MEASURING PRECALCULUS SELF-EFFICACY, GRIT, AND ACHIEVEMENT IN UNIVERSITY PRECALCULUS COURSES TAUGHT WITH AN ONLINE FLIPPED MODEL

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Dedication

For my family. Especially my loving wife Kate, without whom I would be lost.

Acknowledgements

As I write this, I feel a mixture of emotions. Certainly, I feel glad that the process has ended, and so I feel a sense of relief. Also, a sense of happiness, excitement, and joy. But it's a specific kind of happiness. It's a feeling that we're probably all familiar with—the feeling that something has successfully ended, and although you did not know how it would turn out, and you experienced some trying moments, perhaps moments of doubt, you ultimately overcame in the end. I suppose the emotion is triumph? It seems strange to refer to triumph as an emotion, but perhaps it shouldn't. It's one-part relief, one-part joy, and two-parts validation—that you reached inside yourself and, despite the failures and missteps, you were able to accomplish something extraordinary. To anyone who reads this, I hope you can reflect on a moment in your life where you felt this kind of triumph. I hope you can remember it, and realize how extraordinary you are. Triumph—to me it's the most beautiful emotion.

To my dissertation committee chair, Dr. Suzanne Brown, I greatly appreciate your unwavering patience and support. When I was in the 5th grade, my teacher graduated with a master's degree from UHCL, and you were her thesis advisor. In this personal way, it's incredibly special to me that I'm part of your rich legacy at the University of Houston-Clear Lake. I hope that I can make even 10% of the impact through my career that you've made in yours. To my methodologist Dr. Michelle Peters, you're one of the best researchers I've met and one of the hardest working people I've known. There's no question you invested substantial amounts of time in my success, and I greatly appreciate all the time you've given me. I plan to continue researching and any future contributions

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ABSTRACT

MEASURING PRECALCULUS SELF-EFFICACY, GRIT, AND ACHIEVEMENT IN UNIVERSITY PRECALCULUS COURSES TAUGHT WITH AN ONLINE FLIPPED MODEL

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The purpose of this study was to examine the relationship among precalculus self-efficacy, grit, and achievement in university Precalculus classes taught with an Online Flipped Model (OFM). The researcher developed the *Precalculus Self-Efficacy Survey* (PCSES) to measure precalculus self-efficacy. For the purposes of validating the PCSES, at the same medium-sized university in the gulf coast region of Texas, 141 students were purposefully selected from every section of Precalculus offered in the 2020-2021 academic year (three in fall 2020 and two in spring 2021). To examine relationships among precalculus self-efficacy, grit, and achievement in Precalculus classes taught with an OFM, 81 students were purposefully selected from every section of Precalculus offered in fall 2020. All sections were taught with the same format by the same instructor. At the beginning and end of the semester, students' precalculus self-efficacy was measured with the PCSES, and their grit was measured with the 12-item Grit Score (GS). A comprehensive final examination measured achievement at the end of the semester. Pretest and posttest PCSES and GS scores were analyzed using two-tailed paired *t*-tests to determine if there was a statistically significant mean difference by the end of the semester. Pearson correlations were used to determine the relationships between precalculus self-efficacy and achievement, as well as grit and achievement. Multiple regression techniques were used to determine if precalculus self-efficacy or grit could predict achievement; also, they were used to investigate if grit moderated the relationship between precalculus self-efficacy and achievement. Findings suggested that, although precalculus self-efficacy increased when an OFM was used, grit decreased. Furthermore, a positive relationship existed between self-efficacy and achievement, and a positive relationship existed between grit and achievement. Finally, precalculus self-efficacy was found to be a significant predictor of achievement, whereas grit was not. No statistically significant evidence was found to suggest grit moderated precalculus self-efficacy and achievement.

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CHAPTER I:

INTRODUCTION

For entering college students who major in Science, Technology, Engineering, and Mathematics (STEM), only 40-50% actually complete a STEM degree (Seymour et al., 2019). Research may offer a partial explanation. In a meta-analysis of 225 studies pertaining to undergraduate STEM courses, students in lecture-based classes were 1.5 times more likely to fail when compared to students taught with active learning models (S. Freeman et al., 2014). The Flipped Model (FM) is considered an active learning model that has been shown to produce substantially higher grade point averages (GPAs), passing rates, and retention rates in undergraduate STEM courses, especially for underrepresented students (C. Burke et al., 2020). Few studies have researched student achievement in an online flipped model (OFM), an online adaptation of the FM. However, Swart and Macleod (2020) researched the OFM in undergraduate business courses and found similar levels of student satisfaction between FM classes (offered face-to-face) and OFM classes. More research is needed to determine if the OFM influences student achievement, especially in STEM courses.

Regarding the aforementioned meta-analysis, the attrition S. Freeman et al. (2014) found pertained to all undergraduate STEM courses of various disciplines. However, in a nationally representative sample of students enrolled in Calculus 1, Ellis et al. (2016) found that even a single course could cause substantial attrition. Specifically, Ellis et al. (2016) found that over 30% of the Calculus 1 students self-reported switching their majors away from STEM because of Calculus 1, and that students' mathematical confidence decreased after taking Calculus 1. Therefore, Ellis et al. (2016) found that just one course alone, a first college-level mathematics course, could represent a substantial leak in the STEM pipeline. However, Precalculus is the first college mathematics course for many students (Sonnert & Sadler, 2014), which suggests the importance of addressing retention and achievement in Calculus 1 transfers to Precalculus. To improve student outcomes like achievement, a myriad of studies have researched a variety of affective constructs over the past 50 years (Sonnert et al., 2020). For example, a body of research has accumulated about self-efficacy during that time (Bandura, 1977; Peters, 2013). In addition, researchers have developed newer affective constructs like grit (Duckworth et al., 2007). Specifically, in terms of research regarding self-efficacy and grit, one recent study found that self-efficacy was a strong predictor of academic achievement in children aged 10 to 18; however, grit did not predict academic achievement (Dixson et al., 2016). It is possible that these findings transfer to college-level Precalculus, but similar studies conducted at the college-level are needed to be certain. In conclusion, the purpose of this correlational study was to investigate the relationships between self-efficacy, grit, and mathematics achievement in university Precalculus classes taught with an OFM. This chapter will consist of the study's research problem, the significance of the study, the research purpose and questions, and a list of key terms with definitions.

Research Problem

Over 60 years ago, when noting the attrition from high school, through college, and into the scientific workforce, R. J. Freeman described the problem metaphorically as "a large leak in our educational pipeline" (R. J. Freeman, 1960, p. 16). At that time, too few American students went to college because they either did not have the means or the desire (R. J. Freeman, 1960). Although a long time has passed since 1960, the narrative that the U.S. is falling behind has persisted in U.S. politics and educational policy (Teitelbaum, 2014). As a corollary, the leaking pipeline metaphor has evolved to become the leaking STEM pipeline metaphor, which is still prevalent in STEM education research (Skrentny & Lewis, 2022).

For years, researchers have criticized the STEM pipeline metaphor and suggested alternatives in response to the most important element of STEM attrition today—inequality. For example, Blickenstaff (2005) noted that men were entering the STEM workforce at disproportionately higher rates than their female counterparts, arguing the leaking STEM pipeline metaphor would be more accurately described as a STEM gender filter with a chilly climate. Cannady et al. (2014) argued that the STEM pipeline metaphor had become a harmful scholarly research framework for STEM education policy. Warning the metaphor may make inequality worse, Cannady et al. (2014) put it bluntly, "Simply front-loading women and underrepresented minorities into the 'pipe' at the beginning does not mean that they will end up in the 'cup' at the end" (p. 447). Currently, researchers still point out that inequities remain a systemic problem in the STEM workforce (Skrentny & Lewis, 2022).

Unfortunately, addressing gender inequality in STEM attrition is difficult because it is related to many affective constructs, like self-efficacy. For example, in a sample of 326 students enrolled in College Algebra across 10 states, Peters (2013) found that female students reported lower mathematical self-efficacy compared to male students, despite having similar achievement to their male counterparts. In another study, Ellis et al. (2016) found that, even after grouping a sample of 1,524 high performing students by gender and persistence (i.e., whether or not the student switched their major away from STEM at the end of the term), female students consistently reported lower mathematical confidence compared to males. Ellis et al. (2016) ultimately concluded Calculus 1 could be lowering students' mathematical confidence, a construct of the affective domain. Fortunately, research suggests that female students' physics self-concept (a construct similar to mathematics self-efficacy pertaining to the physics discipline) increased when collaborative, active learning (i.e., student-centered classroom climate) strategies were used in the classroom (Kelly, 2016). Though the present study will not focus directly on mathematical confidence or physics self-concept, it will examine other affective constructs, namely, self-efficacy and grit. Furthermore, these constructs will be studied in a classroom taught using an OFM, a form of active learning. Ultimately, more research about the relationships between affective constructs and classroom climate could provide more ideas about how to address the inequities in STEM attrition.

In addition to gender inequities, the STEM pipeline is leaking across all demographics (Ellis et al., 2016). Although Ellis et al. found that even a single mathematics course could cause students to change their majors away from STEM fields (2016), evidence has existed for decades that students' dissatisfaction with STEM courses causes them to leave the STEM pathway (Seymour, 2002). For example, Seymour (2002) suggested traditional lectures drove students to leave the STEM pipeline, and they recommended that instructors use active learning pedagogies to retain STEM students.

History may suggest Seymour (2002) was correct because, as more colleges and universities adopted the use of active learning models over the following decade, empirical evidence suggested the use of active learning positively influenced student achievement (i.e., higher average grades and fewer course failures) (S. Freeman et al., 2014). It is noteworthy that these findings focused on classes that were taught face-to-face.

Given that active learning models in face-to-face environments often involve group work and social aspects, and the aforementioned findings pertained to affective constructs, the question of whether these findings would transfer to an online environment is a nontrivial one. Even when an online class is taught synchronously, with a regularly scheduled time where all students are online together and can interact, online interactions are not the same as they are face-to-face. Though it is true that the use of webcams and video conferencing software (e.g., Zoom, Skype, etc.) provide the opportunity to bring students face-to-face, a recent study found that the majority of students preferred to keep their web cameras off (Gherheș et al., 2021). If social aspects of the face-to-face environment help to make active learning models successful, will active learning models continue to be successful in online learning environments? Further studies are needed to determine whether the effectiveness of active learning models taught in face-to-face classes transfer to classes taught online.

Online education has existed for decades, and its use was becoming more widespread even before the COVID-19 pandemic (National Center for Educational Statistics [NCES], 2018). In fact, NCES reports 43.1% of undergraduate students took at least one class online in 2015-2016 (NCES, 2018). Although educational studies must exist that have researched online education generally, online classes can be structured in a myriad of ways (e.g., synchronous, asynchronous, etc.). Therefore, for online educational research findings to be externally valid, the context of teaching modality should be considered. To illustrate the prior point with an example, it would be unreasonable to compare face-to-face lecturing with online problem-based learning and conclude face-to-face learning (as a whole) is ineffective. Given that the context of teaching modality is crucial, the narrow subset of education research pertaining to active learning models used in online classes should be considered. Few studies have researched an OFM (an active learning model) in online university Precalculus classes; this study will help address that research gap.

The problem appears to be multifaceted. Students are leaving STEM pathways and mathematics courses like Precalculus and Calculus 1 could be compounding the problem. University Precalculus courses are not studied as often as other entry-level courses such as Calculus 1. This is especially true as it pertains to online classes taught with active learning pedagogy. Therefore, more research about the online teaching of Precalculus with active learning is needed. Furthermore, although some research has been conducted with other populations (Dixson et al., 2016), the relationship between constructs such as self-efficacy and grit is unclear in Precalculus courses taught online with active learning models. More research can inform instructors, which could help retain more students, ultimately contributing to growing a strong STEM workforce for the future.

