Post-Developmental Mathematics Experiences in College Algebra for Stem Students

Maria Cruciani
University of Wisconsin-Eau Claire

Mentor: Katrina Rothrock
University of Wisconsin-Eau Claire

Abstract
Students majoring in a STEM discipline whose sequence of collegiate mathematics begins at the developmental level follow a unique progression towards degree completion. With an elongated sequence of mathematics courses, these students have already had exposure to collegiate mathematics when enrolling in a college algebra course. A structured multiple case study provided a context for understanding students' perceptions about how their developmental mathematics experiences may have influenced their experiences in college algebra. Qualitative data was gathered through interviews with three students who are majoring in a STEM field of study. The selected students had similar quantitative literacy expectations for their degrees but differed in the types of developmental mathematics experiences they had before or during their enrollment in a college algebra course. The goal of the study was to generate an understanding of these students' experiences in college algebra and how their various experiences in developmental mathematics may have contributed to them. For these participants, having previous developmental mathematics seemed to influence awareness of productive study habits, and the importance of getting help.

Keywords:
STEM, Developmental Mathematics, College Algebra, Self-efficacy, Self-regulation

Introduction

Mathematics provides the foundation upon which the fields of Science, Technology, Engineering, and Mathematics (STEM) are built (Brown et al., 2011). Because of this, students who major in a STEM field have a multitude of required mathematics courses to complete (Chen, 2016). Students who start their progression of mathematics at the developmental level do not just extend this sequence of courses, but often their time to degree completion (Bailey, 2010) as developmental mathematics courses are not only prerequisites for degree-credit-earning mathematics courses but also for introductory lab courses in chemistry, biology, physics, and computer science (Park et al., 2021). The proportion of STEM majors who take developmental mathematics and college algebra before a course in calculus is very small (Park & Ngo, 2021) making this population of students especially unique since college algebra is a terminal course for most students enrolled (Herriot & Dunbar, 2009).

Students who have completed one or more developmental courses before enrollment in college algebra will have had exposure to collegiate mathematics. This sets them apart from most college algebra students, the majority of whom are traditional freshmen (Park & Ngo, 2021). Having more collegiate math experience could potentially alter these students' habits, attitudes, and perceptions of college algebra. Prior research has shown that increased resilience to mathematical frustration is heightened in students who have completed developmental mathematics courses prior to enrollment in college algebra (Howell & Walkington, 2020).

Additionally, students may develop persistence upon completion of a sequence of developmental mathematics courses, increasing their probability of degree completion (Wolfe, 2012). These traits may be beneficial to students in STEM fields who will use mathematical concepts throughout their education and future careers.

However, many other students do not react positively to their placement into developmental mathematics (Mitchell, 2014). While the purpose of developmental mathematics is to close gaps in students' understanding and provide them with skills necessary for success in future courses, developmental programs can become a barrier to graduation for some students (Bailey, 2010; Cohen & Kelly, 2020). There are high failure rates for developmental mathematics courses across four-year institutions in the United States (Kosiewicz et al., 2016) with less than a fourth of students enrolled in developmental mathematics completing university requirements for mathematics (Bonham & Boylan, 2012). Additionally, less than half of students who complete developmental mathematics coursework will enroll in a degree-credit-earning mathematics class (Davidson, 2016; Roska et al., 2009). Since a minimum progression of mathematics through calculus is required for most STEM disciplines (Park et. al, 2021), students who are initially placed into developmental mathematics or college algebra have significantly lower chances of graduating with a degree in a STEM discipline given their elongated sequence of mathematics courses (Cohen & Kelly, 2020; Park & Ngo, 2021). These students may also struggle with low self-efficacy in mathematics and imposter syndrome because of their initial placement into lower-level mathematics, which may contribute to a subsequent decision to not major in a STEM discipline (Belser et al., 2018).

The goal of this study was to investigate how having a developmental mathematics course prior to or concurrent with enrollment in college algebra affects the habits, attitudes, and perceptions of students who are majoring in a STEM field of study. The following is the research question that guided the study: How do STEM students who are identified as needing developmental mathematics perceive their academic experiences in college algebra, and what do they believe about how their developmental mathematics experiences have contributed to their academic success in college algebra?

Literature Review

Students majoring in a STEM discipline whose sequence of collegiate mathematics begins at the developmental level represent a unique progression toward degree completion. When these students reach their first degree-credit-bearing mathematics course in college algebra, they have had at least one exposure to collegiate mathematics coursework already. This could affect their approach to the course, and their attitudes and expectations about academic achievement. A review of related literature provides an overview of research on developmental mathematics and college algebra, as well as students in a STEM field of study. To furtherunderstand participants' responses, the review of literature also includes research on self-efficacy and self-regulated learning strategies.

STEM Students

The STEM workforce is vital to the nation's economy (Newton, 2011). As the number of qualified professionals filling STEM positions has decreased, the economic and educational competitiveness of the United States has wavered, leading many to call for an increase in STEM education nationwide (Brown et al., 2011). Students' interest in pursuing STEM degrees has been decreasing as well, with many leaning toward careers in business, literature, the arts, and entertainment (Kassaee & Rowell, 2016).

Student interest in and the probability of majoring a STEM field of study begins in high school (Park & Ngo, 2021) and increases with the successful completion of mathematics and sciences classes (Wang, 2014). As students build confidence and self-efficacy in their ability to do mathematics, the likelihood that they major in STEM increases. Other factors affecting the likelihood students choose to major in a STEM field of study include their socioeconomic background, gender, and race (Newton, 2011). Once in college, incoming freshmen who are aspiring to continue on in graduate school have increased rates of retention in STEM fields and have shown higher motivation to complete their degrees (Wang, 2013).

