in Table 6). Therefore, students conceptualized identity broadly when responding to this prompt, and did not limit their responses to a narrow set of social identities.

Table 6: Percentages of student responses by university for the different themes around student responses to the prompt: If you are comfortable, please share what aspects of your circumstances or particular identity you think may have affected your performance in the course.

			%				
Theme	Description	Example quote	A n = 22	B n = 1	C n = 9	D n = 49	Overall n = 81
Neurodiversity	Student explicitly discusses neurodiversity, such as ADHD or autism	*I have ADD so it's hard for me to sit and focus when I'm alone.*	5	0	11	4	5
Anxiety & depression	Increased anxiety and depression	*My depression got out of control; after six weeks and hiring a wellness coach. I feel like I'm now developing better work habits.*	18	0	11	10	12
Living situation change	Negative impact of living situation such as home environment or having to leave the university	*Moving back home suddenly to a toxic household I was not ready to move back into.*	5	0	56	31	33
Academic impacts	Challenges around remote learning such as social learning, physical classroom, and a lack of consistency	*I couldn't work and understand concepts brought up in class with friends in my program.*	5	100	33	39	41

Technology related	Internet, computer, and technology challenges	*My family relocated to an isolated hunting cabin in my state where cell service is very spotty at best and a 45-minute drive to the nearest public WiFi.*	0	0	22	10	9
Increased job work	Increased work for income	*At this time, I work as a cashier at a grocery store, and many of our team members quit, so there was an increased workload and unexpected shifts that I had to take on at little notice.*	9	0	11	4	6
Financial strain	Includes both job loss and other financial strain	*Loss of job and decreased financial stability meant that I had to work harder to get groceries and afford rent and that made my grades suffer because I had less time to work on school.*	5	0	0	4	4
Health and healthcare access	Illness or healthcare access, includes, but not limited to, COVID	*Got COVID-19 at work spent a week recovering could not study.*	5	0	11	4	5
Non-specific difficult	Generally discusses that things were worse or general disinterest	*It is a lot more stressful at this time and I do not have any motivation.*	9	0	11	12	11
Not problematic	Students discussed how the change made things the same or better	*I was homeschooled, so this setting of school is familiar.*	0	0	11	4	4

Notes: Responses could be coded under multiple themes, explaining why the percentages do not add up to 100% in the columns.

Many students discussed challenges with their living situation, like the quotation in Table 6 that indicated challenges with moving back into their parents' home. On the other hand, some student responses indicated challenges with caring for children: "I have two small children and a wife who works from home now. It's difficult to work here sometimes." The differences in these responses exemplified the diversity of student living situations, and therefore the different learning environments students experienced. Furthermore, these responses challenged the master narrative about remote learning during the pandemic, which did not account for living environments that interfered with remote learning.

Overall, nearly half of all students who responded to this prompt discussed academic - challenges around remote learning, including needing a physical classroom to learn in and realizing how much they learned from the questions their peers ask, but the percentage varied from near 0 to 100% across universities. Interestingly, almost none of the students at University A, which emphasized asynchronous instruction, discussed topics that related to challenges around remote learning.

Only students at Universities C and D reported having technology related challenges as barriers to accessing remote learning. These responses, like the quotation in Table 6 about technology challenges, focused on a lack of internet or slow internet connections, challenges with their computers, challenges with the specific platforms instructors and peers used for communication, and challenges videoconferencing in their living situation. These factors interacted for one student, who wrote:

> Two members of my team unilaterally decided that using Microsoft Teams for our team's virtual meetings would be "easiest for everyone." However, because I do not feel comfortable actively videoconferencing from my apartment due to my living situation …

> MS Teams was not a feasible medium for me. I explained this and proposed several alternative platforms, but the two who had initially proposed it disregarded my concerns and continued organizing meetings through MS Teams, excluding me from the group. On top of everything else I was dealing with at the time, that made me feel so frustrated and dejected that I did not know what to do. I felt alienated from my team and did not know what else to do. I stopped participating in the group.

This student clearly described how multiple factors, including technology, group work partners, and their living situation, led them to simply cease participating in their group, as they felt they had no other options to navigate the situation.