Significance of the Study

Previously in this chapter, the affective domain was discussed, of which self-efficacy is a construct. There are complications with this construct regarding precalculus education. First, self-efficacy is task-specific and is most effectively measured with items specifically tailored to the task being assessed (Bandura, 1986; Pajares & Miller, 1995; Zakariya et al., 2019); however, no precalculus self-efficacy instrument existed. Second, social constructs depend on elements of society that change over time. However, many contemporary studies continue to measure mathematics self-efficacy with the forty-year-old *Mathematics Self-Efficacy Survey* (MSES) (Betz & Hackett, 1983). With items that ask participants to rate their confidence level in balancing a checkbook, it is reasonable to question whether it remains valid. Beyond just instrumentation, some studies have considered the relationship between self-efficacy and grit (Alhadabi & Karpinski, 2020; Dixson et al., 2016). However, more research about these constructs is needed in undergraduate STEM courses. Finally, this study fills a gap in the literature by considering the use of active learning models in classes taught exclusively online. A few studies have researched the OFM in other disciplines (Stöhr et al., 2020; Swart & Macleod, 2020), but currently few have addressed undergraduate Precalculus courses.

Research Purpose and Questions

The purpose of this study was to investigate the relationships between self-efficacy, grit, and mathematics achievement in Precalculus classes taught using an OFM. The research questions are as follows:

1. Is the Precalculus Self-Efficacy Survey (PCSES) a valid and reliable instrument?
2. Is there a statistically significant mean difference in students' precalculus self-efficacy prior to and following the completion of a an online flipped Precalculus course?
3. Is there a statistically significant mean difference in students' grit prior to and following the completion of an online flipped Precalculus course?
4. Is there a relationship between precalculus self-efficacy and mathematics achievement?
5. Is there a relationship between grit and mathematics achievement?
6. Does precalculus self-efficacy and grit predict mathematics achievement?
7. Does grit moderate the relationship between precalculus self-efficacy and mathematics achievement?

Definitions of Key Terms

Active Learning: The process of engaging students in activities that force them to assess their understanding, so that they gain knowledge by participating and working problems. (Michael, 2006).

Blended Learning: A formal education program (i.e., a class) in which a student learns partially at a supervised brick-and-mortar location away from home, and partially online; the learner has some element of autonomy over time, path, and/or pace (Staker & Horn, 2012).

Flipped Model (FM): Originally named the Inverted Classroom Model (Lage et al., 2000; McDaniel & Caverly, 2010), this teaching model is referred to as flipped because the model advocates the traditional roles of lectures and homework be transposed. Students review learning materials (e.g., watch prerecorded lecture videos) before coming to class, where students then work on classwork (instead of homework), often in groups (Bergmann & Sams, 2008, 2012).

Grit: "Perseverance and passion for long-term goals" (Duckworth et al., 2007, p. 1087).

Mathematics Self-Efficacy: Someone's perception of their abilities to complete a mathematical task or to generally be able to successfully participate in mathematical activities in general (Peters, 2013).

Online Flipped Model (OFM): Similar to the FM, students review learning materials (i.e., prerecorded videos) on their own and attend regularly scheduled synchronous online meetings (Stöhr et al., 2020).

Precalculus Self-Efficacy: Someone's perception of their abilities to complete precalculus problems or tasks related to precalculus topics. For the purposes of this study, these topics include knowledge of functions in general, as well as knowledge of the following specific categories of functions: polynomial, logarithmic, exponential, and trigonometric functions. Precalculus self-efficacy is defined as a construct in this dissertation, based on Bandura's self-efficacy theory (Bandura, 1993), and operationalized consistent with the development of calculus self-efficacy (Zakariya et al., 2019).

Student-Centered: "This learning model places the student (learner) in the center of the learning process. The instructor provides students with opportunities to learn independently and from one another…includes such techniques as substituting active learning experiences for lectures" (Michael, 2006, p. 160). Researchers argue *student-centered* is synonymous with *active learning* (Michael, 2006).

Teacher-Centered: A traditional instructional model, considered an antonym of Student-Centered Instruction, often where students passively sit in class while the instructor gives lectures (Michael, 2006).

Conclusion

Unfortunately, many students are leaving the STEM field because of their negative experiences in entry-level mathematics courses. Most of what we know about how to retain students does not necessarily apply to online learning environments. By researching self-efficacy, grit, and achievement in Precalculus courses taught with an OFM, we may be able to find ways to seal the leaky pipeline, which could help ensure a strong STEM workforce in the future. Chapter two contains a review of literature comprising an overview, followed by research pertaining to the following constructs: active learning, the flipped model, affective constructs, self-efficacy, and grit, as well as studies that have investigated the relationships between these constructs.

CHAPTER II:

REVIEW OF LITERATURE

Of the students who start college with the intention to major in STEM, too few actually complete a STEM degree (Ellis et al., 2016; Seymour et al., 2019). Improving student achievement in post-secondary precalculus courses could help diminish STEM pathway attrition. In undergraduate STEM education, researchers have studied how active learning may help improve student achievement outcomes. Reviewing salient literature connects several constructs to active learning, including: the flipped model (FM), self-efficacy, grit, and achievement. This chapter begins with an overview that identifies three literature gaps this study partially addresses. Subsequent sections include a summary of research about active learning, the FM, affective constructs (i.e., self-efficacy and grit), and studies that examine the relationships between these constructs. The final three sections provide a summary of findings, the proposed study's theoretical framework, and a conclusion.

Overview

Over 20 years ago, Seymour and Hewitt (1997) argued that students were switching their majors away from STEM, in part, because of poor teaching. In their ethnographic study, Seymour and Hewitt (1997) found students were switching their majors because they disliked passive lecture-based courses. A contemporary follow-up study suggested this problem still persists (Seymour et al., 2019). Specifically, of the students in their sample, Seymour et al. (2019) found 99% that switched their major away from STEM reported their courses were taught with only lectures. Although lecturing is still the most dominant teaching model in higher education (Harris & Pampaka, 2016), a number of college and university STEM courses have adopted active learning pedagogies over the last 20 years (Rasmussen et al., 2019; Seymour et al., 2019). As a corollary, a plethora of research studies have examined the effectiveness of active learning pedagogy in college and university STEM courses (e.g., those cited in the meta-analysis S. Freeman et al., 2014).

Though many teaching models could be categorized as active learning (Michael, 2006), in the 1990s, researchers began studying one specific active learning model known as the Flipped Model (FM), originally named the inverted classroom (Lage et al., 2000). Since that time, many studies have researched the relationship between teaching model (i.e., FM or traditional lecture) and achievement; enough to conduct robust meta-analyses (Lo et al., 2017; Strelan et al., 2020). Focusing on introductory undergraduate mathematics courses like Calculus 1 and Precalculus specifically, several recent studies have examined the relationship between the FM and achievement (Collins, 2019; Mkhatshwa, 2021; Sahin et al., 2015; Spotts & Gutierrez de Blume, 2020; Ziegelmeier & Topaz, 2015). However, significantly fewer studies have researched the FM in courses taught completely online (A. S. Burke & Fedorek, 2017; Ferguson, 2020; Stöhr et al., 2020; Swart & Macleod, 2020). Given that few studies have considered the FM in an online format, it is unknown as to whether findings from research about the face-to-face FM will translate to online classes, indicating a gap in the literature.

A second literature gap was identified pertaining to the relationship between teaching model, affective constructs, and achievement. Although some research has examined the relationships between classroom climates (i.e., active learning versus traditional lectures), affective constructs (e.g., self-efficacy), and achievement (Peters, 2013; Sonnert et al., 2015), another literature gap exists because few studies have studied the relationship between teaching model (i.e., FM versus traditional lecture), affective constructs, and achievement. A final literature gap was identified pertaining to two constructs from the affective domain: self-efficacy (Bandura, 1977) and grit (Duckworth et al., 2007). In general, affective constructs have been studied in mathematics education for over 50 years (Sonnert et al., 2020), and both grit and self-efficacy have been found to predict mathematics achievement (Bowman et al., 2015; Pajares & Miller, 1995). Though some recent studies have considered the relationship between grit, self-efficacy, and achievement (Alhadabi & Karpinski, 2020; Dixson et al., 2016), few studies have considered the relationship between these constructs, given that the FM is used in online courses.

Ultimately, to at least partially address these literature gaps, this study focused on the relationships between self-efficacy, grit, and mathematics achievement in Precalculus classes taught using the Online Flipped Model (OFM). Given that this study involved the FM, a form of active learning, the next section provides a background about active learning in undergraduate STEM courses, reviews strong evidence regarding its effectiveness, and reports national findings about the extent with which active learning has been used in Precalculus courses.

Active Learning

The concept of active learning has existed for at least a century (Dewey, 1923). However, this dissertation focused on the most current manifestation of active learning in undergraduate STEM courses, the origins of which are exemplified by Seymour and Hewitt (1997). After establishing a historical basis, this section continues with a summary of S. Freeman et al. (2014), a meta-analysis of 225 studies that argues active learning positively influences achievement in undergraduate STEM courses. Shifting focus to the present, this section concludes with findings from Rasmussen et al. (2019), a national study that reports the extent to which active learning is utilized in Precalculus courses across the country.

In an ethnographic study, Seymour and Hewitt (1997) sought to understand STEM pipeline attrition. (Without the loss of generality, the author has replaced the historically used phrase Science, Mathematics, and Engineering and the initialism SME with the updated phrase Science, Technology, Engineering, and Mathematics, along with its acronym STEM.) Focusing on the population of entering freshmen intending to major in STEM fields, the researchers had four goals: (a) identify differences in students' experiences by type of institution; (b) identify attributes that fostered attrition; (c) compare experiences between students belonging to different ethnic, gender, and racial backgrounds; and (d) estimate which factors negatively influence attrition the most (Seymour & Hewitt, 1997). To begin to know where to look, the researchers requested data from the Cooperative Institutional Research Program survey, conducted by the Higher Education Research Institute at the University of California, Los Angeles

(Seymour & Hewitt, 1997). Analysis of these historical data provided a baseline by which to purposefully select 335 students across seven, four-year institutions, which varied in size and location (Seymour & Hewitt, 1997). From 1990 to 1993, the researchers conducted interviews and focus groups with 35 participants, all of which were semi-structured and audio-recorded; ultimately, over 600 hours of data resulted (Seymour & Hewitt, 1997). Separately, 125 students from six different campuses participated in focus groups; these data were held separate for a subsequent validity check (Seymour & Hewitt, 1997).

The researchers analyzed these data with an inductive coding process (Seymour & Hewitt, 1997). Ultimately, Seymour and Hewitt (1997) emphasized the four most common themes self-reported from students who switched their majors from STEM: (a) students lost interest in science; (b) students believed leaving the STEM pipeline would provide a better education; (c) faculty were poor teachers; and (d) the curriculum was overwhelming and too fast paced. "However, complaints about poor teaching were almost universal among switchers (90.2%), and were the most commonly-cited type of complaint among non-switchers (73.7%)," (Seymour & Hewitt, 1997, p. 34). When researchers asked the students to elaborate about poor faculty teaching, students often reported dissatisfaction with lecture-related elements (e.g., filling the board with equations and never turning around, etc.), and suggested they preferred more collaborative learning environments (Seymour & Hewitt, 1997).

Seymour and Hewitt (1997) did not explicitly discuss active learning; however, the phrase active learning may not have been a common phrase at the time. However, considering the definition of Active Learning presented in Chapter I, Seymour and Hewitt (1997) implied students preferred active learning pedagogies over passive lectures. Ultimately this implies that, for nearly 20 years, research has suggested undergraduate STEM students prefer active learning pedagogies over passive lecture. Although research clearly indicates students prefer active learning, does research show that active learning positively influences student achievement? Not only did S. Freeman et al. (2014) find that active learning yielded greater achievement compared to lecturing, the researchers questioned the ethics of continuing to use lecturing as a control in educational research.