Although attrition among STEM students is most common in two-year institutions, four-year institutions are impacted significantly as well (Chen, 2013). In a study from 2003-2009, 48% of bachelor's degree students and 69% of associate's degree students who entered STEM fields had left by 2009 (Newton, 2011). Among underrepresented minorities and women, Kassaee and Rowell (2016) found that 40% of those who began college as STEM majors either switched majors or failed to achieve degree completion. The percentage of students switching from or failing out of STEM degrees is consistently higher among non-traditional students, minorities, and women when compared to their counterparts (Koch et al., 2018). Despite that, Heilbronner (2011) found that once undergraduate degrees are completed, over two-thirds of graduates have remained in STEM fields, with three-quarters of them majoring in a STEM discipline in graduate school.

Both the highest level of high school mathematics taken and first-year collegiate mathematics placements have been identified as factors leading to attrition in STEM majors (Chen, 2013; Park & Ngo, 2021). Heilbronner (2011) proposed that this may be due to students' misunderstandings about the number of mathematics courses required for their degrees, as well as low self-efficacy in mathematics. Taking less challenging or low-level math classes, light credit loads of STEM classes, and underperforming in STEM classes versus non-STEM classes were also prominent factors in students' reported decisions to change majors (Chen, 2016).

College Algebra

College algebra is the most common mathematics course needed for students completing both associate's and bachelor's degrees and most often students' first experience with a collegiate mathematics course (Harrell & Lazari, 2015). The course's principal role is to prepare students for a course in calculus (Herriott & Dunbar, 2009), as students are taught computational mathematics procedures that are important for the development of quantitative literacy which builds a necessary foundation for future mathematics (Haver et al., 2007; Herriott & Dunbar, 2009).

College algebra is a terminal course for most enrolled with only a small percentage of students going on to complete a major in a STEM discipline (Herriott & Dunbar, 2009). Some students who get placed into college algebra have been high achieving in high school and feel upset and insulted by their placement into college algebra (Venezia et al., 2010). Many more, however, are disdainful toward mathematics and have a history of repeated failures (Tunstall, 2018). These negative attitudes contribute to higher failure rates in college algebra compared to other mathematics courses (Porter et al., 2015; Tunstall, 2018).

With only a small percentage of students continuing with more mathematics courses, a large population of students are frustrated with the traditional requirement to take college algebra since its purpose is to prepare students to take calculus (Haver et al., 2007). The challenge of teaching a diverse population of majors has led many institutions to reform college algebra, adapting the curriculum around students' intended majors (Tunstall, 2018). The creation of sections of college algebra that are major specific or have extended class time has led to the placement of temporary supplemental instructors into sections in an attempt to reform the course to better meet students' needs (Porter et al., 2015).

Among freshmen entering college who intend to major in a

STEM discipline, about a third are placed in college algebra, the majority of whom later abandon their field of study (Chen, 2013). It is a difficult battle to retain STEM students who are placed into low-level mathematics courses; students placed into college algebra who are majoring in a STEM field of study only have a 25% chance of being successful in the course (Kassaee & Rowell, 2016). Most students majoring in STEM are placed into Calculus I (Radunzel & Mattern, 2015), with the consequent "weed out" course being upper levels of calculus. Given the low probability of success, college algebra may serve as more of a barrier for students majoring in STEM who are placed into it, thus complicating their progression toward a degree (Cohen & Kelly, 2020).

Developmental Mathematics

Developmental education is intended to close the gap in students' knowledge and mathematical ability and meet the standards for college-level mathematics (Schudde & Keisler, 2019). The number of students placed in developmental courses has been steadily increasing, with mathematics being the most common remedial subject (Davidson, 2016). Nearly 100% of two-year institutions and over three-quarters of four-year universities offer remedial classes for underprepared students (Koch et al., 2018). In 2012, Bonham and Bailey (2012) found that less than one-third of graduating high school students were deemed college ready, and Chen (2016) found that 40% of postsecondary graduates reported taking at least one remedial class while completing their degrees. Many of these students are surprised to learn that they are not deemed ready to enter degree-credit-bearing classes and are frustrated that they must pay for a class that does not further their degree (Mitchell, 2014). While these developmental education classes exist to help students gain the necessary skills to reach their goals, they have often instead become roadblocks to success (Bonham & Boylan, 2012).

However, the persistence of students in degree-credit-bearing mathematics courses is higher for those who first completed a sequence of developmental mathematics courses (Wolfe, 2012). Successful completion of a sequence of developmental courses is positively correlated with degree completion (Howell & Walkington, 2020), and is the most accurate predictor of their chosen field of study and eventual degree completion (Baxter et al., 2017). This early momentum gained by completing mathematics requirements can contribute to overall student success in college (Benkin et al., 2015). Unfortunately, less than one-fourth of students in developmental mathematics will complete the sequence of courses (Bonham & Boylan, 2012). Of those who make it through the developmental courses, less than half of these students complete the additional mathematics courses required for their degree (Kosiewicz et al., 2016). Since students who begin in developmental mathematics have a longer path to complete university mathematics requirements, many give up before reaching degree-credit-earning courses (Bailey, 2010). This pattern of failure can drain institutions' educational resources and increase the amount of time students are in college (Chen, 2016).

The most common demographics of developmental mathematics students include identifying as female, low socioeconomic status, and as a racial minority (Hodara, 2019). Furthermore, students who are placed into developmental mathematics at the start of their undergraduate study often have similar academic trajectories in high school (Benkin et al., 2015). Many do not take Advanced Placement courses, and they tend to experience low academic success in mathematics classes higher than the second level of algebra (Hodara, 2019).

