The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #41094

Understanding Students in Times of Transition: The Impact of the COVID-19 Pandemic on Engineering Students' Math Readiness and Transition into Engineering

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Abstract

The COVID-19 pandemic presented unprecedented challenges in education and significantly impacted learning. During 2020 and 2021, education pivoted to an online format, and many students struggled in this environment. Mathematics was one of the subjects most affected by online learning. At a large R1 university in the mid-Atlantic region, more engineering students than ever before entered their first year, placing in Pre-Calculus instead of Calculus 1, and were classified as pre-math-ready. Being ‘math ready’ and placing into Calculus 1 is critical for engineering students due to the engineering curriculum's reliance on mathematics and the barriers related to the subject. This study shares the experiences of 15 first-year engineering students who were behind in math during the 2022-2023 academic year. Most participants were in their sophomore year of high school, taking Algebra, when the pandemic shifted everything online. The following year, their junior year, the participants navigated Pre-Calculus, and we highlight the participant's varying learning experiences. We found that students faced three type of transitions: 1) COVID Transition, 2) Transition to the University, and 3) Transition into Engineering and couple the transitions with Schlossberg’s Transition Theory to present our findings. We found that students had various experiences that impacted their math readiness and subsequent transition to the university and into engineering. Additionally, students utilized different supports and strategies to help them through each transition. By recognizing students' varied backgrounds, preparation, and experiences transitioning into engineering, the field can adapt to create a curriculum that meets the needs of all students. Due to the enrollment cliff, engineering programs no longer have the luxury of weeding out students and must update their practices to support pre-math-ready students in engineering.

I. Introduction

In 2020 and 2021, high school students and teachers faced unprecedented challenges related to the COVID-19 pandemic. Teachers were doing their best to stay afloat [1], and students struggled to complete their work, felt disconnected from their peers and teachers, and experienced feelings of depression [2]. With varying restrictions across states and school districts [3], high school students had varied learning experiences during this time. The literature has shown that math test scores have been the most affected by school closures and online learning [4]. Moreover, reports from the early pandemic showed that the effects of school closures could exacerbate achievement gaps among students [5]. Students had varying experiences during the pandemic and entered college at different readiness levels.

In the aftermath of the COVID-19 pandemic, there has been a significant increase in engineering students placing below Calculus 1. This is likely due to the changes in academic readiness and the challenges measuring academic readiness since common systems to measure readiness, like the ACT and SAT, were no longer reliable. At our university, the number of incoming first-year engineering students placed below Calculus 1 significantly increased from before the pandemic. This change is not unique to our institution, and many higher education institutions and engineering programs are struggling to adapt [6]. Addressing the changes in math readiness and placement is currently a top concern for universities and engineering programs because of the looming enrollment cliff. This means that in 2026, we will see a change in the number of students pursuing higher education due to declining birth rates [7]. Additionally, there is continued concern about meeting the demand for engineering professionals in order to address the complex challenges of the future [8, p. 21]. Because of this, engineering programs no longer have the luxury of weeding students out.

We use math placement to define the term pre-math-ready. By our definition, an engineering student is classified as pre-math-ready if they are placed below the first-semester math class listed on the engineering degree checksheet, which is often Calculus 1, or they are behind in the math class sequence listed on their degree checksheet. We argue that there have always been first-year engineering students who placed below Calculus 1, but they have rarely been recognized due to the relatively low number of students.

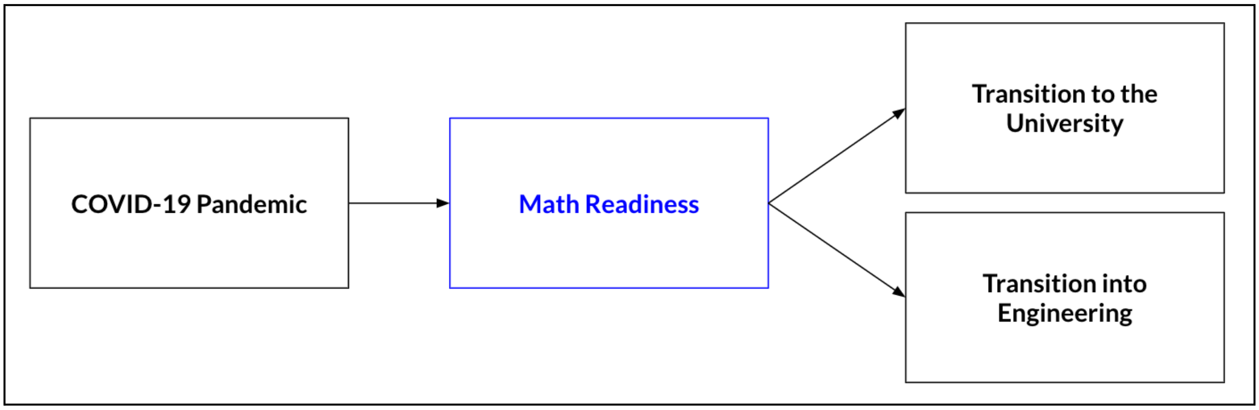
Our university has seen a change in math readiness, as evidenced by the growing number of first-year engineering students placed into Pre-Calculus during their first semester. The change in math readiness and low placement test scores is likely due to the sudden disruption to students' learning environment and the variation in policies and restrictions across schools, districts, and states. Even though students' mathematics readiness and preparations have changed, the engineering curriculums' requirements and reliance on mathematics have remained. Therefore, we wanted to understand students' mathematics experiences before they began their engineering degree and their subsequent transition into engineering. Thus, this study aims to understand pre-math-ready engineering students' experiences learning mathematics during the COVID-19 pandemic and what supports and strategies they used to deal with the transition, as well as understand how their math placement impacted their transition into the university and engineering. The following research questions will guide the study:

1. What were the learning experiences of pre-math-ready engineering students during the COVID-19 pandemic?
    a. What supports and strategies did students utilize to manage their learning during the COVID-19 pandemic?
2. How did pre-math-ready engineering students' math readiness status impact their transition to the university and into engineering?
    a. What supports and strategies did students utilize to manage their transition to the university and into engineering?