Although many student responses focused exclusively on challenges related to circumstances, a few responses discussed the mixed outcomes of the situation:

> DEPRESSION is a real killer. Makes going to class or wanting to do anything remotely useful impossible, but also the anxiety makes me feel so stressed about due dates and falling behind. Also, chronic need to procrastinate everything does not help my performance. But it weirdly got better after the move to online classes, I was more productive because I had access to all the material online and can do it when I want to. With online there is no need to physically go to class which is nice because I can interact and re-watch & listen to the lectures and take my time on them.

This student described how depression and anxiety made it difficult to perform as a student, and how the change in course delivery allowed them to perform better. However, students' experiences with depression and anxiety varied, as was shown in the contrasting response from the student who experienced "severe anxiety issues especially related to phone calls or zoom," as

well as the student's response for the anxiety and depression theme in Table 6, in which they discussed how they needed additional help to navigate the situation.

3.3.2 Learning and Performance

Students' responses to how the change in delivery affected their learning and performance in the course fell into three broad themes of negative, neutral, and positive impacts, as shown in Table 7. Within these broad themes we classified responses into three negative themes, ranging from 24-50% of responses: negative impact for personal reasons, negative academic impact, and negative outcome. There were also two neutral themes, which ranged from 6-18% of responses: independent learning and not much change. There was one positive theme around positive outcomes and impact (13%). Note that, as with all of the open-ended prompts, students' responses could be coded under more than one theme. While the negative themes were most common across all of the universities, neutral and positive responses were not uncommon, demonstrating the range of student experiences in relation to remote learning.

Table 7: Percentages of student responses by university for the themes around student responses to the prompt: How did the change in delivery affect your learning and performance in this course?

			%				
Theme	Description	Example quote	A n = 27	B n = 5	C n = 10	D n = 129	Total n = 171
Negative impact - personal reasons	Personal or internal challenges such as living situation or mental health	*It made it harder to focus because I couldn't get into a work mindset.*	41	22	24	19	24
Negative impact - school or academic reasons	School- or course-related challenges	*[The] learning format was more challenging; class became less hands-on and less engaging.*	42	56	36	39	40
Negative outcome	Negative related to an outcome, such as more difficulty learning or grades dropped	*I went from decent understanding to a point where I think I might not pass.*	50	26	32	41	41
Independent learning	Learning was more independent, has no clear negative or positive	*The way of learning was more on myself.*	4	7	4	7	6
Not much change	Neutral response	*It did not change too much in my opinion.*	12	15	20	19	18
Positive experience and/or outcome	Any positive experience	*It improved it. I found being able to re-watch lectures extremely helpful.*	9	22	20	13	13

Notes: Responses could be coded under multiple themes, explaining why the percentages do not add up to 100% in the columns.

The negative impact for personal reasons theme was present in 24% of students' responses. These responses related to both challenges in the home environment and decreased motivation and focus, saying for example, "with extra distractions occurring around me, paying attention to an online lecture is less stimulating and less effective for me." Students also discussed financial challenges such as "I had to get a job to pay for some of my expenses, so I had more work and I had to manage my time more. It was hard for me to do so much more work with limited time." Students also discussed technical challenges that limited their learning: "I have suffered greatly because I have not had any access to the internet!" Therefore, this theme represented a range of personal reasons that made it more difficult for students to learn.

Similarly, the negative academic themes were present in 40% of the students' responses. These responses primarily related to challenges with course format, remote learning platforms, lack of in-person interactions, and the importance of physically being in a classroom space. Students had negative comments about both synchronous and asynchronous learning. Regardless of the mode of course delivery, students stated that they often felt as though the learning experience was less effective, saying, for example, "my learning ability severely declined because instruction was in-sufficient. I am not being taught the material, I am left to figure it out on my own having to use third party resources or going to tutoring." Frequently students commented on the amount of independent learning required as a negative.

In contrast to the above statement, 6% of students simply observed that they had to learn more independently without discussing it as a negative or positive or said that their learning did not change much. These students did not elaborate much on their experience, and some responses included both neutral themes such as "it did not particularly affect learning in this course because a lot of the learning is practicing on your own."