S. Freeman et al. (2014) wanted to test the null hypothesis that, in terms of achievement, lecturing is more effective than active learning; therefore, the researchers created a meta-analysis of existing research. Given that a substantial sum of studies existed and, to provide a reasonable basis for comparison, S. Freeman et al. (2014): (a) predefined the disciplines (i.e., class rubrics) to be considered STEM classes in their meta-analysis; (b) considered only research that studied both active learning classes and traditional lecture classes; and (c) considered only research that either provided scores for the same assessment for all students in each type of class, or provided final grades for all students in each class. Defining those attributes was important to establish a general framework; however, the volume of studies required a finer filter. Therefore, S. Freeman et al. (2014) identified methodological criteria that each study needed to satisfy in order to be considered (e.g., uniform instructional time, no substantial changes in class format between sessions, comparable student populations, ability to calculate desired statistics, etc.). With the parameters for purposeful sampling defined, the next stage was to conduct a broad search for the studies.

After identifying a consistent method by which to search, using journals, databases, general information sources, and a priori keywords, S. Freeman et al. (2014) searched peer-reviewed journal articles, as well as published and unpublished studies from the so-called *grey literature* (i.e., dissertations, books, and conference proceedings) (see Rothstein & Hopewell, 2009). The search yielded 642 papers initially, from which 225 were purposefully sampled; 158 provided assessment scores, and 67 included final course grades (S. Freeman et al., 2014). After forming three groups by class size (i.e., small, medium, and large class sizes), S. Freeman et al. (2014) further divided the data into subsets: studies that used randomized trials, as well as those that used quasi-random designs. Then, S. Freeman et al. (2014) analyzed the data in the following ways or with the following techniques: pairwise comparisons, correction for sample dependence by using a cluster adjustment calculator, two-tailed hypothesis testing by calculating *z*-scores and *p*-values, performing homogeneity analysis, examining effect sizes, etc.

In terms of effect sizes, the findings suggested that, of the 158 studies in which all students in the study were given a uniform assessment, the exam scores for students taught with active learning were approximately 6% higher, compared to the students taught with lectures (S. Freeman et al., 2014). In addition, from the 67 studies that provided final grade information, students that were taught with lectures were 1.5 times more likely to fail (S. Freeman et al., 2014). Concerns that some studies were unpublished should be alleviated by a post hoc analysis, which showed the results were not due to publication bias (S. Freeman et al., 2014).

Considering these findings, it is reasonable to reject the null hypothesis S. Freeman et al. (2014) originally assumed. Making a powerful point by drawing a comparison, the researchers stated that, had findings of this clarity been found in randomized trials of a medical treatment, the study would have been ended early so that patients would no longer be randomly assigned to a control group and given a placebo (S. Freeman et al., 2014). Although the aforementioned findings were true overall, S. Freeman et al. (2014) reported the most substantial effects were in classes with fewer than 50 students. The researchers also stated that, though these results seem definitive, the teachers from these studies voluntarily chose to redesign their courses with active learning; therefore, universal results could not be guaranteed if this classroom climate were forced on all instructors (S. Freeman et al., 2014). These last two points could partially explain why some national studies, with larger class sizes, (which will be discussed in the section pertaining to self-efficacy) have reported conflicting results (Peters, 2013; Sonnert et al., 2015). However, it is relevant to conclude this section with information about another nationwide study. Specifically, Rasmussen et al. (2019) reported the extent to which Precalculus courses use active learning throughout the U.S.

Bressoud and Rasmussen (2015) reported findings from the Characteristics of Successful Programs in College Calculus (CSPCC) grant, an NSF-funded, national census study. Their findings suggested active learning was a common characteristic of successful calculus programs (Bressoud & Rasmussen, 2015). In a follow-up study, Rasmussen et al. (2019) wanted to know, of the previously identified characteristics of Calculus 1 programs (Bressoud & Rasmussen, 2015), what was the status with all classes from Precalculus to Calculus 2. Specifically, to what extent did mathematics faculty believe each characteristic was important, how would mathematics faculty self-report their department's success with implementing those characteristics, and what do those implementations look like (Rasmussen et al., 2019)?

The researchers collected contact information from the chairs of all mathematics programs in the U.S. that offered any graduate degree in mathematics (Rasmussen et al., 2019). After the contact information was compiled, Rasmussen et al. (2019) contacted each chair and requested they complete the survey. The survey included approximately 100 items related to the aforementioned research questions and the seven characteristics that were previously identified by Bressoud and Rasmussen (2015) (Rasmussen et al., 2019). Overall, 67.6% of the 330 institutions responded (75% of 178 institutions that grant doctoral degrees and 59% of 152 institutions that grant masters degrees) (Rasmussen et al., 2019).

Related to active learning, one item asked respondents to rank eight priorities as either "very important," "somewhat important," or "not important." Overall, 44% of departments indicated they felt active learning was "very important," 47% selected "somewhat important," and only 9% selected "not important," (Rasmussen et al., 2019). These responses were nearly inverted when asked to rank how well their departments implemented active learning strategies; options included "very successful" (15%), "somewhat successful" (61%), "not successful" (16%), and "not applicable" (9%)

(Rasmussen et al., 2019). In terms of specific courses, 22% of departments indicated their Precalculus courses used some active learning strategies (Rasmussen et al., 2019). For Calculus 1 and Calculus 2, the reported proportions were 20% and 14%, respectively (Rasmussen et al., 2019). The researchers pointed out that, although it is promising that departments believe active learning is important, departments are struggling to implement active learning strategies in Precalculus to Calculus 2 classes (Rasmussen et al., 2019). In addition, the researchers projected that the use of active learning will increase in Precalculus to Calculus 2 courses, which underscores the need for more professional development for college and university mathematics faculty. It is reasonable to question whether the COVID-19 pandemic has influenced these trends. The next section contains a summary of research pertaining to the Flipped Model (FM), a type of active learning.

The Flipped Model

This section will begin with a subsection describing the origins of the Flipped Model (FM), followed by a subsection that includes recent research that specifically addresses the relationship between the FM and achievement in Precalculus and calculus courses.

Origins of the Flipped Model (FM)

The purpose of this subsection is to discuss the origins of the contemporary FM. The term *contemporary* is an important quantifier since, just as one might argue active learning originated with John Dewey, the FM could be considered a rebranding of older pedagogical designs focused on independent learning (e.g., students read before class). Surprisingly, to suggest students watching videos before class is what makes a class model flipped might suggest the teaching model originates from the 1960s (Sabella, 1969). Ultimately, for the purposes of this proposal, the FM will be considered a teaching model where the internet is used as a media through which to share video (and potentially other resources) that students watch before class. Therefore, this subsection begins with a summary of seminal research about the FM (Lage et al., 2000), followed by a brief history of how barriers for its utilization diminished from 2000 to 2007. The subsection concludes with a brief etymology of the phrase *flipped model*.

Before being called the FM, Lage et al. (2000) introduced what was referred to as the inverted classroom model. The students learned course content outside of class, by reviewing previously developed course materials and resources (e.g., prerecorded lecture videos, audio-narrated PowerPoint presentations, etc.). Then, in the classroom, students actively worked in groups (e.g., assignments, discussions, experiments, etc.), instead of watching a face-to-face lecture. The purpose of their qualitative study was to introduce an exemplar where the inverted classroom model was used in a university introductory economics course, and to report instructor and student perceptions of the model. Lage et al. (2000) hypothesized the teaching model could be universally beneficial to students of any learning style.

In five microeconomics classes at the University of Miami, Lage et al. (2000) collected data in the fall 1996 term. At that time, approximately 16,000 undergraduates attended the university. Most students were traditional, Caucasian, from upper middle-class households, and generally lived on or close to campus. Approximately 35 sections of microeconomics were offered, with a median enrollment of 40 students per section;

enrollment for the five sections that used the inverted model was similar. Given that a Learning Management System (LMS) was not available before the start of term, the researchers created a website to distribute course materials, as well as lecture videos, voice-narrated PowerPoint presentations, and sets of review questions. Given that the teaching model indirectly required students to use the internet, ubiquity of campus computer labs and network-wired dorm rooms alleviated the researchers' concerns about access.

In addition to thoroughly describing the model, Lage et al. (2000) sought to understand how the students and instructors perceived it. The researchers asked students to complete a questionnaire containing a combination of Likert-scale questions and open-ended questions; then, the researchers distilled a summary of these findings and reported some descriptive statistics (e.g., average class GPA). The instructors, who were also the researchers, provided commentary about their opinions of the model's advantages and disadvantages. Ultimately, the researchers reported students generally liked the plethora of resources provided to them, that student engagement increased, particularly for female students, and that student attitudes increased.

The Lage et al. (2000) study was important because it defined what ultimately became rebranded as the FM. The researchers' goal of providing an initial exemplar was irrefutably achieved. Unfortunately, findings related to student and instructor perceptions were essentially anecdotal. After putting forth the effort to establish learning styles as a theoretical framework, justify how to measure its constructs with validated instruments, and state a hypothesis about which learning styles would match best with a given type of student resource, it seems a missed opportunity to not survey the students, identify their learning styles, and test the hypothesis. However, that there exists a substantial body of research about this teaching model 20 years later suggests the opportunity was not lost, only delayed.

Interestingly, in one of the first published exemplars of this teaching model, the FM provided students with a myriad of choices about how they would learn the material (Lage et al., 2000). Specifically, students were afforded the autonomy to choose their preferred media (i.e., online resources) by which to learn the content. The researchers presented this as one of the model's strengths: "By the second or third unit, most students indicated that they were using specific learning tools predominantly. Some watched the videos repeatedly, whereas others never used them" (Lage et al., 2000, p. 35). Today, watching assigned videos outside of class seems almost a necessary component for any course using the FM. When considered in the historical context of the year 2000, adding video to any teaching model faced barriers on two fronts: instructors lacked resources to create them, and students lacked high-speed internet access or computers to watch them.

In the early 2000s, as high-speed internet became more commonly available in urban and suburban areas, teachers interested in flipping their classrooms still faced another technological barrier—it was difficult to share videos. In January 2005, Chad Hurley and Steve Chen became so frustrated while trying to share videos of a dinner party, they decided to form YouTube (Sorkin & Edmonston, 2006). In fewer than 19 months, Google purchased YouTube for approximately $1.65 billion. After Apple launched iPhone in 2007 (Nocera, 2007), barriers to sharing videos had substantially diminished.

The origins of the name *flipped model* began in 2008; working independently from Lage et al. (2000), Bergmann and Sams (2008) reintroduced the FM concept in a practitioner article. Although this article is commonly cited as the seminal work introducing the FM, the authors did not explicitly refer to the model by name. Later, Bergmann and Sams (2012) wrote a book that may have been the first academic work explicitly referring to the model as *flipped*. Today, the FM has become the preferred phrase when referring to the teaching model. The next subsection includes a summary of recent research regarding the relationship between the FM and achievement.

The Flipped Model and Achievement

Since its inception in 2000, a plethora of studies have researched the FM and achievement; therefore, the following subsection will begin with findings distilled from two recent meta-analyses (Lo et al., 2017; Strelan et al., 2020). The succeeding subsection will focus on recent FM studies pertaining specifically to undergraduate precalculus and calculus courses (Collins, 2019; Mkhatshwa, 2021; Sahin et al., 2015; Spotts & Gutierrez de Blume, 2020; Ziegelmeier & Topaz, 2015).