Very few students majoring in STEM are placed into developmental mathematics courses (Park & Ngo, 2021). STEM majors that are placed in developmental mathematics may experience more friction in their degree pathways, as any momentum that could be made toward upper-level classes is halted by a sequence of prerequisite developmental courses (Park et al., 2021). They may also struggle with feelings of misplacement and doubt, as many of their peers in their discipline are placed into mathematics courses of higher difficulty (Belser et al., 2018).

Self-efficacy

Self-efficacy refers to an individual's belief in their ability to perform a certain task (Bandura, 1977). Self-efficacy is goal-directed, with those who have confidence in their abilities being more likely to set goals and fulfill them (Rittmayer & Beier, 2009). The higher self-efficacy someone has, the more likely they are to put in effort. These self-judgments directly affect the types of tasks individuals choose to engage in routinely (Ayotola & Adedeji, 2009).

Self-efficacy in an educational setting refers to someone making personal judgements about their ability to pass a course or succeed on a particular academic task (Zimmerman, 2000). In this context, someone's beliefs are largely based on mastery experiences (Rittmayer & Beier, 2009). Students' beliefs concerning possible performance outcomes in a subject are the main determinant of how much effort they will offer, and how long they will persist when tasks are challenging (Hackett & Betz, 1989). Self-efficacy varies for each student, depending on the subject at hand, and affects the courses a student may choose to take in high school and beyond (Zimmerman, 2000). A strong positive correlation has been found between mathematics self-efficacy and mathematics achievement (Ayotola & Adedeji, 2009). Mathematics self-efficacy is a strong predictor of mathematics-related performance and is positively correlated with STEM task performance (Hackett & Betz, 1989). Collegiate STEM task performance is affected by the mastery experiences students engage with while in high school (Rittmayer & Beier, 2009).

Self-regulated Learning Strategies

Self-motivated students are proactive about their learning and generate feelings and actions that help them achieve their goals without outside influence (Zimmerman, 2002). When facing academic challenges, these students succeed through the application of strategies that reflect their academic strengths (Zimmerman, 2000). Students with these traits are called self-regulated learners and they can evaluate and organize their mental abilities to achieve the highest level of academic success (Zimmerman, 2000; Zimmerman, 2002). Their methods are personal and incorporate their optimal learning style, to acquire the greatest amount of knowledge (Nota et al., 2004). Strategies self-regulated learners use include setting goals and self-monitoring their progress toward achieving them (Zimmerman, 2000), checking their understanding of concepts through self-checking, self-testing, and self-reflection (Zimmerman, 2002), seeking help when comprehension is not reached (Pons, 1986), and organizing their work and learning for academic courses (Zimmerman, 2002).

The use of self-regulated learning strategies in mathematics can be dependent upon students' level of interest and enjoyment in the course (Cleary & Chen, 2009). Briley et al. (2009) found the more students saw the ability of mathematics to be useful in their future careers, the more willing they were to put effort into adapting their learning to be the most successful. When self-regulated learning strategies are employed in mathematics, students can identify what factors affect their learning, and adjust accordingly (Medina, 2013). Self-regulated learners in mathematics seek help when necessary, identify gaps in their understanding, organize their assignments and subsequently, their learning (Medina, 2013).

Increased use of self-regulated learning strategies has been associated with an increase in students' mathematics achievement and test scores (Cleary & Chen, 2009; Nota et al., 2004). Since self-regulated learners use cognitive strategies to monitor, understand, and direct their learning (Cleary & Chen, 2009), they can evaluate their previous performances and adjust their approaches to learning to improve academic outcomes (Zimmerman, 2000). Using these strategies aid in the development of intrinsic motivation, improving students' relationship with mathematics, and increasing course grades (El-Adl & Alkharusi, 2020). Additionally, students with higher self-efficacy in mathematics are more likely to use self-regulation strategies to monitor their learning (Zimmerman, 2002). The number of strategies employed by students affects their perceptions of their level of understanding and ability to succeed (Berger & Karabenick, 2011). This illustrates the link between self-efficacy and self-regulation, ultimately affecting students' mathematics achievement (Zimmerman, 2002).

Methods

This study consists of three case studies following students majoring in STEM fields who were taking college algebra in the Fall 2022 semester. The selected students had similar quantitative literacy expectations for their degrees but differed in the types of developmental mathematics experiences they had before or during their enrollment in a college algebra course. A structured multiple case study design was chosen to provide a context for understanding students' perceptions about how their developmental mathematics experiences may have influenced their experiences in college algebra. The goal was to generate an understanding of these students' experiences in college algebra and how their various experiences in developmental mathematics may have contributed to them.

Setting

This study was conducted at a mid-size, midwestern public university with approximately 10,000 undergraduate students. The office of institutional research at this university provided documents on the demographics of incoming freshmen in 2021 as well as graduation rates. In 2021, there were 2,100 incoming freshmen at the institution with an average GPA of 3.59.

Among these, 10.2% were students of color, 25.1% were first-generation college students, and 17.2% were low-income students. In the Fall 2022 semester, 619 students were enrolled in college algebra. Of these, 327 students were enrolled in both college algebra and a concurrent developmental mathematics course. Between 2011 and 2021, the rate of undergraduate students at the institution starting in a concurrent developmental mathematics course and graduating in four years was 24.74% and the rate of students starting in college algebra and graduating in four years was 34.18%.