The 13% of students who found that learning was more effective with remote learning often discussed having more time to focus on coursework and/or the accessibility of the course materials. Responses often revolved around independent learning and self-paced work such as "definitely more self-study, which is always a good thing" and "I think it improved as the availability of video lectures made it easy to learn at my own pace." These responses framed the independent work as positive, in contrast to the neutral and negative answers that also discussed the increase in independent work.

3.4 Research Question 3

Finally, in Research Question 3, how did the pandemic affect student views about and plans for careers in engineering and computer science, we examined the impact of COVID-19 on students' plans and desire to pursue engineering and computer science. For this research question we explored student responses to the prompts "did the shift to online learning impact your desire to be an engineer (or work in the computing sciences), why or why not," and "does the pandemic change any of your views about engineering (computer science) affect your plans for the future, why or why not? Tables 8 and 9 provide themes, theme descriptions, example quotes, and percentages of students for each theme for students did not (Table 8) and did (Table 9) have their views about engineering or computer science changed by the pandemic. Tables 10 and 11 provide the same data for students who did not (Table 10) and did (Table 11) have their plans for the future changed by the pandemic.

Table 8: Percentages of student responses by university indicating their desire had not changed for the themes to the prompt: Did the shift to online learning impact your desire to be an engineer (or work in the computing sciences)? Why or why not?

			%				
Theme	Description	Example quote	A n = 63	B n = 20	C n = 20	D n = 249	Overall n = 352
Committed to engineering	No change, discussed commitment to engineering or computing	*No, I still have the same dream of being an engineer.*	38	30	15	30	31
No, non-specific	Did not provide an explanation	*Nope*	22	20	35	31	29
Not a big deal, unrelated to engineering	Either the situation was not a big deal, or that it was unrelated to engineering	*No, I don't see why it has to have an impact.*	16	30	15	18	18
Temporary	Focused on the temporary nature of the situation	*No. This is mostly temporary*	3.2	0	0	4.8	4
Adaptability	Discussed the importance of adaptability	*No, it was just another example of how engineers have to overcome and adapt to any challenges they are faced with.*	3.2	5	0	2.4	3

Positive about remote environment	Described the online situation as positive, including future work at home situations	*No, I preferred being able to work on my own time.*	1.6	15	25	2.4	4
Engineering helpful in a pandemic	The importance of engineering as helpful in the pandemic	*No because I want to make something beneficial for the next pandemic.*	3.2	5	5	2	3
Negative about remote learning	Still committed to engineering, but disliked remote learning	*No, although I now know that I do NOT want to be 100% remote.*	24	10	10	10	13

Notes: Responses could be coded under multiple themes, the reason why the percentages do not add up to 100% in the columns.

Table 9: Percentages of student responses by university indicating their desire **had** changed for the themes around the prompt: Did the shift to online learning impact your desire to be an engineer (or work in the computing sciences)? Why or why not?

			%				
Theme	Description	Example quote	A n = 19	B n = 5	C n = 5	D n = 44	Overall n = 73
Remote learning challenges	Any challenge related to the remote learning environment	*It decreased as I was so stressed out with all the coursework I had and the lack of instruction that I felt like there was no point doing school anymore.*	42	40	0	50	44

May change major	Considering switching majors	*Yes, it made me start questioning if I wanted to be an engineer compared to before I was all for being an engineer. The reason was the way my courses were continuing instruction.*	11	20	0	9.1	10
Less desire/ interest	Desire to be an engineer decreased	*Yes, in a negative way. I feel disconnected and naturally less interested in the subject matter when I have to learn it on my own and not enjoy the reason of why I have to take these classes in the first place.*	21	0	20	18	18
Academic and future job challenges	Students question their ability to become an engineer, perform academically, stay in school, and/or get an engineering job	*Yes, it made me question school for the longest time; if this happens again I may just drop out to avoid all the unnecessary stress.*	16	20	0	20	18
Desire to improve things	Positive change, see engineering as a way to improve the world	*Yes, I need to develop new technology that can make life easier in times of biological hazards.*	0	20	0	4.5	4
Stronger desire for engineering	The situation increased their desire to be an engineer for any reason, e.g., job security or attributes of engineering.	*Doing Matlab and Solidworks made me want to be an engineer more because I was doing real work that was relevant to my career.*	0	20	40	2.3	5

Note: Responses could be coded under multiple themes, the reason why the percentages do not add up to 100% in the columns.