Meta-Analyses

Focusing on teaching and learning with the FM in mathematics courses, Lo et al. (2017) performed a quantitative meta-analysis as part of a broader mixed-methods study. Though there were several research questions, most salient to this literature review was the question as to whether the use of the FM had a significant effect on student achievement (Lo et al., 2017). As a way to purposefully select articles for their meta-analysis in the most comprehensive way possible, the researchers utilized the Preferred Reporting of Items of Systematic Reviews and Meta-Analyses (PRISMA) protocol (Lo et al., 2017). Given that few studies researched the FM before 2012, Lo et al. (2017) restricted their scope to focus on research published within the prior five years. Then, using seven databases, the researchers initially identified 1,469 FM studies (Lo et al., 2017). Purposefully, the researchers selected 61 of the 1,469 articles to answer their qualitative research questions (Lo et al., 2017). Ultimately, only 21 of those 61 studies also fit the researchers' criteria for the quantitative meta-analysis. The majority of the 21 studies considered for the quantitative analysis pertained to U.S. undergraduate calculus classrooms; specifically: (a) 18 were based on classes taught in the U.S.; (b) 17 focused on undergraduate courses typically taught at the freshman or sophomore-level (e.g., finite math); (c) seven studies considered Calculus 1 or Calculus 2 classes (Lo et al., 2017).

The researchers reported the methods by which they reliably compared the studies; for example, when a study considered multiple assessments for achievement, the researchers considered the most summative assessment possible (i.e., a comprehensive final exam) (Lo et al., 2017). Additionally, using Cochran's Q test, Lo et al. (2017) analyzed the heterogeneity among instructors ($Q = 0.159$, $df = 1$, $p = .690$) and students ($Q = 2.316$, $df = 1$, $p = .128$), finding no evidence of heterogeneity among either group. Though all studies researched mathematics classrooms, another comparability concern was that the mathematics subjects varied (i.e., high school algebra to undergraduate differential equations) (Lo et al., 2017). Therefore, Lo et al. (2017) tested for heterogeneity and found no statistical evidence to suggest substantial differences ($Q = 4.951$, $df = 6$, $p = .550$). Though Lo et al. (2017) did not find significant evidence that the studies were heterogeneous, the studies they analyzed still differed in many ways (e.g., course level, student population, etc.). For this reason, Lo et al. (2017) computed effect sizes with random effects analysis, calculating Hedges' g with the means and standard deviations reported in the original studies; ultimately, the researchers found significant evidence that the FM positively influenced student achievement, regardless of mathematics content area (Hedges' $g = 0.298$, $p < .001$).

Strengths of the Lo et al. (2017) study include a comprehensive and systematic methodology, followed by a sophisticated and robust analysis. However, one general limitation is that 18 of the 21 studies included in the meta-analysis were conducted in the U.S.; the pool of studies considered for qualitative analysis ($n = 61$) is arguably more diverse than those considered for the quantitative meta-analysis ($n = 21$) (Lo et al., 2017). Regardless of whether this concentration of studies in Lo et al. (2017) is a threat to its external validity in general, it is a strength for this dissertation because both the study in Lo et al. (2017) and the study in this dissertation focus on similar populations of students (i.e., U.S. undergraduate Precalculus classes). As was stated previously, Lo et al. (2017) found that the FM had a slight positive effect on achievement in mathematics classrooms (Hedges' $g = 0.298$); ultimately, a subsequent more comprehensive meta-analysis found a similar result in mathematics classrooms (Hedges' $g = 0.35$), and an even greater positive effect across all disciplines (Hedges' $g = 0.50$) (Strelan et al., 2020). The succeeding paragraphs will summarize that study.

Strelan et al. (2020) cited a myriad of systematic literature reviews and prior meta-analyses; however, prior meta-analyses were discipline-specific indicating a literature gap. Seeking to know if the FM positively influences achievement across all education-levels and disciplines, how much, and the most effective attributes of a FM (e.g., pre-class quizzes), Strelan et al. (2020) carried out a comprehensive meta-analysis across a myriad of educational disciplines. Following the same PRISMA protocol used by Lo et al. (2017), Strelan et al. (2020) solicited an expert research librarian to comprehensively search through seven databases for research studies, published before January 2018. After purposefully distilling the initial search results, 198 studies consisting of 33,678 total students were considered for analysis (Strelan et al., 2020). The researchers used the Comprehensive Meta-Analysis (CMA) software application to calculate Hedges' *g* effect sizes, as well as the *Q*-statistic to ensure the data were not heterogeneous.

Ultimately, Strelan et al. (2020) found that, across all disciplines, the FM had a small moderate effect on achievement (Hedges' $g = 0.50$, $n = 198$). However, the effects varied considerably by discipline; for example, in IT computer courses the effect size was small (Hedges' $g = 0.30$, $n = 14$), in mathematics the effect size was slightly higher (Hedge's $g = 0.35$, $n = 46$), and in humanities, the effect size was substantial (Hedge's $g = 0.98$, $n = 34$) (Strelan et al., 2020). The results pertaining specifically to mathematics in Strelan et al. (2020) are consistent with Lo et al. (2017), strengthening the argument that the FM positively influences achievement in mathematics. It is important to note that these studies may have analyzed some of the same research; therefore, although they are independent findings, they may not be based on completely independent data. The next subsection will take a closer look at recent research studies involving the FM's use in undergraduate precalculus and calculus courses.

Precalculus and Calculus Courses

In a mixed-methods case study, consisting of 96 students enrolled in one section of Calculus 2 at a university in southeast Texas, Sahin et al. (2015) studied students' perceptions of the FM and compared achievement between traditional and FM lessons. Specifically, the researchers questioned (a) how students from a FM prepared for class, (b) how that preparation differed from students in traditional sections, and (c) what were students' perceptions about the FM (Sahin et al., 2015). The researchers used a four-pronged theoretical framework that categorized the FM as a form of blended learning, since the class sessions were taught face-to-face (Sahin et al., 2015). The researchers partitioned the course content into ten units, three of which were taught with the FM; these results were compared with the remaining seven sections taught with traditional lectures (Sahin et al., 2015). In terms of reported demographics, the majority of the 96 students were male (n = 79); in addition, nearly all the students were freshman (n = 60) or sophomores (n = 34).

The researchers developed two short surveys to address their research questions pertaining to students' perceptions (Sahin et al., 2015). The researchers distributed the first survey at the beginning of each flipped lesson to understand how students prepared for class (i.e., watched videos, read the textbook, or did nothing) (Sahin et al., 2015). The researchers administered the second survey at the end of the semester to understand students' overall perceptions of the FM (Sahin et al., 2015). Finally, the researchers used quiz averages to measure student achievement. Overall, Sahin et al. (2015) found that 47% of students watched the assigned video or other videos, 31% of students read their textbook or other texts, and 22% of students did not prepare for class. The researchers used a dependent *t*-test and found a significant positive mean difference ($p = .001$) in students' quiz grades when comparing the lessons taught with the FM ($M = 8.32$; $SD = 1.36$) versus those taught with traditional lectures ($M = 7.54$; $SD = 1.69$) (Sahin et al., 2015). Finally, 83% of students felt the flipped lessons afforded better preparation compared to traditional lecture (Sahin et al., 2015). Sahin et al. (2015) is relevant in this review of literature because this study focused on a similar course (i.e., Precalculus) and a similar population of students (i.e., undergraduates at a university in the southeast Texas). Unfortunately, Sahin et al. (2015) is not a completely appropriate comparison to the proposed study in terms of class size (96 students versus approximately 40). The next paragraphs will consider research by Ziegelmeier and Topaz (2015), where the calculus classes being studied were located at a small college with approximately 25 students enrolled in each course.

In a triangulation mixed methods design, Ziegelmeier and Topaz (2015) researched calculus classes at a Midwestern liberal arts college, with a total enrollment of approximately 2000 undergraduate students. The researchers wanted to know how students perceived the FM, and whether the FM influenced achievement when compared to the traditional model (Ziegelmeier & Topaz, 2015). Approximately 200 students enrolled in eight sections of Applied Multivariable Calculus 1 over the fall and spring semesters of the 2013-2014 academic year (Ziegelmeier & Topaz, 2015). Two sections were considered in the study; one of the sections was taught with the FM and the other was taught with the traditional lecture method. Both sections had the same instructor and were offered back-to-back, three times per week, for 60 minutes at a time (Ziegelmeier & Topaz, 2015). The students were unaware of any teaching model differences before the semester so enrollment could not be biased based on perceived preference; it is noteworthy that no students requested to be switched to another section (Ziegelmeier & Topaz, 2015). The researchers made every effort to control any other variables by making sure the courses were as similar as possible (e.g., grading scales).

Ziegelmeier and Topaz (2015) used several tools to assess student achievement, including: the Calculus Concept Inventory (CCI) administered before instruction began at the start of term, checkpoint quizzes, unit quizzes, and the final exam (which contained some embedded CCI items). The researchers reported median and mean statistics for all forms of assessment; since all statistics were similar, *p*-values indicated no significant difference (Ziegelmeier & Topaz, 2015). Interesting differences were noted in terms of student perceptions and learning strategies; for example, almost all the students felt there were aspects of the other course they would have preferred (e.g., FM students self-reported preference for more lecture time) (Ziegelmeier & Topaz, 2015). An example of differences in learning strategies is that students from the traditional lecture utilized office hours more than students from the flipped section (Ziegelmeier & Topaz, 2015).

It is noteworthy that Ziegelmeier and Topaz (2015) reported no significant difference in student achievement. The following few sentences discuss possible explanations. As was previously mentioned, the researchers stated that approximately 200 students enrolled in eight sections over the academic year (Ziegelmeier & Topaz, 2015). This averages to 25 students per class, which is approximately equivalent to the enrollment in both sections considered in this study. Given that Selinski and Milbourne (2015) reported that, across the entire country, the average calculus class ranged from 25 to 40 students, the class size in Ziegelmeier and Topaz (2015) may have been relatively small.

Another important finding from Ziegelmeier and Topaz (2015) that aligned with prior research pertained to resources. As was previously mentioned in Lage et al. (2000), one of the first academic studies about the inverted classroom model (i.e., FM), when students are provided many resources with which to learn, those students may have different preferences as to the best resources to facilitate their learning. Those conclusions from Lage et al. (2000) are aligned with findings from Ziegelmeier and Topaz (2015):

> The flipped model is much more than simply moving lectures out of the class and homework into the class. The variety of activities that can be incorporated into the flipped classroom can appeal to many types of student learners and add dimension to any course. (p. 10)

Finally, although the quantitative component of Ziegelmeier and Topaz (2015) did not find significance, students did report a positive opinion about the FM. In addition, the researchers reported that the instructor felt more relaxed in terms of the class pacing; furthermore, Ziegelmeier and Topaz (2015) posited the FM offers more opportunities to use effective teaching strategies. In contrast to the last two studies discussed in this review, the remainder of this subsection will focus on more current research that explicitly studied Precalculus courses.

In a more modern quantitative study, Collins (2019) researched whether use of the FM, along with interleaved practice, influenced student achievement in an undergraduate Precalculus course. Originally a construct from educational psychology, *interleaved practice* refers to students working problems that involve many different learning objectives—questions pertaining to a most recent lesson *interleaved* with questions from prior topics (Scmidt & Bjork, 1992). No student demographics were reported; however, Collins (2019) stated the students were enrolled in an undergraduate 5-hour Precalculus course at a 4-year regional university. In addition, we know that for students to enroll into the Precalculus course, one of two strict criteria needed to be met; specifically, a student must have either passed a preceding algebra course with at least a B- or a student must have earned a successful score on a placement test (Collins, 2019).

Collins (2019) utilized a quasi-experimental design by collecting data twice; once in fall 2016 and once in spring 2017. Each time data were collected, Collins (2019) formed a treatment (i.e., experimental) group with as many participants as possible from classes taught using the FM. In addition, each time data were collected, Collins (2019) purposefully formed a comparison (i.e., control) group by randomly selecting an equitable number of participants from every other Precalculus course at the same institution in the same semester. For the fall 2016, the treatment group consisted of participants from two sections of Precalculus, with a total of 54 student participants. The fall 2016 comparison group consisted of a purposeful sample of 59 students across all seven of the other sections of Precalculus that were taught that term. For the spring 2017, the treatment group consisted of one section of Precalculus in the spring 2017 with a total of 24 student participants (Collins, 2019). The spring 2017 comparison group consisted of a purposeful sample of 36 students across all three other sections of Precalculus that were taught that term (Collins, 2019). The researcher taught all the treatment groups; however, there were a variety of instructors that taught the other sections of Precalculus (Collins, 2019).