Between the fall of 2011 and the fall of 2022, there have been 3,739 students who have majored in a STEM field of study and graduated from the institution. Among these students, 218 had their first mathematics course at the developmental level, 80 students took a co-requisite developmental mathematics course with college algebra, and 1,296 students started in college algebra. The four-year graduation rate for undergraduate STEM majors at the institution who were required to take developmental mathematics was 49.2% and the four-year graduation rate for undergraduate STEM majors at the institution who did not need to take developmental mathematics was 28.04%.

Participants

Three participants were chosen from the 327 students enrolled in college algebra in the Fall 2022 semester at the institution where the study was conducted. John (a pseudonym) was a male non-traditional transfer student majoring in geology who had to complete one developmental mathematics course before enrollment in college algebra was allowed. He did not pass developmental mathematics in the Fall 2021 semester but passed the same course in the spring semester of 2022. Maggie (a pseudonym) was a female traditional freshman majoring in biology. She had been placed into a concurrent co-requisite developmental mathematics course alongside college algebra for the Fall 2022 semester. Tessa (a pseudonym) was a female traditional freshman also majoring in biology. She completed a summer developmental mathematics program before enrolling in college algebra for the Fall 2022 semester. As STEM majors, all three participants needed to take mathematics through Calculus I.

Data Collection

Potential subject selection began just before the start of the Fall 2022 semester. Researchers identified potential subjects who were enrolled in college algebra and had experience or would have experience with developmental mathematics in one of the following ways: one or more previous semesters of developmental mathematics, participation in the institution's summer developmental mathematics program, or concurrent enrollment in the co-requisite developmental mathematics course intended to supplement students' learning in college algebra.

Verbatim transcripts of nine in-depth interviews conducted over the first half of the semester formed the basis for the study's qualitative analysis. Each of the three participants was interviewed three times. Interviews lasted an average of 30 minutes, and participants were asked questions regarding their study habits, organizational practices, self-efficacy, previous mathematics experiences, and perceptions of achievement in their college algebra course. All interviews took place in the same private room at the institution where the study was conducted. The first interview with each participant was conducted during the second week of the Fall 2022 semester. Second interviews occurred two weeks later, and the final interviews were conducted two weeks after the second interview. To maintain the authenticity of participants' speech during analysis, interview transcripts were analyzed using manual in vivo coding. Since in vivo means "In that which is alive" (Saldaña, 2014), codes were created during qualitative analysis based on the actual language used by each participant. The frequency of each code was measured in each of the nine interviews. To validate the researcher's interpretation of participant responses, the transcripts and coding schemes were subjected to expert review by three mathematics education professors at the institution. The investigator triangulation confirmed findings in coding schemes and also raised the researcher's awareness of an additional code possibility. After examination, instances suggested for the proposed additional code were determined to be adequately contained within one of the existing identified codes.

Instrument

The researcher-developed semi-structured interview protocol (Campbell, 2015) included probes and follow-up questions. Questions asked during interviews were scripted, meaning that they were specific and followed a set sequence (Marshall & Rossman, 2016, p. 150); predetermined follow-up questions provided an opportunity to clarify further personal meaning intended by participants. Questions on study habits, organizational practices, and students' self-efficacy were developed based on findings from the literature review. Follow-up questions were intended to uncover student attitudes and student perceptions of success in the course. Most questions were open-ended and used the words "why" and "how" to prompt participants to tell their personal stories and opinions about their current experiences in their college algebra course (Campbell, 2015). The researcher intentionally acted just as a listener to reduce any researcher bias (Chenail, 2011).

Results

After analyzing all nine interview transcripts, in vivo coding revealed six codes from patterns in participants' speech. The six codes could be categorized broadly into two overarching themes of participants' self-efficacy and participants' use of self-regulated learning strategies.

The following results include descriptions of both the labeled codes as well as the themes they support. John, Maggie, and Tessa all expressed ideas that exhibited each of the six codes at some point during each of their three interviews.

Participants' Self-efficacy

Codes relating to participants' self-efficacy included instances when participants' speech indicated beliefs in their ability to successfully complete mathematical tasks expected of them in their college algebra class, as well as their beliefs in their ability to be successful in college algebra overall. Three codes were developed: 'confidence in mathematics,' 'memory,' and 'perseverance.' Responses coded as 'confidence in mathematics' included instances when participants expressed self-assurance about their ability (or inability) to succeed in the course. Participants' responses about not remembering how to do mathematics were coded 'memory', as well as instances when participants attributed their lack of success to a lack of memory. Responses about how participants reacted when faced with challenges (whether persevering or giving up) were coded as 'perseverance.'

An additional code, 'self-efficacy attitudes,' was identified relating to the attitudinal responses displayed by participants. Although not directly indicative of self-efficacy, these attitudes appeared to be related to participants' beliefs about their ability to succeed in college algebra and often seemed to indicate a lack of self-efficacy. Participants expressed ideas that suggested they believed that they could not complete one or more tasks, or they could not be successful in their college algebra course overall and were seeking a reason to explain their shortcomings. Expressions of these beliefs included instances when participants described that their failures were a consequence of the difficulty of the course material, the poor preparation provided by their developmental mathematics course, poor instruction or instructor behaviors, or a problematic format of the course. Frequencies for participants' self-efficacy codes are shown in Table 1.