Table 10: Percentages of student responses by university indicating their views or plans **had not** changed for the different themes around student responses to the prompt: Does the pandemic change any of your views about engineering (computer science)? Or affect your plans for the future? Why or why not?

Theme	Description	Example quote	A n = 65	B n = 14	C n = 19	D n = 228	Overall n = 410
No	Non-specific	*No.*	45	21	37	37	38
Same goals	Goals have not changed, remain positive about engineering	*No, I have a goal and I am sticking to it.*	11	14	16	25	21
Pandemic connection	Positive connection between the pandemic and engineering	*No, If anything I see engineering as even more important because engineering is saving people's lives in times like this.*	15	14	5	11	11
Engineering characteristics	Positive characteristics of engineering, e.g,. resilience, adapts to remote work	*Nope. I'm confident in my future career's ability to support me financially even through situations such as these as this line of work can be done remotely if need be.*	8	36	21	9	10
Unrelated	Engineering and the pandemic are unrelated	*My views did not change since computer science has nothing to do with the pandemic.*	5	7	11	8	7

Temporary	The pandemic is temporary	*Life will eventually return to normal; I'm not too worried.*	9	0	0	8	7

Notes: Students were given either the engineering or computing prompt, depending on the class they were in. Responses could be coded under multiple themes, the reason why the percentages do not add up to 100% in the columns.

Table 11: Percentages of student responses by university indicating their views or plans **had** changed for the different themes around student responses to the prompt: Does the pandemic change any of your views about engineering/computing? Or affect your plans for the future? Why or why not?

Theme	Description	Example quote	%				
			A n = 14	B n = 12	C n = 6	D n = 52	Overall n = 84
Job insecurity	Current or future insecurity around jobs or internships	*Yes, I was always told engineers are guaranteed a job after graduation, but very few people are getting hired.*	29	83	83	37	45
Academic challenges	Academic challenges, e.g., delayed graduation or lack of confidence in skills	*Yes, because I might fail classes.*	43	0	17	8	13
Switching majors	Considering switching majors	*The pandemic makes me contemplate switching out of the engineering field.*	0	0	17	12	8

Dropping out	Dropping out or switching universities	*Maybe/Yes? I think I'm going to join the Navy. It's been harder to find jobs, and it's going to take a while for things to get back to normal. If I did find a new job I don't know if I'd really be able to get a good sense if I actually like engineering.*	7	8	0	8	7
Positive pandemic-engineering	Positively connect engineering to the pandemic	*Yes, engineers can help in a pandemic and can still resolve problems to help the world.*	14	0	0	15	12
More motivated	Positive about engineering, e.g., job security, can learn remotely well	*Yes, it showed me engineers are needed everywhere, because they help keep things going all around the world.*	0	0	0	13	8

Notes: Students were given either the engineering or computing prompt, depending on the class they were in. Responses could be coded under multiple themes, the reason why the percentages do not add up to 100% in the columns.

Overall, 83% of students reported that the shift to remote learning did not impact their desire to be an engineer or to work in the computing field and 80% of students indicated the pandemic did not change their views or plans for the future (Tables 10-11). Within these large-scale categories, students provided a wide range of reasoning to support their response. We found that the majority of students who had not changed perspectives/plans were still positive about engineering or computing fields. However, those who said their perspectives/plans had changed primarily responded negatively about engineering or computing fields. We also had a small number of students who did not follow this trend, which is discussed in detail for each prompt.

3.4.1 Changes in desired career path due to remote learning

Table 8 shows the responses of the students who indicated their desire to be an engineer or work in computing *had not* changed as a result of remote learning. Of these students, about one third indicated their views had not changed because they still had a strong commitment and/or desire to be in the profession, and another one third did not provide a reason. About one-fifth wrote they did not think of the pandemic as related to engineering or computing. Additionally, 13% of students wrote about still being committed to engineering or computing, but that they disliked remote learning. See Table 8 for the full range of student responses.