To assess student achievement, Collins (2019) purposefully selected a subset of questions from the course final exam, referred to as *Sample Final Scores (SFS)*. Collins (2019) used independent sample *t*-tests to determine if there were statistically significant mean differences on the SFS between each pair of treatment and comparison groups. Collins (2019) found a statistically significant mean difference between the treatment and comparison groups in both the fall 2016 semester ($p < .001$) and the spring 2017 semester ($p < .01$). To address another research question in the study, Collins (2019) recorded the students' final grades through subsequent courses in the calculus sequence to determine if there were any differences in passing rates (i.e., a final grade of C- or better) after students had matriculated through the FM Precalculus course. No statistically significant differences were reported in passing rates of the students' subsequent courses (Collins, 2019).

The primary purpose of the study was to determine if use of the FM, as well as interleaved practice, influenced achievement in Precalculus. Ultimately, Collins (2019) found that the FM influenced achievement; however, Collins (2019) admits the difference in instructors was an obvious limitation. In fact, educational researchers agree selection bias is a common threat to internal validity in quasi-experimental designs (Gopalan et al., 2020). Although the methodology Collins (2019) followed took efforts to improve internal validity, it was clear that the instructor limitation was substantial, especially when it was explained that the FM instructor had far more experience when compared to the other instructors. The next few paragraphs will summarize Spotts and Gutierrez de Blume (2020), a quantitative study of high school Precalculus students. Although its design has fewer internal validity concerns, it is extremely limited in scope and focuses on a narrow set of learning objectives (Spotts & Gutierrez de Blume, 2020).

In an effort to provide more empirical evidence about the FM in American high school classrooms, Spotts and Gutierrez de Blume (2020) examined the relationship between use of the FM and student achievement creating a quantitative study of suburban high school students in Georgia. Rather than studying student achievement broadly (i.e., over an entire school year), Spotts and Gutierrez de Blume (2020) focused more narrowly on a few learning objectives regarding matrices and vectors. This study followed a quasi-experimental pretest-posttest design; ultimately, two pre-existing Precalculus classes were selected for this study, which formed the basis of experimental and control groups (Spotts & Gutierrez de Blume, 2020).

The first class served as the basis for the experimental group (n = 28), and the second class served as the basis for the control group (n = 32). Of the original number of students in each class, Spotts and Gutierrez de Blume (2020) used student demographic information to purposefully select 22 students from each to form the official experimental and control groups. Spotts and Gutierrez de Blume (2020) reported demographic backgrounds for both groups, which indicated both sections had similar characteristics. To measure student achievement, the researcher created an assessment; to address validity, the researcher based the assessment on the framework from the Georgia Department of Education (Spotts & Gutierrez de Blume, 2020). Spotts and Gutierrez de Blume (2020) found the instrument to be internally consistent by using KR-20 (matrix operation pretest = .71, matrix operation posttest = .74, vector operations pretest = .69, vector operation posttest = .72).

The researchers rigorously analyzed the data by first screening for outliers and checking for normality from skewness and kurtosis values (Spotts & Gutierrez de Blume, 2020). After a myriad of other pre-analysis considerations, Spotts and Gutierrez de Blume (2020) performed a 2 x 2 multivariate analysis of variance (MANOVA), controlling for familywise Type I error with the Bonferroni adjustment. Ultimately, Spotts and Gutierrez de Blume (2020) found mixed results. Specifically, students in the FM class performed significantly better than students from the traditional classroom for the matrix operation learning objective, but not for vector learning objective (Spotts & Gutierrez de Blume, 2020). Having achieved a partially expected result, the researchers discussed potential reasons why significance was not found for both learning objectives. For example, Spotts and Gutierrez de Blume (2020) posited students may have had previous knowledge about some of the material; alternatively, that one learning objective may have been more procedural or conceptual than another. The next several paragraphs will summarize Mkhatshwa (2021), the final study considered in this section, which used mixed-methods to research university Precalculus classes taught with the FM.

Today, videos are so commonly used with the FM, educators may perceive the FM as necessitating the inclusion of pre-recorded video for students to review outside of class. Recall however that Lage et al. (2000), one of the first academic studies about the FM, originally provided students with a myriad of resources through which to learn—including videos. In a mixed-methods study that sought to examine student achievement, student perceptions, and classroom features of the FM, Mkhatshwa (2021) assigned students required reading to complete outside of class. In class, students worked in groups on homework problems (Mkhatshwa, 2021). Mkhatshwa (2021) researched classes taught at a regional campus of a large public research university, where enrollment was mixed between traditional and non-traditional students. Ultimately, 134 mostly freshman participants were enrolled in five courses from fall 2016 to spring 2019 (Mkhatshwa, 2021). All five courses were taught by the same instructor, four of which served as control group sections ($n = 105$), while one served as an experimental section ($n = 29$) (Mkhatshwa, 2021). Students were placed into Precalculus by earning an 80% on a placement exam, passing a preceding intermediate algebra course with a C, or by earning high enough scores on standardized entrance exams (e.g., Scholastic Aptitude Test) (Mkhatshwa, 2021).

Achievement was measured by three exams as well as the final exam (Mkhatshwa, 2021). Means were analyzed with a one-way analysis of variance (ANOVA) across all the sections and, if significance was found, further analysis with

Tukey's Honestly Significant Difference (HSD) test was performed (Mkhatshwa, 2021). To identify students' perceptions, Qualtrics surveys were administered to students at the beginning and end of the course (Mkhatshwa, 2021). In analyzing the data with multiple one-way ANOVAs followed by post hoc analysis, Mkhatshwa (2021) found no statistically significant differences in scores for Exam 1, Exam 2, or Exam 3 between the experimental group and any of the control groups. However, Mkhatshwa (2021) found that the final exam mean score for the experimental group was significantly higher for the spring 2017 control group ($p < .001$) and the spring 2018 control group ($p < .001$); no significance was found between the experimental group and the fall 2016 or fall 2017 control groups. Additional findings suggested the students' perceptions of textbook reading increased during the semester; furthermore, students' anxiety about taking a class with the FM decreased. Although Mkhatshwa (2021) controlled for the instructor by being the same teacher for all the courses, it would be difficult to measure the instructors' proficiency with both teaching models.

It was previously stated that, by using meta-analyses, Lo et al. (2017) and Strelan et al. (2020) both found strong evidence that classrooms utilizing the FM produces better outcomes for student achievement compared to the traditional lecture model. However, the results from studies in precalculus and calculus courses discussed here have been mixed (Collins, 2019; Mkhatshwa, 2021; Sahin et al., 2015; Spotts & Gutierrez de Blume, 2020; Ziegelmeier & Topaz, 2015). Many of the aforementioned studies included threats to internal and external validity among their limitations. Therefore, a need exists for more large-scale studies that utilize robust statistical analyses that could control for differences between institutions and instructors (e.g., Hierarchical Linear Modeling). In summary, there is strong evidence to support the claim that the FM positively influences student achievement; however, there are still questions as to why some studies do not yield similar results.

Online Classes and the Flipped Model (FM)

As has been described previously, the FM flips what students traditionally do *inside the classroom* and what students traditionally do *outside the classroom*. This begs the question—what happens if there is no physical classroom? The definition of the FM in this dissertation (Bergmann & Sams, 2008, 2012) does not explicitly exclude the use of virtual classrooms in an online environment. Furthermore, the FM satisfies the definition of *active learning* (Michael, 2006) regardless of whether the classroom exists physically or virtually. Given that few studies have researched an Online Flipped Model (OFM) specifically, this section begins by summarizing a comparative study of criminal justice students' engagement across three modalities: traditional face-to-face, traditional online, and FM classes (A. S. Burke & Fedorek, 2017). Then, the subsection will summarize a study that compared Precalculus and Calculus 1 students' attrition in face-to-face and online classes (Ferguson, 2020). Finally, the subsection will conclude by summarizing two of the earliest studies of an OFM, the first of those studies measured differences in student achievement (Stöhr et al., 2020) and the other compared student satisfaction (Swart & Macleod, 2020).

A. S. Burke and Fedorek (2017) examined the relationship between student engagement and course modality in upper-level undergraduate criminal justice classrooms. A total of 92 students spread over three classes (traditional face-to-face, traditional online, and FM) took the same crime control course, taught by the same instructor, in the same academic year (A. S. Burke & Fedorek, 2017). The researchers measured students' self-reported student engagement with questions the researchers adapted from the 2013 National Survey of Student Engagement (A. S. Burke & Fedorek, 2017). While controlling as many variables as possible, such as learning objectives, assessment, and coursework, the researchers allowed differences in the courses that were directly related to the differences in course modalities (e.g., the FM class had access to lecture recordings whereas the face-to-face classes received the lecture once) (A. S. Burke & Fedorek, 2017). Instead of analyzing these survey data with formal statistical analysis, A. S. Burke and Fedorek (2017) compared percentages from the results and discussed how those findings compared to prior research.

A. S. Burke and Fedorek (2017) hypothesized students would be more engaged in the class that used the FM as prior research suggested (see Bradford, 2005; Machemer & Crawford, 2007); however, the researchers' findings yielded negative outcomes compared to the traditional face-to-face and traditional online sections. In addition to serving as a negative case that illustrates the need for further research, A. S. Burke and Fedorek's (2017) research is salient because the researchers individually compared teaching modalities, online learning and the FM, that the study in this dissertation combined. Though it is difficult to tell explicitly, one may question what A. S. Burke and Fedorek (2017) meant when they referred to the online class as a *traditional online* course. Though not stated explicitly in the description of A. S. Burke and Fedorek (2017), the researchers' description of the course seems to describe an online course taught asynchronously. If true, the research study in this dissertation may yield different results since the OFM utilized in this study was taught with a synchronous modality. The next few paragraphs will describe the study by Ferguson (2020), which compared attrition in online and face-to-face Precalculus and Calculus 1 courses.

In an effort to refine previous research by Smith and Ferguson (2005) and to provide updated findings, Ferguson (2020) studied attrition in Precalculus and Calculus 1. Consider the following findings from Smith and Ferguson (2005): First, there was a statistically significant mean difference in dropout rates for students enrolled in online mathematics courses compared to online courses in all other disciplines. Second, Smith and Ferguson (2005) found there were no statistically significant mean differences in dropout rates for face-to-face courses. Aside from wanting to know whether similar findings were valid 15 years later, the Ferguson (2020) follow-up study sought to address confounding variables that limited the findings from Smith and Ferguson (2005). Given that all mathematics classes were pooled together in Smith and Ferguson (2005), differences between the courses (e.g., learning objectives, instructors, and difficulty levels) were impossible to parse. Therefore, Ferguson (2020) targeted only Precalculus and Calculus 1 courses taught face-to-face and online, and the researchers controlled as many variables as possible. Using a consistent definition of attrition, the researchers formed a purposeful sample of 195 students enrolled at a community college in Southern Virginia in the fall 2015 semester (Ferguson, 2020). Ultimately using two-sample *t*-tests, Ferguson (2020) found there was a statistically significant mean difference in attrition for

Precalculus taught online versus face-to-face; however, there was no statistically significant mean difference for the same comparison in Calculus 1. It is noteworthy that Ferguson (2020) suggested online mathematics classes may have special barriers in online classes taught asynchronously; for example, there may be substantial technological barriers for students to seek help with learning notation. This is a concurrent finding with A. S. Burke and Fedorek (2017) if we assume the online instruction in A. S. Burke and Fedorek (2017) was asynchronous. Although these technological difficulties exist for both Precalculus and Calculus 1 students, Ferguson (2020) explained that one substantial difference between the groups was that Calculus 1 was rarely an entry-level mathematics class at the community college where the study was conducted. Precalculus was often students' first college mathematics class at their institution (Ferguson, 2020).