II. Background Information

This section further outlines the pandemic's unique challenge to engineering students' mathematics readiness. The pandemic significantly affected students' mathematics readiness and subsequent placement, which is particularly challenging due to the reliance on mathematics in the engineering curriculum. We argue that the pandemic impacted student math readiness, which subsequently impacted their transition to the university and into engineering, as illustrated in Figure 1.

Figure 1
Relationship between Pandemic, Math Readiness, and Transition to University/Engineering



A. COVID-19's Effect on Education

The COVID-19 pandemic brought unprecedented challenges to the education system, and many students struggled. Due to school and home life disruptions during the pandemic, students reported difficulty completing their schoolwork. Specifically, female and underrepresented minority (URM) students reported having more difficulty completing schoolwork [9]. With varying restrictions across states and school districts [3], high school students had varied learning experiences during this time.

Recent work has shown that the pandemic significantly affected student test scores. Kuhfeld et al. used test scores from 5.4 million students between grades 3 and 8 to measure achievement differences in math and reading from before the pandemic to Fall 2020 and Fall 2021. They found that students' math scores dropped more than their reading scores compared to Fall 2019. The gaps were significantly larger for students from low-socioeconomic status (SES) backgrounds and underrepresented minorities [10]. This aligns with reports from the early pandemic that showed that the effects of school closures could exacerbate achievement gaps among students [5]. The magnitude of the COVID-19 pandemic highlighted the effect learning disruptions have on students and their academic trajectory [11].

B. Mathematics and Engineering

The engineering curriculum is incredibly complex. Curriculum complexity is "the impact of curricular structure on student progression" [12]. This idea describes the effect a specific curriculum can have on students' progression in their major by considering corequisite and prerequisite chains. Prerequisite and corequisite chains are curriculum requirements describing the sequence in which courses must be taken. Many upper-level classes list prerequisite or corequisite requirements that must be taken before or in parallel with a class in order to register. Engineering curriculum tends to be complex because of the long prerequisite and corequisite chains required by many engineering programs[13]. Long prerequisite chains require students to pass many classes in order to take upper-level courses. Example papers have used curricular analytics to evaluate programs and provided example curriculum maps. The curriculum maps highlight the length of complex pathways within the engineering curriculum, and these examples show that the longest prerequisite chains begin with Calculus 1 [13], [14], showing its importance in the engineering curriculum.

The pandemic's effect on students' mathematics placement is particularly concerning for engineering students because of the complexity of the curriculum. Mathematics is an essential part of engineering, and Calculus 1 and 2 are often considered barriers or “weed out” courses for engineering students [15]. If students start in Pre-Calculus instead of Calculus 1, they often have lower percentages of persistence [16]. At most schools, the curriculum does not support students who begin their degree in Pre-Calculus, and in order to persist, they need to do a significant amount of independent work to catch up and succeed [17]. Due to the long prerequisite chains, students need to begin their degree in Calculus 1 to take engineering-specific classes in the correct sequence [18]; however, recent literature has shown that despite the multiple mathematics-related prerequisites in engineering, introductory engineering courses use minimal calculus content [19], showing there is room to update the current prerequisite requirements. In the aftermath of the COVID-19 pandemic, there has been a call to create mathematics corequisites to help students better transition from high school to college [20]. Therefore, we specifically analyze the effect math readiness has on students' transition to the university and into engineering.

III. Theoretical Framework

To analyze the data and conceptualize the results, we combined definitions of transition from transition theories with Schlossberg’s transition theory. The transition theories and definitions and Schlossberg’s transition theory are outlined below.

A. Student Transitions

Since there is no singular accepted definition of transition [21, p. 5], and many definitions exist, we have chosen to use Gale and Parker’s definition of transition, which they describe in their typology of student transitions in higher education. They define transition as “the capability to navigate change” [22]. This definition focuses on students' capabilities during times of change instead of just focusing on the process of change. Gale and Parker developed three transition typologies based on higher education research. The types of transitions include Transition as Induction (T1), Transition as Development (T2), and Transition as Becoming (T3).

T1, Transition as Induction, describes the pathway that students take by moving into higher education. This often describes the transition from high school to college, but other circumstances could be considered. Students who experience this type of transition must navigate the structures, systems, and policies of the institution. From here on out, this will be referred to as “Transition to the University.” T2, Transition as Development, describes students' life stage and their transformation from one identity to another (i.e., major, career, etc.). Students who experience this type of transition must navigate norms and expectations related to their new identity (i.e., norms of being an engineering student). From here on out, this will be referred to as “Transition into Engineering.” T3, Transition as Becoming, describes transitions as fluctuation of life experiences rather than a discrete moment of change.[22]. T3 transition was not used in our analysis. Overall, Gale and Parker’s typology of transition can be used to explain the students' transition to the university and into engineering; however, in this context, pre-math-ready engineering students experienced another transition - the disruption caused by the COVID-19 global pandemic.