Table 9 shows the responses of the students who indicated their desire to be an engineer or computer scientist *had* changed due to the shift to remote learning. These students most frequently wrote about the challenges related to remote learning negatively impacting their desire — of note, two of the universities only had 5 responses each for this prompt. The second most common answers also indicated a negative impact on their desire or interest due to challenges either in their academic performance or in getting a future job. Some students indicated a

positive impact in their desire to work in engineering or computing—discussing specifically how engineering can improve the world, such as during the pandemic, or the positive traits of engineering.

3.4.2 Changes in views of and plans for the future due to the pandemic

As shown in Table 10, students who wrote that their views and plans for the future *had not* changed due to the pandemic predominantly did not describe a reason (38%) or wrote that they were committed to the same goals of being an engineer or computing professional (21%). Students also discussed positive characteristics of engineering or computing (10%), that engineering or computing and the pandemic were unrelated (7%), and that the situation was temporary (7%). As with the desire prompt, a few students said that their views or plans had not changed but wrote a negative response, writing about graduating later, challenges with the remote format, maintaining a negative perspective about engineering or computing, and the challenges of an uncertain future.

For students who wrote that their views and plans *had* changed (associated themes shown in Table 11), by far the most common reason was job insecurity, either in their current job, or for future internships or jobs (45%). Many students were also concerned about academic challenges, such as failing courses (13%), switching majors (8%), or considering dropping out or switching universities (7%). The students who responded yes but from a positive perspective wrote about how the pandemic helped them understand the importance of engineering or computing in the context of situations such as the pandemic (12%), or that they were generally more motivated about engineering or computing for reasons such as job security or that the work can be done well in a remote environment (13% at University D, 0% at all others).

4. Discussion

While the pandemic was universal, it was not experienced identically. These differences in experience are consistent with socio-cultural theory, as each individual experienced the pandemic through their own socio-cultural lens. The main findings from this study are (a) student stress was related to a lack of basic supports and personal circumstances; (b) motivation, or lack thereof, was particularly problematic in the remote setting and for self-directed learning; and (c) student career plans were mostly unchanged due to the pandemic. Observations a and b are consistent with literature that was published during our writing and revision process, and observation a particularly counters the master narratives common at institutions of higher education during the shift to remote learning, which assumed that students had the support and circumstances necessary to rapidly transition to remote learning (Day et al., 2021; Goldrick-Rab, 2020; Gonzalez-Ramirez et al., 2021; Iyer & Chapman, 2021). However, our observations that student interest in their field and their career plans were mostly unchanged and that students were often unprepared for self-directed learning are not yet evident in the published literature. Our findings that reinforce what others have found, as well as our new findings about students' largely unchanged career plans and lack of preparation for self-directed learning, can be helpful in informing future situations where shifts to remote learning are necessary.

4.1 Lack of Supports and Increased Stress

The assumptions around how students could participate in learning during the emergency shift were informed by a master narrative about students' experiences, which included the assumption that students could rapidly transition into a situation that supported their learning both physically and psychologically. At all four universities, administrators felt that remote learning was better than nothing and that it was vital to stay on schedule. In contrast to this

master narrative, our results provide information about situations common to many students that countered this master narrative, providing evidence for potential alternative narratives about student experiences. Furthermore, the alternative of pausing for long enough for faculty and students to adjust to the new situation was not implemented at any of the universities in our study yet providing time for adjustment may have decreased stress for all involved.

Common factors that influenced students' ability to participate in and perform well in their courses during remote learning in Spring 2020 were (a) inadequate internet access, (b) increased stress levels, and (c) stress related to courses and their remote format. For example, students' variation in internet connectivity (factor a) countered the master narrative assumption that all students could readily access remote learning. Students' inability to access courses remotely provides evidence for the need to create access to learning in a range of ways. As a counter-example to the master narrative that students had adequate internet connectivity, at University A faculty were encouraged to use asynchronous delivery as the primary mode of teaching to obviate challenges associated with connection quality. Thus, although at least some access to the internet was still assumed, the underlying assumptions around the master narrative about internet connectivity were not uniform across universities. However, based on student feedback and concerns about motivation, the advice for fall 2020 at University A changed to all faculty being strongly encouraged/expected to have at least some components of synchronous delivery, with recordings of synchronous interactions posted for those unable to attend in person. Because the shift from asynchronous to synchronous teaching happened after we collected data, we do not know how this shift impacted students at this university.