Table 1. *Frequencies for Participants' Self-efficacy Codes*

Participant	Code	Interview 1 Pos a /Neg b	Interview 2 Pos a /Neg b	Interview 3 Pos a /Neg b	Totals Pos a /Neg b
John	Confidence in Mathematics	2/1	3/10	5/11	10/22
	Memory	6	6	5	17
	Perseverance	2/13	2/8	9/1	13/22
	Self-efficacy Attitudes	28	19	20	67
Maggie	Confidence In Mathematics	9/0	6/2	11/2	26/4
	Memory	3	3	4	10
	Perseverance	3/0	5/0	5/0	13/0
	Self-efficacy Attitudes	10	21	62	93
Tessa	Confidence in Mathematics	4/3	5/4	6/4	15/11
	Memory	4	7	7	18
	Perseverance	4/1	8/0	8/3	20/4
	Self-efficacy Attitudes	21	10	20	51

[a] Pos: Statements identified as positive 'confidence in mathematics' included instances when participants expressed self-assurance about their ability to do mathematics. Statements identified as positive 'perseverance' included instances when participants persevered or expressed a plan to persevere when faced with challenges.
[b] Neg: Statements identified as negative 'confidence in mathematics' included instances when participants expressed self-assurance about their inability to do mathematics. Statements identified as negative 'perseverance' included instances when participants gave up or expressed a desire to give up when faced with challenges.

Participants' Use of Self-regulated Learning Strategies

Codes relating to participants' use of self-regulated learning strategies included instances when participants' speech indicated actions of seeking help, plans for or descriptions of organizational practices, or task strategies to benefit learning. Two codes were developed: 'seeking help' and 'task strategies.' Participants' speech that described getting assistance from tutors or friends, the internet, or their plans to do so was coded as 'seeking help.' Notably, this code often appeared following participants' expressed doubt in their ability to complete assignments or understand the material for college algebra. Codes classified as 'task strategies' included participant responses that discussed their goals for the course and their plans to achieve them, initiatives taken by participants to increase their understanding of the material, and participants' descriptions of how they would study and prepare for quizzes or exams.

Frequencies for participants' use of self-regulated learning strategies codes are shown in Table 2.

Table 2. *Frequencies for Participants' Use of Self-regulated Learning Strategies Codes*

Participant	Code	Interview 1	Interview 2	Interview 3	Totals
John	Seeking Help	17	9	10	36
	Task Strategies	2	5	13	20
Maggie	Seeking Help	2	7	11	20
	Task Strategies	7	14	9	30
Tessa	Seeking Help	6	3	4	13
	Task Strategies	9	15	19	43

Discussion

The three participants in this study all had an unusual mathematics course path for a STEM major, having been identified as needing some sort of developmental support. However, participants' responses varied substantially when describing their experiences in college algebra. The following section discusses each participant's trajectory throughout the study, organized by identified codes, and offers possible patterns displayed by each participant throughout the interview process.

Confidence in Mathematics

John and Tessa seemed apprehensive at the beginning of the semester, often describing feelings of uncertainty about taking college algebra. They had both previously experienced doing mathematics coursework in a college setting; it is unclear whether those experiences contributed to their apprehension about taking college algebra.

> *I don't have a super great past with math. In high school I took Introduction to Algebra and, uh, part of Algebra I. I failed Introduction to Algebra probably two or three times, it was horrible. I didn't really care though, it was whatever. I don't know if I hated math, I just didn't see the point to it and I didn't attend. So, then I didn't know what was due or what was going on so I didn't pass. Then in college I've had [a developmental mathematics course] which was really difficult because it was like online. Um, but there was the tutor lab where I got a lot of individual attention and I got to ask a lot of questions and learn different ways to do problems which was helpful. I went there all the time. (John, Interview 1)*

> *Math in high school at first was good, kind of just learning the basics and stuff. But as classes got more difficult each year you don't review any of the basics, and you just keep adding on. It got intense and I didn't really like it as much. This summer I had a developmental mathematics class that had an independent structure. I'm glad I passed otherwise I'd be in a lower level of math right now. (Tessa, Interview 1)*

Maggie, on the other hand, began college with high confidence in her ability to do mathematics. She enrolled in a developmental mathematics class concurrently with college algebra in her first semester of college. In Interview 1, she described her successes in high school mathematics and never mentioned any feelings of unease or apprehension towards college algebra.

> *I really liked math in high school. It came easy to me because I work well with numbers. So, whenever there were just numbers in math I always did really well. When I was in fifth grade, I know it was a long time ago, but we did this standardized testing thing, and I won the presidential award for math. So, I always worked really well with math. (Maggie, Interview 1)*

All three participants described quite different histories with mathematics. Maggie's recent successes likely explain why she expressed confidence about doing mathematics so much more often during her first interview.

Maggie and Tessa both had more instances of expressing confidence in their ability to do mathematical work than not. John, however, increasingly discussed his lack of confidence as the semester progressed. In Interview 1, John indicated that he felt confident doing mathematics. By Interview 2, however, he frequently expressed ideas that demonstrated a lack of confidence in his ability to be successful doing the mathematics work needed, and that continued into Interview 3. It is possible that his negative tutor lab experience influenced this shift, as well as the timing of the first exam which occurred between Interview 1 and Interview 2. When John was in developmental mathematics, he felt that if he could use the tutoring lab, he could be successful. When his tutoring lab experiences in college algebra did not meet his expectations, he became distressed and doubtful in his ability to pass the course.

A code that was proposed by expert reviewers during triangulation was mathematics anxiety. John and Tessa both had instances of speech that expressed their anxiety about college algebra. In comparison to Maggie, neither John nor Tessa had as strong of a mathematics background. Neither spoke much about being confident in mathematics, which could explain why they both described themselves as having anxiety, and Maggie did not. These instances were identified as a 'lack of confidence' in their frequency counts for this study.