In addition to Gale and Paker's typology, we consider students' education experiences during the COVID-19 pandemic as a transition. Brown and Heanoy et al. used a Transition Theory lens to evaluate the COVID-19 pandemic. By their definition, "a transition is an event or series of events that causes fundamental changes in the 'fabric of daily life'—what people do, where they do it, and with whom" [23]. This definition undoubtedly describes the effects of the pandemic in the early days. Students were no longer going to school in person, were not held to the same standards, and very little about their daily life was the same. This theory has been applied to the COVID-19 pandemic, and scholars argue that it should only be considered a transition for people whose pre- and post-pandemic lives look very different [23], [24], which we believe represents student experiences in this study. Students who were in high school during the peak of the COVID-19 pandemic experienced a distinctive transition to their learning experiences, which will be referred to as "COVID Transition."

Overall, we posit the students in this study have experienced three distinctive types of transition: 1) Transition to the University, 2) Transition into Engineering, and 3) COVID Transition.

B. Schlossberg's Transition Theory

The three types of transition will be coupled with Scholossberg's transition theory to conceptualize the results. Schlossberg theorizes that a person's adaptation to change includes three parts: approaching change, taking stock, and taking charge. We specifically considered how a person "takes stock" while experiencing a transition. Taking stock includes the four S's (*Situation, Self, Support*, and *Strategies)*, which are the resources one has to help support the change they experience [25], [26]. Regardless of the transition a person faces or the stage of the transition they are in, they will deal with the transition differently based on the four S's because these are the resources available to them [27].

Barclay conceptualized Schlossberg's theory and described the four S' specifically for college students [28, pp. 25–28]. *Situation* includes assessing the situation in the context of students' transition and considering the type of transition. For this study, students had an unanticipated transition to emergency remote learning and an anticipated transition by beginning college. *Support* considers the support systems students have to help them during their transition. *Self* consists of personal/demographic factors and psychological resources that may impact their maturity, sense of control, and outlook. Finally, *Strategies* are the coping resources, strategies, or actions students employ to deal with transitions.

For this study, we couple the definitions of transition with Schlossberg's transition theory to anchor our results. This coupling helps us understand how engineering students' mathematics readiness was impacted by the COVID-19 pandemic and how their math readiness impacted their transition to the university and into engineering.

IV. Methods

A. Methodology

This study utilized a case study [29] to understand how engineering students' mathematics readiness was impacted by the COVID Transition and how their math readiness impacted their Transition to the University and Transition into Engineering. This study's case is bounded by the type of university and type of student. The university referenced is a large research university where the engineering student population represents about 30% of the undergraduate population. At this institution, engineering students should enroll in Calculus 1 during their first semester to be on track in their major. The participants of this study are first-year engineering students enrolled in Calculus 1 during their second semester, so they are not on track for the engineering major and are, therefore, classified as pre-math-ready. Since the number of pre-math-ready engineering students has grown post-COVID, the case likely represents similar student experiences at other large engineering programs.

B. Participants and Sampling

Since the case involves several individuals situated in the same context [30], purposeful sampling was used [31]. The participants in the study are first-year engineering students at a large R1 university in the Mid-Atlantic region enrolled in Calculus 1 during their second semester. After receiving approval from the IRB, we collaborated with the General Engineering Advising Coordinator at the university to contact all first-year engineering students enrolled in Calculus 1 during the spring semester. If students were interested in being interviewed, they were asked to fill out a screening questionnaire to gather background information. Students needed to be a pre-math-ready engineering major and in high school during the peak pandemic school years to be eligible to participate. Students who filled out the screening questionnaire and met the eligibility criteria were contacted to schedule an interview. Of the students who met the criteria, 15 participated in our interviews. A list of participants and their demographic information can be found in Table 1.

Table 1

Participant Information

Pseudonym	Gender Identity	Race/Ethnic Identity	Engineering Major
Hunter	Male	White	Mechanical
Andrew	Male	Caucasian	Aerospace
Maria	Female	Latina	Computer
Brady	Male	White	Mechanical
Jonah	Male	White	Civil
Jaya	Female	Indian (Asian)	Aerospace
Jacob	Male	White	Civil
Claire	Female	White	Aerospace
Sebastion	Male	Black/African American/Native American	Mechanical
Jaden	Male	Black	Mechanical
Sidd	Male	White, Indian	Civil
Skylar	Female	White	Biological Systems
Kiara	Female	Race - African American / Black Ethnicity - Hispanic and Caribbean	Biomedical
Shay	Genderqueer	White	[removed for anonymity]
Juan	Male	Hispanic	Computer

Note: Students were asked to self-describe their racial/ethnic and gender identity.

C. Data Collection

We performed semi-structured interviews with the participants of the study lasting approximately 25 to 40 minutes during the Spring and Summer of 2023. The interview protocol was developed to capture an understanding of students' experiences during the pandemic and their transition to engineering, and we attempted to capture students' experiences and perceptions about how the pandemic affected their learning. After conducting the interviews and determining a theoretical framework, we realized the protocol mapped nicely to the four S's from Schlossberg's transition theory, further aligning our methods. We asked students specifically about the *situation* they faced, aspects about them*selves*, and the *support* they received transitioning remote learning during the pandemic, to the university, and into engineering. Student responses often focused on the *strategies* they used to manage their transition.