Students struggled with numerous factors relating to their circumstances and identity. Many of these factors were beyond students' or their university's control, such as their living

and/or job situation. But some factors students struggled with were ones that universities or instructors could improve, such as challenges with remote learning. These types of responses align with previous studies, which discuss a range of challenges students experienced, including unsafe and/or unstable living situations and food instability (Day et al., 2021; Goldrick-Rab, 2020; Gonzalez-Ramirez et al., 2021). Years of data from student success initiatives have demonstrated that master narratives treat the student experience as monolithic and thus are unlikely to prepare universities to support the learning of all students (e.g., Estrada et al., 2016; Jordt et al., 2017; Katrevich & Aruguete, 2017; O'Leary et al., 2020). This is even more the case in an emergency situation, when universities and instructors have even less control over the student experience. Therefore, as universities pursue development of supports for particular groups of students, they should also be explicitly planning for how this support could be adapted for emergencies or to meet the needs of students with a wide range of experiences.

4.2 Support for Self-Directed learning

Part of the master narrative around the emergency switch to remote learning was that students could adapt well to increased levels of self-directed learning. Students who struggled with the increase in independent learning were likely to have predominantly experienced situations where "being a good student" meant sitting and listening to an instructor and following directions. Yet, in the emergency shift to remote learning, the master narrative, or "rules," of being a good student changed – students had more responsibility to learn on their own and needed to restructure how they navigated their courses and sought help. Furthermore, students had lost the familiar social context and social interactions in an in-person classroom setting.

Self-directed learning was a particularly interesting theme in students' responses to prompts analyzed for Research Question 2, as students wrote about it as both a challenge and as

a benefit in the switch to remote learning (Table 7). Tekkol and Demirel (2018) found that undergraduate students' self-directed learning skills are positively correlated with GPA. Therefore, students who were already struggling were likely to have more trouble with the transition to remote learning, potentially leading to inequitable impacts on students. Our findings show that many students were unprepared for the self-directed learning components of remote learning. This is a particularly important contribution to literature about students' experiences during remote learning, as we have not found represented in other related literature and self-directed learning skills are something that instructors can directly help students improve.

4.3 Lack of Changes in Career Plans

There were largely no changes in students' desire to be an engineer or computing professional, their views of engineering or computing, and their future plans. However, for those who did experience changes in desire or plans, major factors involved remote learning challenges, job insecurity (both current and future), and academic challenges, including delays in graduation and uncertainty about their academic preparedness. These themes likely relate to situations in which students' experiences contradict the master narrative, such as more general narratives about the high-level of academic achievement of engineers (Shi, 2018). Many of these factors may interact with students who experienced challenges related to the increased requirements of self-directed learning.

4.4 Recommendations for Teaching and Learning

The recommendations formed from our data have implications for what institutions of higher education and instructors do in an emergency situation, but also how institutions and

instructors can change their practices going forward so if/when emergency situations occur in the future the response to student needs can be smoother and more effective.

One of the features of an emergency situation is the critical impact of time. Institutions, instructors, and students were all doing the best they could with existing resources because there was very little time to develop new resources. One idea for future emergency situations is for institutions to allow time for instructors and students to make adjustments. Imagine how learning might have been different if instructors and students were given a month to settle into new pandemic routines and for institutions to provide learning resources, rather than demanding adherence to the existing academic calendar. Another, perhaps less radical idea, is to consider what resources can be planned for in advance. For example, having data about student internet access (or other physical needs) available might have helped with decision making. How could institutions adjust routine data collection in the future to help them make time sensitive decisions in the future?

Another way institutions can be planning ahead and building resources is for instructors to support more self-directed learning all the time. Focusing on self-directed learning also aligns with student learning outcome seven from ABET, the accreditation agency for engineering and other technology programs, "an ability to acquire and apply new knowledge as needed, using appropriate learning strategies" (ABET Engineering Accreditation Commission, 2018, p. 5). Self-directed learning skills will make students more resilient as students and more successful as professionals. Additionally, instructors can help students build collaborative peer support networks. Both personal and institutional social networks are important for student success, particularly for those with marginalized identities (Mishra, 2020). By helping connect students through interactive learning activities that help students build relationships with each other and

their instructors, these networks could also help support students as they build self-directed learning skills, learn how to rely on each other for help, and learn how to more effectively reach out to their instructors for help as well. These networks could range from more traditional in class group work to course related social network forums, such as Discord and Slack.