Memory

All three participants mentioned in some manner that they struggled with remembering material in mathematics and worried about this affecting their performance in college algebra.

> *I wish I would have taken college algebra in the summer right after [my developmental mathematics class] because then I would have remembered it better. Math just doesn't stick with me. We are doing a review unit right now, but I don't remember if we did this stuff before. It seems familiar. but I don't remember any of it so it's hard because I feel like I'm seeing it for the first time again. (John, Interview 1)*

> *[My concurrent developmental mathematics course] is a huge help because those simple concepts are the ones that I have figured out that I don't remember or have lost. So, it's really helpful to have that refresher, and then when I go to college algebra it's like-Oh I know how to do this. Otherwise, I think it would be hard for me to remember how a lot of that basic math works because I didn't take math my senior year of high school so it has been a while. (Maggie, Interview 2)*

> *I usually wait a day after the lecture to do the homework that covers that stuff. Then I can refresh my brain and see what I actually retained from lecture. Usually, it's pretty good and if I don't remember something there is an example like it on the worksheet, we take notes on during lecture. (Tessa, Interview 2)*

All three participants seemed to equate memory with learning or achievement. They frequently used the word 'remember' on occasions when 'learn' might have been more appropriate. While recall is a part of mathematics, it is in conjunction with past and present learning. Students who use effective strategies in mathematics will both recall old learning and make connections to current learning (Schneider & Artelt, 2010). John, Maggie, and Tessa worried about their ability to remember procedures. Their focus in mathematics seemed to be centered on memorization instead of gaining conceptual understanding. However, this could be common for any student who had practiced studying mathematics with a procedural focus and may not be associated with participants' developmental mathematics background.

Perseverance

Even though John seemed to have a discouraging start to college algebra, he did increase the amount that he spoke about persevering in mathematics or on mathematical tasks as the semester progressed. After Interview 2, John started to express his willingness to turn things around. While he had not yet made any changes by Interview 3, he continued to share his intent to improve his work ethic toward assigned homework and studying. He recognized that he was not set up for success in the course with the routine he was using and continued to express his willingness to improve his habits.

Maggie and Tessa expressed some doubt in their abilities after they received their scores on the first exam, but both spoke more about persevering in mathematics and creating plans of action to increase their performance on successive exams. Throughout the study, Maggie's responses showed high perseverance, even after receiving a surprisingly low score on her first exam. Maggie stated she had never done poorly on a mathematics exam before, so this may be related to her increased tendency to blame her failures on the structure of the course and her instructor.

Self-efficacy Attitudes

All three participants expressed dissatisfaction with either the format of the course or their professor. John was adamant that his professor was inhibiting his success in the course throughout all three interviews. Interview 1 was conducted just one week into the semester and when asked about his outlook on college algebra, John expressed the following.

I'm not like nervous, but I do think it's going to be hard especially if [the professor] continues like [the professor] is now, just showing us one way and going so fast. There is never any time to ask questions or to think. I mean- I think I'll definitely pass. It's not hard what we are doing. But I'm going to struggle. Math is not my strongest thing, numbers are hard. I just really wish [the professor] didn't teach like that. I thought it was going to be better. [The professor] is very frustrating. (John, Interview 1)

Throughout the following two interviews, John continued to claim that he would be doing better if he had a different professor and was reluctant to ask his professor for help during office hours. John expressed his desire to go to the developmental mathematics tutor lab repeatedly throughout all three interviews, as if that would eliminate his struggles in college algebra.

Maggie did not express blame towards her professor until Interview 3 which occurred soon after she received an unexpectedly low score on her first exam. She was surprised and chose to focus on the professor as a root cause of the low score.

I feel like I did so much better than the grade [the professor] gave me. He just has no clue how he is grading. He didn't have a set way to grade or didn't take the time to look at our work. I don't even think meeting with him would be helpful. Just the couple questions I've asked him about the exam haven't gone well. [The professor] doesn't understand why I am so upset and what he did wrong. So now I'm terrified for future exams. I guess I have to learn to do everything the exact way that [the professor] does or I'm going to lose points. I lost like 8 points because I didn't show some work or do a problem using his method. We only have three exams so they all count a lot. I am so frustrated. (Maggie, Interview 3)

Notably, this was Maggie's first experience taking a mathematics class beyond high school. College course structures, time spent in the classroom, and relationships with instructors are very different than in high school, so this could have contributed to Maggie's frustration. John and Tessa had experienced these aspects of collegiate mathematics in their previous developmental sections, which may explain their differing reactions to frustrations in mathematics.

With regard to participants' attitudes about developmental mathematics, Maggie's outlook on her concurrent developmental mathematics course was positive throughout all three interviews. She did not view it as a hindrance as many developmental mathematics students do, but rather as a beneficial opportunity to review important skills.

> *My math skills are definitely improving. It's all coming back to me. [My concurrent developmental mathematics course] is a huge help because those simple concepts are the ones that I don't remember or have lost. So, it's really helpful to have that refresher, and then when I go college algebra and it's like oh yeah, I know how to do this. (Maggie, Interview 2)*

This was expressed especially strongly in Interview 3, which could be due to the tension that had developed between her and her professor after the first exam. Maggie rarely mentioned her concurrent developmental mathematics course unless prompted during the first two interviews, but in Interview 3, when discussing her exam in college algebra, she mentioned the professor for her developmental mathematics course in response to a question about attending office hours for her college algebra course.