Ferguson (2020) is relevant to the study in this dissertation because both studies consider Precalculus. When considering Ferguson (2020) and the aforementioned research of S. Freeman et al. (2014) in juxtaposition, it is natural to question why the outcomes were different. Specifically, Ferguson (2020) suggests Precalculus students' attrition may be higher for online classes. However, S. Freeman et al. (2014) suggests student outcomes (i.e., achievement) are more likely in courses that utilize active learning. Fortunately, the last two research articles summarized in this section may help explain why the findings from Ferguson (2020) and S. Freeman et al. (2014) were different because, although they do not study Precalculus specifically, they are two of the few studies that consider an OFM. The next few paragraphs will describe the first of those studies, Stöhr et al. (2020), which examined the efficacy of an OFM in terms of student achievement (Stöhr et al., 2020).

Utilizing Transactional Distance Theory (TDT) as a theoretical framework for their quantitative study, Stöhr et al. (2020) sought to measure how student achievement was influenced by: (a) the OFM in general; (b) student participation in certain synchronous and asynchronous activities; and (c) the questions students asked through the course. Stöhr et al. (2020) followed a longitudinal, quasi-experimental study design, and collected data from six iterations of a graduate nuclear modeling course in Sweden. As the course transitioned modality from face-to-face in 2009, to an OFM by 2016, the researchers collected data, including home assignments (achievement), attendance in course activities (student participation), and volume and type of questions students asked (student questions), from 52 students (Stöhr et al., 2020).

To measure student achievement, the researchers analyzed the scores of students' homework, where the maximum of each assignment was 20 (Stöhr et al., 2020). Stöhr et al. (2020) formed a purposeful sample by restricting analysis to only students who had completed all the assignments. After sorting the assignments into groups (face-to-face versus OFM) and calculating sample statistics, the researchers analyzed these data with Levene's test for equality of variances (Stöhr et al., 2020). Ultimately, based on the outcome of the equality of variances test, the researchers performed independent *t*-tests with unequal variance (Stöhr et al., 2020). Regarding student participation, Stöhr et al. (2020) calculated attendance percentages which they analyzed with a cross-correlation analysis. Finally, the researchers extracted students' questions from different media (e.g., online forums) and categorized as homework-related, administrative (i.e., related to logistics of the course), and course content questions (i.e., related to lectures in webcasts) (Stöhr et al., 2020).

Although the researchers found no statistically significant mean difference in student achievement overall, the researchers found increased "polarization" (i.e., like a bimodal spread) in student achievement from the OFM class (Stöhr et al., 2020, p. 9). In the discussion of findings, Stöhr et al. (2020) explained possible justifications of the findings through the lens of TDT, the aforementioned theoretical framework. As an implication for future research, Stöhr et al. (2020) suggested OFMs be studied qualitatively to determine why it works for some students, and which practices would be best to serve all learners. Stöhr et al.'s (2020) description of polarization between students' performance is reminiscent of the face-to-face FM (A. S. Burke & Fedorek, 2017). The final article in this section is a summary of research by Swart and Macleod (2020), which also utilized TDT to examine the relationship between an OFM and student satisfaction business classes.

In a quantitative study, Swart and Macleod (2020) questioned whether there was a statistically significant mean difference in student satisfaction in a face-to-face Business Analytics class taught with the FM compared to students taught with an OFM. If Swart and Macleod (2020) had researched student achievement, the internal validity would have been threatened if all the courses did not use the same learning objectives and populations of students. However, since Swart and Macleod (2020) studied student satisfaction, which is relatively less dependent on course learning objectives, it is reasonable to assume the researchers would not lose generality by pooling the results of both graduate and undergraduate Business Analytics courses. Although the learning objectives may vary in rigor since the course was offered at different levels, the course content was arguably similar enough for the Student Satisfaction construct (Swart & Macleod, 2020). The researchers afforded due diligence to control for differences in the Business Analytics classes by purposefully assigning two instructors to teach the courses; one instructor taught the undergraduate class and the second instructor taught the graduate class (Swart & Macleod, 2020).

Regarding the setting, the classes were all composed of students at a university in Greenville, North Carolina, where 4,200 undergraduates and 806 graduate students were enrolled in the College of Business (800 undergraduates attended entirely online, as did 710 graduate students) (Swart & Macleod, 2020). In terms of the sample of student participants, a total of 726 students participated (529 online students and 197 face-to-face students) (Swart & Macleod, 2020). Guided by TDT as a theoretical framework, the researchers created a Likert-scale questionnaire, which included elements from Zhang's Scale of Transactional Distance (Swart & Macleod, 2020). The reader should note that validation of Zhang's Scale of Transactional Distance can be found in Zhang's (2003) doctoral dissertation. For the last item on the questionnaire, the researchers asked students if they would recommend the course to a friend, simply indicating "yes" or "no," (Swart & Macleod, 2020).

To answer their first question, Swart and Macleod (2020) used independent *t*-tests and found no statistically significant difference in student satisfaction, assuming both equal and unequal variances. This finding was supported when Swart and Macleod (2020) also calculated an insufficient effect size for Cohen's *d*; therefore, there was no difference in student satisfaction whether the FM was adapted online or taught in the standard face-to-face way. Given that their second question was measured with a single item on the questionnaire, Swart and Macleod (2020) used SPSS to produce a binary logistic regression table which suggested students were equally likely to recommend the course to a friend, regardless of whether the FM was offered online or face-to-face. This was supported by a separate Chi-Square test, which suggested a negligible effect $(\phi = .019 < .1)$.

Overall, the findings from Swart and Macleod (2020) suggest increased student satisfaction in FM classes translates to an online adaptation. Although it is too early to tell whether these findings will generalize to the population of undergraduate students enrolled in entry-level mathematics courses, taken together, the results of Stöhr et al. (2020) and Swart and Macleod (2020) are anecdotally encouraging. It is noteworthy that both Stöhr et al. (2020) and Swart and Macleod (2020) considered an OFM through the lens of TDT. Therefore, it is natural to question if an OFM will relate to other affective constructs in a similar way to other active learning modalities, like the face-to-face FM. The next section will provide some background about affective constructs in general, followed specifically by *self-efficacy* and *grit*.

Affective Constructs

Along with prior mathematics preparation, how one feels about their mathematical abilities influences future mathematics learning (Sonnert et al., 2020). In fact, Sonnert et al. (2020) provided evidence that mathematical confidence, mathematics attitudes, and a myriad of other affective constructs have been studied extensively in educational research for over 50 years. For the purposes of this dissertation, the self-efficacy (Bandura, 1977) and grit (Duckworth et al., 2007) affective constructs were considered. The following subsection focuses on self-efficacy, beginning with the origins of self-efficacy (Bandura, 1977), as well as mathematics self-efficacy and the validated instruments that measure it (Betz & Hackett, 1983; Pajares & Miller, 1995). The subsection continues with a summary of a study that examined the relationships between self-efficacy, classroom climate, and achievement (Peters, 2013), and concludes with a summary of a study that researched the relationship between self-efficacy, the FM, and achievement (Cho et al., 2021).

Self-Efficacy

In a seminal work, Bandura (1977) defined the concept of self-efficacy as the belief in your own ability to perform a specific task. Eventually developing the concept into a theoretical framework, Bandura (1977) "hypothesized that expectations of personal efficacy determine whether coping behavior will be initiated, how much effort will be expended, and how long it will be sustained in the face of obstacles and aversive experiences," (p. 191). Expanding on Bandura's ideas, Betz and Hackett (1983) operationalized mathematics self-efficacy as a construct by creating the Mathematics Self-Efficacy Scale (MSES). The MSES consists of three subscales and, although it was shown to be reliable, Pajares and Miller (1995) improved the problem subscale from the MSES and formed what they dubbed the Mathematics Self-Efficacy Survey–Revised

(MSES-R). The availability of these reliable instruments enabled additional mathematics self-efficacy studies like Peters (2013), which will be summarized over the next few paragraphs.

Although researchers found evidence in post-secondary classrooms that mathematics self-efficacy and mathematics achievement are directly correlated (Hackett, 1985; Pajares & Miller, 1994), Peters (2013) questioned whether classroom climate, would influence mathematics achievement by mediating through mathematics self-efficacy. With classroom climate operationalized as either teacher-centered (i.e., lecture-based, passive learning) or student-centered (i.e., active learning), Peters (2013) formed a purposeful sample of 15 faculty from 4-year public universities across 10 states, as well as their 326 college algebra students. The faculty involved in the study varied in rank (four professors, five lecturers, and six graduate students), in age (22 to 60 years; M = 38.3 years, SD = 13.1 years), in teaching experience (1 to 31 years; M = 9.1, SD = 8.1), and gender and ethnic demographics (10 women and 10 Caucasian) (Peters, 2013). The students varied in terms of age (ranged from 16 to 65; M = 23.4, SD = 8.3), gender (190 female and 135 male), ethnic background (194 Caucasian, 57 African-American, and 33 Hispanic) (Peters, 2013). At the beginning of the term, the instructors completed a survey known as the Principles of Adult Learning Scale (PALS), which uses a Likert-scale to measure the extent to which an instructor follows teacher-centered or student-centered pedagogy (Peters, 2013). At the end of the term, the students completed the aforementioned MSES-R, and their final examination scores were collected (Peters, 2013). The analysis with Hierarchical Linear Modeling (HLM) provided more evidence of the link between mathematics self-efficacy and mathematics achievement; however, classroom climate was not found to predict achievement and there was no significant evidence that classroom climate mediated achievement through self-efficacy.

Given that Seymour and Hewitt (1997) suggested dissatisfaction with teacher-centered lectures is causing undergraduate students to leave the STEM pipeline and active learning was gaining popularity in college and university-level STEM education (Mazur, 2009), Peters (2013) addressed an important literature gap. Upon initial reading, the Peters (2013) finding that classroom climate did not predict achievement is surprising, given that many studies had previously found a link between those constructs; furthermore, that the 225-study meta-analysis by S. Freeman et al. (2014) reported significant correlation between classroom climate and achievement only a year later. Upon broader inspection however, using similar, albeit technically different constructs, Sonnert et al. (2015) used HLM to analyze a nationally-representative sample of over 3000 students at more than 120 colleges and universities, and found that so-called *ambitious teaching* (i.e., use of active learning pedagogies), had a negative influence on student attitudes.

Explanation for the different findings could be related to classroom size or differences in student populations. Specifically, in terms of class size, S. Freeman et al. (2014) found active learning had diminished (but still statistically significant) effect sizes for classes over 50 students, of which the sample from Sonnert et al. (2015) contained many. Though classroom size was less than 50 students for almost all of those involved in Peters' (2013) study of college algebra students, only 2.5% of those students self-reported majoring in a mathematics-related field; therefore, many of those students may not have needed Precalculus or Calculus 1 to complete their degrees. If true, that suggests the population in Peters (2013) was fundamentally different than the population of students considered in S. Freeman et al. (2014), who strictly considered studies of introductory STEM courses where STEM-intending students would be enrolled. In summary, the study by Sonnert et al. (2015) considered the same population of students as S. Freeman et al. (2014), but the findings from Sonnert et al. (2015) were more closely aligned with findings from Peters (2013), compared to S. Freeman et al. (2014). These inconsistent findings, among even large studies, suggest more research is needed about the relationship between self-efficacy, classroom climate, and achievement in first college mathematics courses. In addition, one study highlighted similar inconsistencies in the relationship between the FM and self-efficacy (Cho et al., 2021). Specifically, Cho et al. (2021) found self-efficacy may help explain why the FM positively influences student achievement on an inconsistent basis, which will be elaborated in the next two paragraphs.