D. Data Analysis

The interview transcripts were analyzed through two cycles of coding - open and deductive [32]. The first coding cycle allowed us to familiarize ourselves with the data. This highlighted that students consistently discussed aspects of their transition during the pandemic and into engineering. Once we identified a transition framework, we were able to develop a codebook that combined the definitions of transition with Schlossberg's transition theory. The second cycle of coding deductively mapped the codes and themes found from the open coding cycle to the codes from the finalized codebook. Table 2 defines the four S's alongside the transition types in the study context. We organized the results by the type of transition and highlighted how students' experiences map to the four S's of Schlossberg's transition theory.

E. Trustworthiness

Reporting on the quality, credibility, and validation of qualitative research are best practices to ensure the study's trustworthiness [33]. In engineering education, Walther et al. [34] provide validation strategies to ensure the quality and trustworthiness of qualitative research.

Theoretical validation of a study should reflect the complexity of the lived experience under investigation. This can be validated through the use of an opposing case analysis. As can be seen in the findings, there were many similarities and substantial differences in students' experiences. Considering alternative or opposing perspectives is particularly important to ensure the reliability of a case study [30]. Communicative validation of the study should connect the author's interpretations to the literature. We reported our findings by aligning them with relevant theoretical frameworks in higher education. Finally, process reliability should ensure that data gathering is done dependably. The first author developed a data collection and reflection process established in the first interview, and that was followed for all subsequent interviews, which included recording the interviews and filling out a structured memo directly after the interview ended. Ideally, I wanted to collaborate with the participants to share the transcripts and findings with them [31]; however, it was beyond the scope and timeline of this project.

Table 2
Codebook

Transition Types	Four S's	Definition in Study Context
COVID Transition	Situation	Explains students' situation when the pandemic began (ex: school practices and home life)
	Self	Considers the students' outlook on their education and future at the beginning and throughout the pandemic (ex: regret over the lost education)
	Support	Refers to the support students received from school and home during the pandemic (ex: teacher availability).
	Strategies	Describes the strategies students used during the pandemic to cope with the disrupted period of learning (ex: cheating on exams)
Transition to the University (policies and structures)	Situation	Explains the situation that pre-math-ready engineering students face as they enter the university related to the policies and structures that exist in engineering (ex: math placement)
	Self	Considers the pre-math-ready engineering students' outlook on the policies and structures that exist in engineering as they transition to the university(ex: feelings about the barriers in engineering)
	Support	Refers to the help that pre-math-ready engineering students receive in engineering related to the policies and structures as they transition into the university (ex: academic advising support)
	Strategies	Describes the strategies pre-math-ready engineering students use to navigate the policies and structures in their major to get on track (ex: taking summer classes)
Transition into Engineering (identity)	Situation	Explains the situation that pre-math-ready engineering students face as they enter engineering related to their identity formation (ex: friendships in first-year engineering)
	Self	Considers pre-math-ready engineering students' outlook on their place in engineering related to their perceived identity and sense of belonging in engineering as they transition into the major (ex: plans for their future career)
	Support	Refers to the help that pre-math-ready engineering students receive in engineering related to identity formation as they transition into the major (ex: affinity groups)
	Strategies	Describes the strategies pre-math-ready engineering students use to develop their engineering identity when they may be left out in the major (ex: joining engineering clubs)

F. Positionality

Our positionalities and identities as researchers inevitably shape our analysis and approach to research [35]. The engineering education field has established that positionality is operationalized as reflexivity, and researchers should identify and acknowledge their biases and experiences to improve research quality [36]; therefore, reflecting on positionality and biases is critical to our roles as researchers. We are both currently working in the field of engineering education. The first author is a graduate student in engineering education, and the second author is an assistant professor of engineering education. We were both students when the COVID-19 pandemic began, so we understand the experience of education uncertainty during the early days of the pandemic; however, we were already in higher education, not high school. The first author worked as a supplemental math and science educator at four public schools during the 2021-2022 school year and is very familiar with the challenges in high school education and changes in academic readiness during this time period. Neither author was ever pre-math-ready in college;

we both placed beyond Calculus 1 and were considered ‘math ready’ when we began our engineering degree. Through experiences as educators, we have both informally talked to many students about their math experiences during the COVID-19 pandemic and lockdown. Based on our experiences, we are collectively interested in curriculum barriers in engineering related to mathematics and how we help students succeed in math and engineering. We are particularly committed to making the field of engineering more inclusive and have concerns about current trends and climate in higher education, especially considering the looming enrollment cliff.

G. Limitations

This study is limited in a few ways. First, the interviews captured students' perspectives at one point in time. More insights could have been found by interviewing participants at multiple time points throughout their first year. Additionally, students opted to participate in the interviews, so it may not represent all pre-math-ready engineering students. This means there could be more perspectives that pre-math-ready engineering students have that were not discussed in these interviews. Finally, the findings from this paper are from one research site; therefore, student experiences once they transitioned to the university and into engineering only refer to one context/school.

V. Results

The following sections detail the results describing students' experiences transitioning to emergency remote learning during the pandemic, to the university, and into engineering, with the four S’s from Schlossberg’s transition theory highlighted.