> *No, I probably won't [attend]. I feel like [the professor] doesn't understand what we're asking. [The professor] doesn't understand like our background knowledge at all. I really like my [concurrent developmental mathematics] professor. He is really good at answering homework questions. We have a lot of time in class to work on homework. He shows the steps you have to do to solve problems and he'll go slow if he thinks you aren't understanding him which I like. (Maggie, Interview 3)*

Maggie and John both spoke more positively about their developmental mathematics experiences as the three interviews progressed, which could have been a response to their frustrations about the results of the first exam in college algebra. Tessa expressed a positive outlook on the summer developmental mathematics program throughout all three interviews, repeatedly expressing her appreciation for having had that opportunity. This attitude of feeling behind or stuck may have led to Tessa's increased communications about perseverance and how little she blamed her instructor compared to John and Maggie. Tessa's fear of falling behind may have driven her to work hard and get through her mathematics requirements quickly. John expressed negative feelings about his experiences in developmental mathematics during Interview 1, saying that it was not a good experience, and he did not like the format of the independent online course but found the tutoring lab for developmental mathematics helpful. However, by Interview 3, John expressed that he wished college algebra had the same format and resources as his past developmental mathematics courses. While this was likely partially due to this appreciation of the developmental mathematics tutoring lab, he also stated that he missed the videos that went with the old online homework platform, part of the very structure he previously did not appreciate. This shift in his perspective on developmental mathematics likely occurred because of John's low achievement in college algebra and his mounting frustrations with the difficulty of the material, the tutoring lab, and his professor.

Seeking Help

The theme of seeking help was prevalent in interviews for John and Maggie. At the institution where this study was conducted, there is a separate tutoring lab for students in developmental mathematics. John frequently used the developmental mathematics tutoring lab during the two semesters he was enrolled in developmental mathematics. He expressed plans during Interview 1 to use a tutoring lab again, acknowledging that he could no longer use the developmental tutoring lab, and would need to go to another one intended for students in classes starting at college algebra and above. He planned to use tutoring for homework assistance and for exam preparation, continuing the routine he was used to from developmental mathematics. However, in Interview 2, he expressed dislike for the new tutor lab.

> *So, I'll go there and work on my assignments. But to be real it's like not that helpful tutor wise. I mean it is nice to have a quiet place to work on math, and a couple of the tutors have been helpful. But it hasn't been like great in helping me understand the material better. I miss the tutor lab from [my developmental mathematics course]. (John, Interview 1)*

His frustration with the new tutor lab was expressed repeatedly in both Interview 2 and Interview 3, especially when John was preparing for exams. This likely explains the noticeable reduction in the number of times John mentioned seeking help over the course of the study. By Interview 3, John switched to just using his friend for help. John appeared to depend on one-on-one help in college algebra, similar to the pattern of behavior he described when discussing his experiences in developmental mathematics. When one-on-one help was not received at the beginning of the semester in the new tutor lab, he described his frustration and desire for someone to provide this. John talked about using Photo Math multiple times as a solution. Photo Math is an app that instantly retrieves solutions to homework problems submitted with a photo. He claimed in Interview 2 that using the app was necessary since he was not receiving the assistance he needed. However, later in Interview 3, he contradicted this by saying,

> *I know I need to stop using Photo Math and just spend more time trying to figure out the homework. We also have a textbook that I haven't even used yet, so I might try reading that to see if it is helpful. And I think there are like problems in there and stuff that I could work through. (John, Interview 3)*

Even though John expressed a desire to be able to work independently, he struggled to make that transition in college algebra. Maggie, however, had success with the tutor lab for college algebra, and the frequency at which she discussed seeking help increased with each interview. Maggie described using the tutor lab to check her understanding and build her confidence in mathematics during Interview 2.

> *I liked the tutor lab more than class because I felt more comfortable asking questions. [The tutor] also didn't move on until I had confirmed that I understood why certain steps were taken while we figured out the problem. (Maggie, Interview 2)*

Maggie went to the tutor lab, not just to get help with homework problems, but also to satisfy her desire to have someone confirm her understanding about mathematical ideas. She seemed to view the tutor lab as more of a supplemental opportunity to work collaboratively and check for understanding, rather than a resource to provide immediate homework assistance that John desired.

Tessa mentioned during Interview 1 that she planned to go to the tutoring lab or contact her professor if she ever found herself needing help with college algebra but did not continue to discuss it as much as John or Maggie. While she acknowledged these resources in the subsequent two interviews as well, she ultimately did not choose to seek help from any outside sources.

Tessa never attended the tutor lab or contacted her professor for help, despite stating an intention to do so and admitting that she needed help. Tessa did mention in Interview 3 that she had been doing homework with friends but used that opportunity to check answers rather than work collaboratively on problems. Tessa seemed to view mathematics as a subject one does independently, not collaboratively. This aligned with her expressed preference for her lecture-based college algebra class over her previous developmental mathematics summer program which was student-centered and group activity-based. Her inclination toward a lecture-based format could also be attributed to her tendency toward shyness, her lack of history with collaborative learning environments in mathematics, or simply personal preference. Although Tessa and Maggie were both traditional freshmen, they responded very differently to opportunities to seek out and use available support.

Task Strategies

All three participants showed an increased use of task strategies as the interviews progressed, with Maggie and Tessa describing them more often than John. Maggie and Tessa had similar strategies for keeping track of assignments, such as using a planner or spreadsheet to write down weekly assignments and checking them off upon completion. John did not use any strategies to keep track of assignments aside from using the institution's web-based learning management system. John stated during Interview 3 that he bought a planner but then admitted that he was not using it. Tessa and Maggie also mentioned using self-regulated learning strategies to check their understanding, such as self-testing and self-checking. Discussions about using self-regulated learning strategies increased for all three participants during interviews when they were studying for quizzes and exams. When responding to the interview question about preparing for quizzes and exams, the following responses were given.