4.5 Limitations

The context in which these Spring 2020 data were collected has unique value and also raises additional questions. In this case, the transition to remote learning was rapid and unexpected; a situation that could also occur due to a variety of extreme environmental circumstances. Thus, even though we assumed that the observed differences between the four universities in the spring semester were from the context of each university, many confounding variables might have influenced the differences discussed in this study, including students' specific majors, instructors' competencies in technology, prior academic experiences, or external support. Moreover, despite relatively high response rates, our results may only represent those who had internet stable enough to participate and not those with less stable internet. Similarly, students needed to be engaged with their courses enough to know about the survey and motivated enough to complete the survey. In addition to the limitations of our data collection, our identification of master narratives occurred through their emergence in our observations of the emergency shift to online learning, we did not use a systematic process to identify the master narratives. Therefore, there are likely other relevant master narratives that we did not identify.

While all data were collected during the Spring 2020 semester, the impacts of the ongoing COVID-19 pandemic, including shifts to remote and hybrid learning have persisted

through at least the spring semester of 2022. Because our data were collected at the beginning of the pandemic, student experiences and their interests in persisting in engineering may have changed over time. Additionally, responses to the pandemic have changed differently in different locations over time: some schools stayed remote for several semesters, others returned to learning in-person with mandatory precautions, and other schools were in states that banned any COVID-19 precaution requirements. Further, as cases accumulated over time, students were more likely to know someone who was sick or dying of COVID-19. As a result, the experiences of students have become more varied as the pandemic has persisted. Therefore, our results may not be able to be extrapolated to future semesters.

Our data and results emphasize the ways individuals might not fit the master narrative. While in some ways it is good to acknowledge that no two people experience the same event identically, in other ways this is problematic. By not disaggregating our data by social identities or other characteristics we aren't capturing systemic issues that are affecting only students with certain identities. For example, journal publication rates during the pandemic decreased more for women than for men, and the most for Black women (Staniscuaski et al., 2021). This type of inequitable impact can only be captured when data are disaggregated by identity. Our strategy for data presentation and analysis was influenced by our need to maintain the privacy of our participants and the confidentiality of the information they shared with us. But in a larger dataset that would help ameliorate privacy and confidentiality concerns, analysis by social identity is important to help identify systemic issues.

4.6 Conclusion

Students should know that they are not alone in their struggles. When students were asked about personal circumstances that affected their ability to perform, nearly half of students

who gave an explanation listed motivation as a challenge. While not identically experienced, this lack of motivation seems more than just a personal circumstance, and something universities should be aware of if they are forced to move to remote learning due to other emergency situations. During non-emergency times, proactively and thoughtfully creating and investing in flexible and adaptable support systems for students may help students be more resilient to future challenges.

While this was an emergency situation, and different from regular online learning, lessons learned from the emergency switch to remote learning can help inform higher education practices in creating more equitable access to education on a broader scale (Hodges et al., 2020). In the US, students have experienced significant localized emergencies, such as Hurricane Harvey's disruption in the Houston area and Hurricane Katrina's disruption in the New Orleans area. Due in part to climate change, environmental degradation, and growing populations, both localized and large-scale events that disrupt higher education will only become more frequent. The more we can learn from student experiences in the Spring of 2020 and throughout the COVID-19 pandemic, the better, more resilient, and equitable higher education structures will be.

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Supporting Information

Supplementary Table 1: A comparison of engineering and computer science student responses at university B for closed-ended prompts.

	Engineering (%)	Computer Science (%)
Percentages of student responses to the prompt: "How stable was your internet connection during the online portion of this class (end of March to early May)?"		
Extremely unstable	7	14
Very unstable	4	0
A little more unstable than stable	11	29
Equally unstable as stable	19	0
A little more stable than unstable	48	14
Very stable	11	29
Extremely stable	7	14
Percentages of student responses to the prompt: "Relative to before the midsemester change to online classes, what is your level of stress?"		
Much less than before the change	15	0
A little less than before the change	15	14
About the same as before the change	19	29
A little more than before the change	30	29

A lot more than before the change	22	29

Percentages of student responses to the prompt: "Which of the following personal situations affected your stress level?"