A. COVID Transition - RQ1

The majority of students we interviewed, 14 out of 15, were in their sophomore year during the 2019-2020 school year when the pandemic began, and most were taking some version of Algebra 2. The following school year, 2020-2021, the students were navigating their junior year and taking Pre-Calculus. Students had a variety of experiences at the beginning of the pandemic and throughout the 2020-2021 school year. A notable characteristic of the participants is that all of the participants took Pre-Calculus in high school, with many also taking Calculus, but, based on my definition, they were classified as pre-math-ready, showing the impact the pandemic had on their math readiness and subsequent math placement.

The immediate onset of emergency learning due to the pandemic in March 2020 led to schools taking vastly different approaches. Jaya described how her school approached online learning during the early days of the pandemic.

> So, we didn't start school again until almost exactly a month after COVID initially hit. So we had a month of just nothing. And our teachers were like, go outside, don't do homework. When we officially went back to school... It wasn't a full school day. I didn't have nine periods every day. It was an hour from 11 to 12, one period per day.

Jaya described how her school had one period per day and rotated through classes, so by the end of the school year, she had only gone to her math class three or four times since the pandemic started. Similarly, Skylar described their school's policy during the early pandemic, which featured no interaction with teachers or students.

> We didn't have school for two weeks, and then they just ended up canceling school for the rest of the year. We never went back. So they put us on this online platform called

> Edgenuity, which really sucked. We didn't have to have a certain grade to pass, we just had to complete the module.

Alternatively, Hunter described his experience from the early pandemic, and it was very different compared to Skylar and Jaya's,

> But with math primarily, it didn't really change much because my school transferred into complete online almost immediately. So we had everything on our own special school website…But we did all of our classes through Google Meets, I guess, video call lectures, and then all of the homework and stuff was assigned through Google Classroom or Schoology.

Instead of meeting a handful of times, like Jaya, or completing online modules, like Skylar, Hunter took all his classes online and had an experience similar to in-person learning. Hunter stated that he only had 36 students in his graduating class, so replicating a normal school day in a smaller school setting may have been more feasible. The juxtaposition in experiences (***situation***) between these students shows that incoming engineering students are entering with varying degrees of learning gaps imposed by the early pandemic. Some participants explained their feelings about the learning gaps. In her description of school during the pandemic, Skylar explained that the online modules she was required to do did not have a grade associated with them, so many people cheated because all the answers could be found online. Looking back, both Skylar and Jaya expressed their disappointment in not learning anything during the early days of the pandemic (***self***).

The variation in school approaches to the pandemic was also prominent during the 2020-2021 school year, after the early days of the pandemic. Brady described how his school did Zoom classes during the Fall 2020 semester and transitioned to a complicated hybrid system during the spring semester. Brady expressed that the hybrid system was better than the fully online system, but learning when he was online was still challenging. Jaden described a similar hybrid system his school followed during the 2020-2021 school year. However, he said that as the number of COVID cases increased, the system fell through, and they needed to move online, which led to students being given the option to be in person or virtual.

> So starting my junior year, it was completely virtual, and then in, I want to say, November, they tried going back in person, in a high-risk style. So it was by last name, so A through K went Monday, Tuesday, and Wednesday, I think it was. And then all the other last names went Thursday and Friday. And they tried that, and it lasted for two weeks, and then COVID cases were going up again, so they had to go back to completely virtual until I want to say, March of 2021, where they made it optional. So you could continue to be virtual, or you could go back in person, and I chose to go back in person.

Claire's school district gave students the option to either be in person or virtual for the 2020-2021 school year, "And then my county was really, really weird with the whole COVID thing. So, they had an online school and an in-person school and you could choose which one." Originally, Claire's parents made her go in person, but she had a lot of anxiety going in person, so she decided to go online for the rest of the year. The pandemic caused varying experiences among students, and they each had different outlooks and attitudes on their experiences during this time (***self***).

During the pandemic, teachers were doing their best to stay afloat in a new teaching system, meet the needs of their students, and take care of their own health and well-being. Subsequently, the support students received changed significantly. Jacob described how the lecture style changed, and the ability to ask questions in class became non-existent during remote learning (***support***).

> Pre-pandemic, teachers would teach on the board and stuff and would hand out notes, and would be interactive with the class. And we'd do practice problems and assignments. During COVID, it was, they shared your screen of their little cam. They went through the notes and just lectured for 45 minutes. No one really interacted, especially when it was fully virtual… And then the opportunity to ask questions really wasn't there because of the remote setting.

As the school policies changed, a lot of students were learning in a hybrid system. Juan expressed similar issues of being able to ask questions in the hybrid system "It was a bit frustrating for the online students because they could hardly communicate with the teacher. The teacher would only be focused on the people right in person, which made sense" (***support***).

One of the things that was challenging during the pandemic was the lack of interaction with peers. Working in small groups is a common pedagogical practice, but the pandemic made it difficult to implement. Shay said when their teachers figured out how to do break-out rooms, it really helped their learning, "it took my teachers a while, but they figured out how to do break-out rooms, which was actually really beneficial because we got to work in small groups." Overall, students had varying experiences with their teachers (***support***) during the pandemic that impacted their learning.

All students coped with the transition to remote learning differently and utilized different strategies to help them get through their classes. One of the most prominent strategies students discussed was cheating. During the pandemic, teachers and students were trying their best, and cheating became more common because they were learning in a new environment with different policies. Skylar described her learning experience during the early pandemic and how she coped with the transition to the new 'normal.'

> I did not learn a single thing. I cheated on the whole thing because all of the answers were online… I probably could have taken it more seriously, but it just really sucked. I think a lot of people did the same thing. I just didn't want to sit at my laptop all day and be taught by some video. I would've rather been on Zoom with an actual teacher.