> *[The professor] gives us a review sheet and a practice quiz so I will look over the sheet. Then I take the practice quiz multiple times. I also look over the homework that we have done and I try to like redo those problems so I would be ready if they showed up on a quiz or exam. I also like explaining things to the tutors in the math lab. This helps me know if I'm saying something wrong, or if I'm misunderstanding something. I've never studied like that before so I like that they have me do that a lot in the math lab. I find that really helpful for studying. (Maggie, Interview 3)*

> *I have Microsoft Excel sheets where I write down the bad problems from the week that we did in class or were on the homework. So, I will re-do those until I understand it. (Tessa, Interview 3)*

> *For the last exam I just like did the practice quiz [the professor] gave us. But like I said, I didn't really see any results from that because the next day I wouldn't remember how I did the exam the first time. For this exam today, the practice quiz he gave us was only like two questions. So, I guess it was helpful to see like these are the types of problems that will be on the exam, but I would have liked more practice than that. For quizzes, I never really have a ton of time to study because there is always homework due. So, I am always just trying to finish the homework before the exam. (John, Interview 3)*

As previously discussed, Maggie used the tutor lab as an opportunity to talk through her understanding of concepts and to check the accuracy of her procedures. Tessa identified problems for which her understanding was lacking and compiled them into a spreadsheet. Both demonstrated metacognitive awareness of their learning progress in college algebra and used self-testing strategies when preparing for quizzes and exams. John seemed to be playing catch-up when quizzes and exams occurred. This lack of preparation could be related to concerns he expressed about the tutoring lab and his struggles with being in charge of his own learning in college algebra. Although he expressed wanting to change his approach to studying, he did not demonstrate any self-regulated learning strategies in his organization or preparation for exams.

Conclusion

This analysis examines how the backgrounds of students in a STEM discipline may affect their experiences in their first degree-credit-bearing mathematics course in college. For these participants, having previous or concurrent developmental mathematics experience may have influenced awareness of productive study habits and the importance of getting help. John's and Tessa's previous developmental mathematics experiences seemed to help guide their response to the first exam in college algebra and John's previous developmental mathematics experiences affected his intended methods for studying for college algebra. Notably, developmental mathematics experiences did not appear to affect any of the participants' organizational practices.

Participants' attitudes and beliefs seemed to influence their ability to engage in productive learning behaviors. Maggie's strong confidence in mathematics likely positively affected her perseverance and attitude as the semester progressed, whereas John's fragile confidence probably negatively impacted his willingness to use task strategies that he otherwise knew could be productive. Tessa's summer developmental mathematics experience seemed to positively influence her perseverance as she experienced challenges in college algebra. Although studies have shown that developmental mathematics courses can become a barrier for many students, for these STEM majors, developmental mathematics appeared to provide important experiences and resources that may have provided them with skills essential for being successful in future STEM classes.

Limitations

Inferences made from this study are limited to a small, unique population of students who attended the institution in this study, majored in a STEM field of study, and participated in a developmental mathematics course either prior to or concurrently with enrollment in a college algebra course. The three participants all had different instructors who taught with different curricular resources and therefore likely had considerably different experiences in their classroom interactions, opportunities for learning, and grades. This is likely to have affected their perceived experiences in college algebra and their responses during interviews.

By its nature, data generated from interviews is self-reported qualitative data. While self-reported data provides a clear picture of how the participant interprets their experience, there is a high likelihood of inaccuracy, as participants may filter their responses for self-enhancement, fear of judgment, or because of other insecurities. Participants may also have misremembered or misinterpreted a situation or provided the researcher with a description that is either an oversimplification or an extreme response. These possibilities would affect the analysis of in vivo coding since this method is dependent upon the participant's speech patterns.

Finally, the researcher-participant relationship for both Tessa and John could have influenced participant responses. Before Tessa's enrollment in college algebra in the Fall 2022 semester, Tessa had participated in a summer developmental mathematics program in which the researcher was a student mentor. Similarly, the researcher had been a tutor in the developmental mathematics program on campus and had worked with John on numerous occasions over the two consecutive semesters he spent in developmental mathematics before his enrollment in college algebra.

Future Research

All three participants expressed negative feelings about either the format of the course, the instruction style of their professor or both. All three instructors had varying teaching styles, classroom environments, homework and exam formats, and student interactions. Further research into the effects of instruction style and course format may inform how these differences may influence student attitudes and overall achievement for STEM majors in college algebra.

The participants also expressed negative feelings about the online homework platforms used by each instructor. Research on student perceptions and outcomes when using a mastery-based homework platform could be conducted for introductory mathematics courses at the postsecondary level.

A similar quantitative study of developmental mathematics students moving into college algebra who are majoring in a STEM discipline could be conducted, with a larger sample size and standardized instrument to measure student attitudes, habits, and organizational practices. This study could also be longitudinal and look at these students' progression through all their required mathematics courses.

Further research into students' language which reflects their understanding of learning could be conducted. An interesting finding from this study was participants' repeated use of language about their memory of mathematics to describe learning. A study looking into students' perceptions of what learning is and what memory is could produce meaningful insights to their approach to learning mathematics.

Finally, a longitudinal study could be conducted on this population of students that focuses on their development and use of self-regulated learning strategies. A combination of qualitative interview data and a quantitative instrument could be employed to construct a full picture of the progression of the use of these strategies, and their effects on student achievement.

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