Findings suggest that the FM can improve academic achievement in some cases (O'Flaherty & Phillips, 2015), but not in others (Sonnert et al., 2015). Cho et al. (2021) sought to identify student characteristics and pedagogical factors in the FM that influence students' affective domain. Researchers solicited 350 students in 12 classes taught with the FM at a university with a highly competitive acceptance rate in South Korea (Cho et al., 2021). There was little variance in student demographics, including age ($M = 21.85$, $SD = 2.31$), and previous GPA ($M = 3.47$, $SD = 0.59$); however, there were slightly more females than males in the sample (Cho et al., 2021). The researchers developed a survey that consisted of a student background subscale, as well as four additional subscales that measured perception of the FM, self-efficacy, student enjoyment, and student boredom (Cho et al., 2021). The survey was determined to be reliable by using Cronbach's alpha ($.73 < a < .94$), (Cho et al., 2021).

After administering the survey to the students at the end of the semester, the researchers calculated descriptive statistics, checked bivariate correlations, and interpreted the data with Hierarchical Regression Analysis (Cho et al., 2021). Student enjoyment increased when students: (a) perceived the course materials as meaningful and helpful, (b) believed the instructors facilitated their learning in the class sessions, and (c) actively participated in the classes. Student boredom increased when students perceived the course materials as unimportant or unhelpful, and when the students participated less in the classroom activities. Shifting to a different affective construct, the next subsection introduces the origins of grit (Duckworth et al., 2007) and summarizes recent research findings pertaining to grit (Bowman et al., 2015; Credé et al., 2017).

Grit

Given that a group of individuals all have equal intelligence, Duckworth et al. (2007) studied "why some individuals accomplish more than others" (p. 1087). Ultimately, Duckworth et al. (2007) conceived of the concept of grit as the "perseverance and passion for long-term goals," (p. 1087) and, during interviews with experts in a variety of fields, hypothesized that grit may influence achievement more than innate talent or intelligence. Over the course of six psychological studies, Duckworth et al.

(2007) developed and validated the 12-Item Grit Scale (GS) to measure grit. During that process, Duckworth et al. (2007) generally found that grit: (a) was not correlated with Intelligence Quotient (IQ), (b) was strongly correlated with conscientiousness, and (c) accounted for more variance in achievement than did conscientiousness. The aforementioned studies considered different populations and, in some of those populations, Duckworth et al. (2007) found that grit was positively correlated with: (a) higher levels of education, (b) age, (c) fewer career changes when controlling for age, and (d) higher GPA. However, Duckworth et al. (2007) found that grit was negatively correlated with SAT scores. Ultimately, Duckworth et al. (2007) firmly established grit as bidimensional affective construct—bidimensional because it is the duality of both persistence of effort to succeed, as well as a consistent interest in achieving long-term goals (Bowman et al., 2015).

In an attempt to parse the relationship between both elements of grit and a variety of student outcomes (e.g., college GPA, intention to persist in college, etc.), Bowman et al. (2015) designed a pair of psychological quantitative studies. For instrumentation, Bowman et al. (2015) compared scores of both subscales of the GS: Perseverance of Effort (PE) and Consistency of Interest (CI). In the first study, Bowman et al. (2015) formed their sample with 417 undergraduate students that were enrolled in a psychology course at Bowling Green State University (BGSU). Based on the findings and limitations of the first study, Bowman et al. (2015) purposefully formed two groups of students for the second study; 938 students from BGSU and 1,089 students from the University of Wisconsin at La Crosse (UWL). In every sample, a majority of the students were female

(76%, 71%, and 76%), white (80%, 92%, and 87%), and underclassmen (71%, 82%, and 86%) (Bowman et al., 2015).

In both studies, Bowman et al. (2015) analyzed both subscales for grit (persistence of effort and consistency of interest) with multiple regression to isolate each dependent variable and determine the extent to which grit could predict each dependent college experience variable. Regarding data organization, Bowman et al. (2015) partitioned the student outcomes into two sets: Continuous dependent variables including student outcomes determinable at the present time, like *college GPA* or *college satisfaction*; ordinal dependent variables included outcomes involving a student's future intention, like *intention to persist in college* or *intention to change major*. For their analysis, Bowman et al. (2015) used least squares regression for the continuous dependent variables, and ordinal logit regression for the aforementioned *intention* variables. Ultimately, Bowman et al. (2015) produced five findings: (a) grit predicted many of the student outcomes (both academic and nonacademic); (b) the PE subscale was a superior predictor of each student outcome compared to the CI subscale; (c) the size of the institution did not change relationships with grit; (d) PE predicted college GPA; (e) student demographics did not change relationships with grit. If the findings from Bowman et al. (2015) are generalizable, it would suggest that persistence is by far the most dominant component of grit. Fortunately, a meta-analysis by Credé et al. (2017), which included Bowman et al. (2015), provides evidence with increased external validity.

In a meta-analysis that distilled findings from 73 studies representing 88 distinct samples and 66,807 participants, Credé et al. (2017) sought to clarify the structure of grit and study how grit influences performance, retention, conscientiousness, and cognitive ability. The researchers outlined how they initially identified 778 possible datasets, as well as their purposeful method to narrow those datasets to 88, which fit their criteria (Credé et al., 2017). Additionally, the researchers explained how they coded and statistically transformed those data (e.g., calculation of Mosier reliability estimates for composite variables) into a single dataset, the analysis of which would be valid despite being collected from 73 different studies (Credé et al., 2017). After rigorous statistical analysis based on the random-effects model, including measurements of unreliability, the researchers confirmed there was no statistically significant publication bias, with $\alpha = .05$ (Credé et al., 2017).

In total, Credé et al. (2017) produced three important findings. First, the researchers found insufficient evidence to support the claim that grit is a multivariable construct dependent upon persistence and consistency (Credé et al., 2017). Second, Credé et al. (2017) found that grit was not as strongly related to student achievement and retention as other constructs, like cognitive ability. Third, the researchers argued that grit narrowly predicts student achievement overall (Credé et al., 2017). Noting that grit was strongly correlated with self-control, which is an element of conscientiousness, Credé et al. (2017) suggested that grit could be a useful predictor to purposefully select students in retention intervention. With findings that questioned whether grit is a valid construct or simply a repacked version of conscientiousness, Credé et al. (2017) suggested future grit research focus on the perseverance aspect. These findings align with findings from Bowman et al. (2015), which suggest perseverance is the most important component of grit; however, they go further and question whether grit is distinct of conscientiousness. Although Credé et al. (2017) found that grit mildly predicts student achievement, it is reasonable to question whether a model that combines grit and self-efficacy would more efficiently predicts student achievement than these constructs do separately. The next subsection reviews studies that have researched relationships between both self-efficacy and grit.

Self-Efficacy and Grit

In a study of 609 academically gifted middle and secondary students, Dixson et al. (2016) researched whether grit, hope, and academic self-efficacy predicted academic achievement, while controlling for demographics and perceived ability. The students were selected from a summer gifted and talented student program and were aged 10-18 (M = 14.34, SD = 1.44), and were approximately equitable among genders (42.3% male and 57.7% female) (Dixson et al., 2016). Students were admitted to the program based on a variety of measures, including grades, standardized test scores, teacher recommendations, etc. (Dixson et al., 2016). Ethnic demographics were reported, which included 380 Asian American students (62.3%), 25 Hispanic American students (4.1%), 11 African American students (1.8%), and 193 students among other ethnic identities (31.7%) (Dixson et al., 2016). Socioeconomically, approximately 13.1% of the students were from low income backgrounds, 34.8% from middle income backgrounds, and 46.5% from upper income backgrounds (Dixson et al., 2016). In terms of instrumentation, students were asked to self-report their perceived ability (the control variable), as well as their academic achievement (the dependent variable) (Dixson et al., 2016). Then, the Short Grit (Grit-S) scale was used to measure grit, hope was measured with the Children's Hope Scale (CHS), and academic self-efficacy was measured using the Self-Efficacy for Academic Achievement Scale (SEAA) (Dixson et al., 2016).

The researchers established structural validity by analyzing the survey results with factor analyses. Given that grit and hope were both established, the researchers performed confirmatory factor analysis (CFA), considering a variety of fit indices (Dixson et al., 2016). Based on their analysis of the grit construct, a two-factor model best fit the data (Dixson et al., 2016), which agreed with the literature (Duckworth & Quinn, 2009). The same analysis led the researchers to select a one-factor model for hope (Dixson et al., 2016). Given that a dearth of literature supported the SEAA, the researchers performed exploratory factor analysis (EFA) with principal axis extraction, and accepted a one-factor model (Dixson et al., 2016). Finally, the researchers used hierarchical regression techniques to determine if grit, hope, and academic self-efficacy predicted academic achievement (Dixson et al., 2016).

Dixson et al. (2016) found that, when controlling for students' perceived ability, both hope and academic self-efficacy were significant predictors of academic achievement, whereas grit was not. The researchers reported that gifted and talented programs generally lack the ethnic and socioeconomic diversity and are often not nationally representative; in this study, the sample participants also lacked diversity in those terms (Dixson et al., 2016). Another obvious limitation was that children were trusted to self-report their perceived ability and their academic GPA (Dixson et al., 2016). This study suggests that grit may not help strengthen the ability of self-efficacy to predict academic achievement; however, the next few paragraphs describe another study that found grit may play an important role in predicting achievement.

Alhadabi and Karpinski (2020) examined the relationships between grit, self-efficacy, achievement orientation goals, and achievement, in a sample of 258 university students at a large public university in the midwestern region of the U.S. In terms of sample demographics, females outnumbered males by more than two to one (26.7% males and 73.3% females), a point estimate for the age was approximately 25 years ($M = 25.48$, $SD = 8.77$), and the majority of the students were undergraduates (67.1%) (Alhadabi & Karpinski, 2020). In terms of instrumentation, the researchers gave the students an online survey with four sections, including demographic and academic background information, the modified Achievement Goal Orientation scale, the modified Self-Efficacy scale, and the Short Grit scale (Alhadabi & Karpinski, 2020). Based on existing literature, the researchers hypothesized a multivariable model to describe the relationship between the constructs they considered and performed Path Analysis (PA) with multivariable regression and robust statistical techniques to determine if the model fit the data (Alhadabi & Karpinski, 2020).

The final PA mediation model indicated a good fit and each path was significant in the expected direction ($p < .05$) (Alhadabi & Karpinski, 2020). Specifically, both grit subscales (perseverance of effort and consistency of interest) had a positive direct effect on self-efficacy, as well as small positive indirect effect on achievement (Alhadabi & Karpinski, 2020). In addition, self-efficacy had a positive indirect effect on achievement (Alhadabi & Karpinski, 2020). Limitations of the study included the potential for diminished external validity, as well as being based on self-reported data and a potential for response bias (Alhadabi & Karpinski, 2020). Ultimately, the study by Alhadabi and Karpinski (2020) was statistically robust and sound; however, in terms of applicability to the study in this dissertation, Alhadabi and Karpinski (2020) considered general academics rather than mathematics specifically. Interestingly, the findings related to grit were significant and contrary to Dixson et al. (2016), which considered similar constructs. One reason there may be a discrepancy is because of substantial differences in the sample demographics (students with a mean age of approximately 14 compared to university students with a mean age of approximately 25), instrumentation, or statistical method of analysis.

Summary of Findings

This review of literature has discussed a myriad of research studies and has yielded many findings. First, students are still switching their majors away from STEM, and prolific use of lecturing as a teaching model may be to blame (Seymour et al., 2019). For the purposes of this study, the FM (Bergmann & Sams, 2012; Lage et al., 2000) is considered a teaching model that utilizes active learning (Michael, 2006). Two meta-analyses found the FM positively influences achievement in mathematics classrooms (Lo et al., 2017; Strelan et al., 2020).