Skylar wishes she had taken her classes more seriously, which Shay echoed in their experience: "And all honesty, I didn't really learn much because it's hard to learn online. It's really easy to cheat on assignments. I'm not proud of that, but yeah." Both Skylar and Shay coped with the difficult transition to online learning by cheating (***strategies***) because they were not learning much from their teachers.

Like Skylar and Shay, other students emphasized how cheating was pretty common or how it was tempting to look up the answers because learning and assessment looked different. Jaya expressed that it was easy for people online to cheat with the hybrid system "It's so easy for people to cheat if they're at home, and especially because they're not really paying attention to the people online. They're mostly paying attention to us because we're actually in school." Jacob explained that he wished he had put more effort into his schoolwork during the pandemic, but it was tempting to cheat,

> It was easy and tempting just to cheat, just to look things up, to not even actually try. And I feel like that was part of something that I could have done better, forcing myself to just actually try and learn, but my desire to do schoolwork and to really care, during COVID, just was gone. I logged in and submitted what I needed to, but that was it.

Since students were trying to learn during unprecedented times, it is understandable that they utilized cheating to cope and manage their transition (***strategies***).

Considering Schlossberg's Transition Theory in the context of the COVID transition, student experiences dealing with the transition can be described using the four S's. Overall, students had varying experiences during the pandemic and different coping strategies, but ultimately, all of their mathematics readiness suffered, which subsequently affected their transition to the university and into engineering.

B. Transition to the University - RQ2

Engineering has strict policies and structures because of the heavy reliance on mathematics in the curriculum. Due to the changes in standardized tests during the pandemic, many schools needed new ways to evaluate their students and place them into the appropriate math classes. This proposed many hurdles for pre-math-ready engineering students transitioning to the university. Due to the recent change in math placement mechanisms, many pre-math-ready engineering students discussed their experience with the ALEKS exam. At our university, the ALEKS math placement test was implemented in 2020 when existing placement mechanisms could no longer be used, and this test became a barrier for many students.

Jonah expressed the difficulty he had with the placement test prohibiting him from enrolling in Calculus 1, "It was a little frustrating because I wasn't able to get a good enough score to be in Calc 1 last semester." Furthermore, the process surrounding the placement exam caused confusion for Jaden,

> At the time, I didn't fully understand that not getting a high enough score means I had to take Pre-Calculus. I thought it was just if I got a high enough score, I would be guaranteed a seat, and then the seats that were remaining would be going to people who didn't get a high enough score.

The structures and policies surrounding the placement exam frustrated many pre-math-ready engineering students by limiting their ability to take the math class required on their major checksheet (***situation***).

Kiara highlighted her frustration with the exam's focus on topics she learned at the beginning of high school.

> I get why we do it [the ALEKS assessment]. I think it's really good for determining where you need to be for chemistry. I don't think it's as good as determining where you need to be for math. There's a lot of those questions, I felt like they were asking me questions that I learned when I was in ninth through tenth grade… I think, at times, it was slightly an unfair judgment of where people were because I think that sometimes they're testing things that you haven't learned.

Many students expressed challenges or frustration with the placement test and how they were disappointed because it put them behind in their major. This shows their outlook on the policies and structures related to their math readiness at our university (***self***).

Moreover, considering students' feelings during the transition to the university, Juan described how the expectations in school changed, and the new circumstances added more pressure, “Also, there is an expectance of ‘you need to understand the material now,’ and also added pressure of, say, finances also play a role in that.” Juan described how finances become a consideration when transitioning to college, adding more pressure on him to succeed and do well. The change in expectations and pressure pre-math-ready engineering students face in their transition to the university caused specific feelings about their ability and outlook on their engineering degree (***self***).

Brady described the support he received to successfully transition to the university and his math class, which was the tutoring he was able to participate in.

> I went to there [tutoring] for Calc and they helped me a lot. Just because it's a one-on-one with someone who's taking the class. I can be like, "How do I do this? What's the theory behind this? How do I go through these individual problems?"

In addition to individual tutoring, students highlighted the Pre-Calculus coordinator as someone who helped them succeed in Pre-Calculus to prepare them for Calculus 1. The coordinator had many online resources for students and hosted a Wednesday night help session that benefited students and their math success (***support***).

One of the main ways pre-math-ready engineering students were planning to cope with the policies and structures at the university was to take summer classes to catch up. At our institution, engineering students are not eligible to matriculate out of engineering and into their specific engineering major until they complete Calculus 2. Therefore, many pre-math-ready engineering students choose to take Calculus 2 over the summer between their first and second year to get into major-specific classes for the subsequent fall semester. Some students, like Jaya, took multiple classes over the summer to be on track for their desired major.

> So right now I'm taking physics, general physics one and calc two, so that way I can apply for aerospace by the end of the summer and then hopefully get into aerospace so I can take aerospace classes in the fall.

Due to the shortened timeline, the classes would be challenging, but catching up is really important for students. One student expressed this when they said,

> I know it's going to be a lot, especially because there's so short amount of time, the classes themselves are two hours or something like that. They're long. I know it's going to be a lot, but I personally just really want to be back on track, which is why I'm doing it.

Furthermore, it is common at our institutions for advisors to recommend taking summer classes at a community college because it is normally a better student experience. Sidd highlighted this sentiment,

> So if I didn't take those, next semester I'd be taking the two civil and environmental engineering classes and then just Calc two which wouldn't be enough credits. And everyone advises that. It's a lot easier if you take it at a community college or something.