Living with multiple other people	16	9
Sharing space with siblings	8	0
Home schooling your children	0	0
Lack of a consistent place to work	10	6
Increased workload at your job	0	3
Loss of a job	3	6
Personal illness	1	3
Concerns about my finances	14	9
Unhealthy living environment with others where I live	4	3
Caring for ill friends or family	3	6
Recent death of family member or close friend	1	6
Living alone	1	3
General angst about the economy	19	15
General angst about COVID-19	18	21
Other, please describe	3	9

Percentages of student responses to the prompt: "Which of the following course-related issues affected your stress level?

Classes in general	27	31
The online format for class	34	15
Unreliable internet	18	23
Insufficient computer here at home	0	0
Limited access to software (e.g., MATLAB, Solidworks, ANSYS)	11	15
Limited or no access to textbook	4	8
Other- please describe:	7	8

Percentages of student responses to the prompt: "After the move to the course being online, which of the below best describes how included you felt in the course?"

When thinking about my instructor:		
I felt more included online than I did in the in-person class	0	0
I felt equally included online as I did in the in-person class	46	71
I felt less included online than I did in the in-person class	54	29
When thinking about my classmates:		
I felt more included online than I did in the in-person class	0	0
I felt equally included online as I did in the in-person class	46	86

I felt less included online than I did in the in-person class	54	14

Supplementary Table 2: Student Reported Race and Ethnicity (A)

	# of participants (%)	College of Engineering (%)
American Indian (Alaskan Native)	4 (4)	6 (5)
Asian	8 (7)	62 (2)
Black or African American	1 (1)	28 (1)
Hispanic, Latino, or Spanish	9 (8)	318 (12)
Middle Eastern or North African	2 (2)	
Native Hawaiian or Other Pacific Islander	3 (3)	3 (0.1)
White	81(72)	1874 (72)
Prefer not to respond	2 (2)	
A race, ethnicity, or origin not listed	2 (2)	
Total	112 (100)	2617 (100)*

*Include 165 international students, 135 students of two or more races, and 26 unknowns.

Supplementary Table 3: Student Reported Race and Ethnicity (B)

	# of participants (%)	College of Engineering (%)
American Indian (Alaskan Native)		
Asian	11 (22)	35 (6)
Black or African American	2 (4)	13 (2)
Hispanic, Latino, or Spanish	6 (12)	81 (13)
Middle Eastern or North African	1 (2)	
Native Hawaiian or Other Pacific Islander		
White	30 (60)	374 (61)
Prefer not to respond		
A race, ethnicity, or origin not listed		
Total	50 (100)	612 (100)*

*Include 65 international students, 35 students of two or more races, and 9 unknowns.

Supplementary Table 4: Student Reported Race and Ethnicity (C)

	# of participants (%)	College of Engineering (%)
American Indian (Alaskan Native)		2 (0.3)
Asian	6 (17)	56 (9)
Black or African American	1 (3)	54 (9)
Hispanic, Latino, or Spanish	7 (19)	157 (26)
Middle Eastern or North African	1 (3)	
Native Hawaiian or Other Pacific Islander	1 (3)	
White	15 (42)	288 (47)
Prefer not to respond	4 (11)	
A race, ethnicity, or origin not listed	1 (3)	
Total	36 (100)	612 (100)*

*Include 11 international students, 22 students of two or more races, and 22 unknowns.

Supplementary Table 5: Student Reported Race and Ethnicity (D)

	# of participants (%)	College of Engineering (%)
American Indian (Alaskan Native)	5 (1)	5 (0.1)
Asian	22 (6)	85 (2)
Black or African American	13 (4)	81 (2)
Hispanic, Latino, or Spanish	10 (3)	98 (3)
Middle Eastern or North African	17 (5)	
Native Hawaiian or Other Pacific Islander	2 (1)	1 (0.02)
White	298 (80)	2678 (74)
Prefer not to respond	2 (1)	
A race, ethnicity, or origin not listed	2 (1)	
Total	371 (100)	3628 (100)*

*Include 561 international students, 99 students of two or more races, and 20 unknowns.