Sidd emphasized the importance of being back on track in engineering and the potential benefits of taking Calculus 2 at a community college. A very common practice for students to cope with the policies and structures at the university when they are pre-math-ready is to take summer classes to catch up. This was a very popular option for the participants in this study, with nearly all planning to take summer classes in order to apply to their major in the fall (***strategies***).

C. Transition into Engineering - RQ2

Students' identity formation in their transition into engineering was not as significantly affected by their math readiness status. Many students who participated in interviews discussed taking high school engineering classes, which developed their interest in engineering and encouraged them to pursue it as a major, which we explored in another conference paper [37]. By having exposure to engineering in high school, pre-math-ready engineering students transition to college with some engineering identity because of their experiences.

Some students expressed that their interest in engineering was influenced by the opportunities they had in high school. If students are exposed to engineering early on, it may be easier to develop their engineering identity as they transition into engineering. Andrew attended an engineering high school where they learned about different engineering disciplines, and he described his high school experience,

> It was like a subset within our regular high school. So, I took all my core classes from the normal high school. But then, I had classes for all the engineering disciplines. So, I had, like, an aerospace class. We had an electrical class, and there was a civil class, but I didn't take it.

Although Andrew was already interested in engineering because his dad was an engineer, taking discipline-specific classes at his high school solidified his interest in aerospace engineering. These classes made for a smooth transition into the introductory engineering classes because he was already familiar with some software, like CAD (***situation***).

Similarly, Claire could engage in engineering classes in high school, but she had to drive herself there. Engineering classes were only an option at a high school across town.

> I was at two different high schools, which was a little weird because we have my high school, and then we have a fancy, rich kid high school that has all the fun programs they have, like a little engineering class.

Although the logistics of participating in the engineering class were challenging, Claire enjoyed learning CAD, working on projects, and engaging in engineering teams. Both Andrew and Claire had positive engineering experiences in their high schools that helped them decide to study a specific engineering discipline. Interestingly, Andrew and Claire have parents who are/were engineers, so they likely had social influences during high school, encouraging them to get involved in engineering early on (***situation***).

Students' interests in engineering are important to consider when characterizing their identity formation during their transition into engineering. Some students described their experiences with physics that encouraged their interest in studying engineering. Hunter highlighted how his experience with physics encouraged him to study engineering,

> It [physics] just really made sense to me, so I was thinking about more what I could use that for in my life, because I wanted more of it. And I didn't want to just stick with basic elementary physics. I wanted to get more in depth with it, and I thought probably the best way to do that would be to go into engineering.

Similarly, Jonah developed an interest in engineering because of his high school science classes: “Well, I've always just been interested in designing things. I took some physics and science classes in high school. And I really enjoyed those, so I figured I might as well try engineering.” Students' interests play a major role in their personal beliefs about engineering and transitioning to and identifying as an engineering student (***self***). However, not all students had positive outlooks on their personal circumstances as they transitioned to engineering. Specifically, Shay described their feelings of imposter syndrome entering engineering after struggling with math,

> Because I didn't think how to word this, but the way that things have gone for me in math with calculus and having to drop it, I guess it's kind of a sort of imposter syndrome like I'm not going to be able to do everything everyone else in the class is going to because I've had a struggle with calculus. So I guess just the feeling is the worst part of it.

Shay described how their math readiness status impacted their transition to engineering and their feelings about their place in engineering (***self***).

Although the participants transitioned into engineering and completed their first year, they likely have not completely developed an engineering identity. Students mostly talked about their identity formation through the lens of their past experiences, which we classified as ***situation*** and ***self*** from Schlossberg’s Transition Theory. Notably, students did not discuss ***supports*** or ***strategies*** that helped them form an engineering identity during their transition into engineering.

VI. Discussion and Implications

In the following sections, we discuss the findings in relation to broader literature the implications this work has for engineering education.

A. COVID Transition

The COVID-19 pandemic was a major disruptive transition that students faced. The results show that students had varying school experiences, ultimately affecting their math preparation. By understanding the experiences of students who were in high school during the peak COVID years, we see that their math readiness was impacted due to their various learning experiences, and the current mathematics-related curriculum barriers in engineering are frustrating. The findings and insights from this work can be applied beyond the COVID-19 pandemic. For example, students will continue to face disruptive transitions that affect their education, such as natural disasters [38], school shootings [39], [40], teacher strikes [41], [42], or individual disruptive transitions, like the death of a parent [43]. These transitions will affect students' academic readiness, and they should be supported to pursue engineering regardless of their math readiness when entering college. Mathematics is an essential part of the engineering curriculum, and students often need to begin their degree in Calculus 1 to take engineering-specific courses in the correct order to graduate on time. Beyond the COVID-19 pandemic, disruptive transitions can impact engineering students' math readiness and subsequent transition to college and into engineering.

B. Transition to the University

We found the policies and structures at our university significantly impacted the experiences of pre-math-ready engineering students. The current engineering curriculum assumes that students enter college on an even playing field. However, the playing field is far from even, and there are many differences across students' math readiness abilities, especially after the pandemic. With the looming enrollment cliff, the concern about addressing engineering students' math readiness changes will grow, and universities should consider the policies and structures in place that impose barriers on pre-math-ready engineering students.

Contextualizing our results beyond the COVID-19 pandemic, there has been a significant amount of work showing that differences in math achievement can be related to students' opportunities, not their achievement ability [44]. The National Research Council has shown that students from low-SES backgrounds are behind their peers in math when entering elementary school [45, pp. 96–97]. The math achievement gap for students of low-SES backgrounds can be present as early as kindergarten [46]. Furthermore, the instruction students receive can impact their math readiness and math achievement. Literature has also shown that differences in mathematics achievement between students who are underrepresented minorities and those who are not underrepresented can be attributed to the type of instruction URM students receive [47]. This shows that students' math readiness depends on factors outside their control.

The curriculum complexity imposes significant barriers on pre-math-ready engineering students, whose math readiness is likely impacted by factors outside of their control. Additionally, considering the enrollment cliff, there has been a call for institutions to use data to inform practices to respond to the uncertainty of future enrollment [48]. Some examples of utilizing data to inform practices can be examining the amount of Calculus needed for introductory engineering classes in order to amend the prerequisite requirements [19]. Recent work has shown that engineering students who were placed into Pre-Calculus and were successful were just as likely to succeed in engineering as students who were placed into Calculus 1 and were less successful [49]. Coupling math prerequisite reform with appropriate math placement can significantly help pre-math-ready students succeed in engineering.

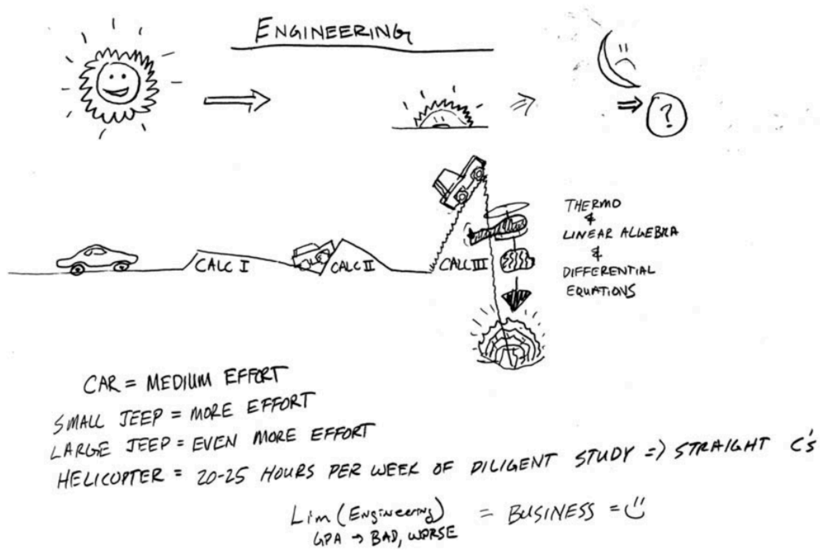
C. Transition into Engineering

Although the results showed that math readiness status had minimal impacts on the participant's engineering identity formation, we only collected data at one-time point. The participants had just completed their first year and had not applied to their engineering major. Therefore, math readiness may still impact students' transition into engineering and their engineering identity formation in the following semesters. We know that mathematics can be the biggest barrier for students to persist in engineering and significantly impact their feelings towards the field; a 2014 study asked students who dropped out of engineering to draw their experience in engineering that led them out of the major. Students cited individual and institutional factors as reasons for leaving engineering [50]. The illustrations from this study show the challenging barriers mathematics has on engineering students and their feelings towards engineering (Figure 2).

One participant explained the imposter syndrome they felt due to their math readiness. Imposter syndrome is the feeling that you don't belong in space and feel like a 'fraud' [51]. Imposter syndrome is commonly felt by historically underrepresented students in engineering [52] and may cause them to drop out [53]. If pre-math-ready engineering students feel more imposter syndrome, it can have detrimental effects on who pursues engineering, which introduces significant equity concerns in the field.

Overall, these findings illuminate the complexity of pre-math-ready engineering students' experiences with the pandemic, the university and in engineering. We advocate that universities and engineering programs should develop a more nuanced approach to address math readiness concerns in engineering, which will address equity concerns and benefit schools as they prepare for the looming enrollment cliff.

Figure 2
Bob's Journey Map from Meyer & Marx [50].



VII. Conclusion

The results from this paper show that students faced an unexpected transition when the pandemic began, which affected their math readiness. Subsequently, due to their math readiness, they faced challenges transitioning into engineering because of the existing policies and structures at the university, and students utilized different supports and strategies to help them through each transition. The results from this study warrant the need to develop ways to better support pre-math-ready engineering students in the curriculum.

This work was initially motivated by the change in students' academic readiness due to the pandemic. However, we argue that pre-math-ready students interested in studying engineering have always existed but have rarely been recognized. The pandemic exacerbated the number of pre-math-ready students entering engineering, which has prompted concern and interest in the problem. Pre-math-ready students will continue to exist in engineering due to other disruptive transitions or general inequities across the United States public school system. Regardless of the number of pre-math-ready engineering students in the future, the engineering curriculum and student support systems must adapt to accommodate all students interested in studying engineering. Due to the enrollment cliff, engineering programs no longer have the luxury of weeding students out and must update their practices to support pre-math-ready students in engineering. Our hope is that all students interested in studying engineering will be able to do so, regardless of their high school mathematics preparation.

Finally, we want to acknowledge that math is important for engineering; however, we believe there is room to update the curriculum and policies to help improve equity in engineering as it relates to math placement and readiness. Potential changes to the engineering curriculum can make engineering more inclusive and equitable for all students interested in studying engineering.

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