Recent research has studied the relationship between the FM and achievement; however, studies have found mixed results (Collins, 2019; Sahin et al., 2015), that the FM does not influence achievement (Ziegelmeier & Topaz, 2015), or that the FM positively influences achievement (Mkhatshwa, 2021; Spotts & Gutierrez de Blume, 2020). Few studies have investigated an online adaptation to the FM; however, one study that did found no significant difference in student achievement (Stöhr et al., 2020), and another found similar student satisfaction from face-to-face FM classes translated into OFMs (Swart & Macleod, 2020).

In terms of relationships between affective constructs and achievement, two studies found that student-centered classroom climates or *ambitious teaching* methods negatively influence student achievement to a small, but significant degree (Peters, 2013; Sonnert et al., 2015). Peters (2013) also provided more evidence that self-efficacy positively influences achievement. In addition to self-efficacy, Bowman et al. (2015) found that grit positively influences mathematics achievement. Few studies have considered the relationship between grit, self-efficacy, and achievement; however, one recent example found that self-efficacy influences achievement whereas grit does not (Dixson et al., 2016). Another study found that grit indirectly influenced achievement and moderated self-efficacy which also indirectly influenced achievement (Alhadabi & Karpinski, 2020). Ultimately, this review of literature suggests that results are mixed and more research is needed to clarify relationships between affective constructs and achievement in OFMs.

Theoretical Framework

The theoretical framework will include a combination of Self-Efficacy from Bandura (1977) and Grit from Duckworth et al. (2007); specifically, an adaptation of the mediation model outlined by Alhadabi and Karpinski (2020). The next few paragraphs will describe self-efficacy and grit. This section concludes with an explain the mediation model that Alhadabi and Karpinski (2020) developed, and how all these constructs combined into the theoretical framework in this study.

Self-efficacy is defined as one's confidence in one's self to perform a specific task (Bandura, 1977). Researchers suggest self-efficacy can determine how much persistence and effort an individual will exert, and whether they will attempt a task or avoid it. (Bandura, 1997). In fact, one study suggests that self-efficacy has an important relationship with avoidance in pre-service teachers (Kilmen, 2022). Research has consistently shown that self-efficacy positively influences achievement (Alhadabi & Karpinski, 2020; Bowman et al., 2015; Dixson et al., 2016; Peters, 2013). Precalculus students may be motivated to work harder as they see gains in achievement (e.g., on in-class assignments); in essence, as their self-efficacy increases. Furthermore, the social aspect of the class may help students persist through moments of low self-efficacy until they can understand difficult concepts.

Grit is defined as a combination of perseverance of effort and long-term consistency of interest (Duckworth et al., 2007). Regarding recent studies considering grit, results have been mixed; specifically, Bowman et al. (2015) found grit positively influenced achievement, whereas Dixson et al. (2016) found grit did not positively influence achievement. In fact, Credé et al. (2017) questioned whether grit was a construct distinct from others (e.g., conscientiousness). Regardless of whether Credé et al. (2017) is correct, both Credé et al. (2017) and Bowman et al. (2015) agree that perseverance of effort was the most important subscale for grit. Therefore, if students' self-efficacy increases, students may gain confidence and increase their willingness to persist. The social group component of the course may help grit increase for some individuals that may feel a competitive spirt among their groupmates.

Alhadabi and Karpinski (2020) used path analysis to develop a mediation model showing the relationship among many constructs, including grit, self-efficacy, and achievement; however, Alhadabi and Karpinski (2020) considered all university students in general. Recall that other studies have shown active learning (S. Freeman et al., 2014) and the FM (Spotts & Gutierrez de Blume, 2020) positively influence achievement. Specifically, this study examined the relationship among self-efficacy, grit, and achievement, given that an online university Precalculus classroom utilized an OFM. Since Alhadabi and Karpinski (2020) considered additional constructs, like academic performance and mastery, this study considered a modified version of the mediation model designed by Alhadabi and Karpinski (2020) as a theoretical framework.

Conclusion

This review of salient literature connected several constructs to active learning, including the FM, self-efficacy, grit, and achievement. Ultimately, three literature gaps were identified that are partially addressed in this study. Studies that were considered included constructs like active learning, the FM (an active learning pedagogical model), affective constructs (i.e., self-efficacy and grit), and studies that examine the relationships between these constructs. The following chapter explains the methodology used for the study in this dissertation. Specifically, the chapter includes an overview of the research problem, the research purpose and questions, the research design, population and sample, instrumentation, data collection procedures, data analysis, privacy and ethics considerations, and study limitations.

CHAPTER III:

METHODOLOGY

The purpose of this correlational study was to examine the relationships among self-efficacy, grit, and mathematics achievement in Precalculus classes taught with an Online Flipped Model (OFM). The research was conducted at a medium-sized, primarily non-residential university in the Texas gulf coast region. At the beginning and end of the semester (i.e., pretest/posttest), a purposeful sample of undergraduate students completed the *12-Item Grit Scale* (GS) (Duckworth et al., 2007) and the *Precalculus Self-Efficacy Survey* (PCSES; which was developed and validated as part of this study). Comprehensive final examinations were used to measure mathematics achievement. The researcher analyzed the data using descriptive statistics, exploratory factor analysis (EFA), two-tailed paired *t*-tests, Pearson product-moment correlations, and regression techniques. This chapter includes an overview of the research problem, operationalization of theoretical constructs, research purpose and questions, research design, population and sample information, instrumentation, data collection and analysis, ethical and privacy considerations, and study limitations.

Overview of the Research Problem

Students have been leaving the STEM pipeline since before STEM was a widely used acronym (R. J. Freeman, 1960; Seymour & Hewitt, 1997). In an attempt to address the leaking pipeline, this study examined the relationship among precalculus self-efficacy, grit, and student achievement, while exploring the teaching of Precalculus with an OFM. First, Ellis et al. (2016) found that Calculus 1 may be diminishing students' mathematical confidence (an affective construct) to such an extent that students could be deciding to exit the STEM pipeline because of Calculus 1 alone. Therefore, it is natural to question if similar relationships exist among Precalculus (another common first college-level mathematics course) and combinations of affective constructs (i.e., grit and self-efficacy). Second, although utilization of active learning models is correlated with higher overall GPA and lower failure rates (S. Freeman et al., 2014), more research is needed about OFMs and mathematics achievement in university-level Precalculus courses. With so many teaching models, instructional modes, institution types, and demographics to control for, a comprehensive study of the aforementioned topics would require an abundance of data. Therefore, preliminary research is needed to determine if larger studies are warranted. Ultimately, this study researched the relationship among grit, precalculus self-efficacy, and achievement in university Precalculus courses, taught with an OFM.

Operationalization of Theoretical Constructs

This study considered three constructs: (a) precalculus self-efficacy, (b) grit, and (c) mathematics achievement. Precalculus self-efficacy is defined as a students' belief in their ability to solve Precalculus problems and was measured with the *Precalculus Self-Efficacy Survey* (PCSES). Grit is defined as having persistence and passion for long-term goals, and was measured with the *12-Item Grit Scale* (GS). For the purposes of this study, mathematics achievement was defined as the amount of Precalculus content knowledge a student learns in a given semester and was measured with Precalculus final examination scores.

Research Purpose and Questions

The purpose of this correlational study was to examine the relationships among self-efficacy, grit, and mathematics achievement in flipped online undergraduate Precalculus classes. The research questions for this study were:

1. Is the *Precalculus Self-Efficacy Survey* (PCSES) a valid and reliable instrument?
2. Is there a statistically significant mean difference in students' precalculus self-efficacy prior to and following the completion of an online flipped Precalculus course?
3. Is there a statistically significant mean difference in students' grit prior to and following the completion of an online flipped Precalculus course?
4. Is there a relationship between precalculus self-efficacy and mathematics achievement?
5. Is there a relationship between grit and mathematics achievement?
6. Does precalculus self-efficacy and grit predict mathematics achievement?
7. Does grit moderate the relationship between precalculus self-efficacy and mathematics achievement?

Research Design

A correlational design was employed to examine the relationships among precalculus self-efficacy, grit, and achievement. At the beginning and end of the semester, a purposeful sample of undergraduate students enrolled in Precalculus courses, taught with the OFM at a medium-sized university in the Texas gulf coast region, completed the PCSES and GS. In addition, students also took a comprehensive final examination at the end of the semester. Quantitative data were analyzed using descriptive statistics, EFA, two-tailed paired *t*-tests, Pearson product-moment correlations, and regression techniques.

Population and Sample

The population for this study included all undergraduate students enrolled at the same medium-sized university in the gulf coast region of Texas. A total of 9,053 students attended in the start of the fall 2020 to spring 2021 academic year. During that time, the average age of undergraduate and graduate students was approximately 26 and 32 respectively. Socioeconomic status parameters of the students were as follows: 24.6% received Pell Grants, 34.9% received student loans, and 22.1% had no financial aid. Table 3.1 shows more demographic information for the fall 2020 to spring 2021 academic year.

Table 3.1

University Student Demographics (2020-2021)

	Frequency (*n*)	Percentage (%)
1. Gender		
Male	3,298	36.4
Female	5,755	63.6
2. Race/Ethnicity		
Asian	767	8.5
Black	782	8.6
Hispanic	3,592	39.7
White	3,162	34.9
International	347	3.8
Other	403	4.5
3. Enrollment by College		
Business	2,612	28.9
Education	1,528	16.9
Humanities	2,448	27.0
STEM	2,403	26.5
Undecided	62	0.7
4. Classification		
Freshmen	432	4.8
Sophomore	442	4.9
Junior	2,522	27.9
Senior	3,186	35.2
Graduate	2,471	27.3
5. Residency		
Texas Residents	8,630	95.3
Out of State	77	0.9
Non-residents	346	3.8

Any student who satisfied the prerequisite could have registered for Precalculus by self-enrolling. The prerequisite required students to have earned at least a C- in

College Algebra, or have equivalent preparation (i.e., pass the departmental placement test developed by the Mathematical Association of America). Given the prerequisite requirements and degree programs at the research site, almost all degree-seeking students that enroll in Precalculus are majoring in programs from the STEM college at the time of enrollment. Therefore, Table 3.2 shows demographics pertaining to the STEM college for the start of the fall 2020 to spring 2021 academic year.

Table 3.2

STEM College Student Demographics (2020-2021)

	Frequency (*n*)	Percentage (%)
1. Gender		
Male	1,442	60.0
Female	961	40.0
2. Race/Ethnicity		
Asian	307	12.8
Black	122	5.1
Hispanic	878	36.5
White	798	33.2
International	187	7.8
Other	111	4.6
3. Classification		
Freshmen	1,969	81.9
Graduate	434	18.1

In the fall 2020 semester, three Precalculus courses were offered online at the research site; a purposeful sample of Precalculus students from each section was solicited to participate in this study. For the purposes of validating the PCSES, more Precalculus students were purposefully solicited to take the survey in spring 2021. Those students were selected from all three sections of Precalculus, which were taught by different instructors.

Online Flipped Model

For purposes of this study, an *Online Flipped Model* (OFM) was devised and utilized for three sections of Precalculus offered in fall 2020. In a traditional *Flipped Model* (FM), learning materials (e.g., prerecorded lecture videos) and supplemental resources (e.g., PowerPoints) are provided to students, who are expected to learn the material independently before class. Later, in a face-to-face class meeting, students work in groups on classwork assessments. Therefore, the "flip" describes the roles of instruction (inside class to outside class) and formative assessment (outside class as homework to inside class as group classwork). In this case, the instructor's goal was to create an OFM that was as similar to a traditional FM as possible, so that the only substantial change was the in-class sessions were conducted synchronously online instead of face-to-face in an actual classroom on campus. To accomplish this, the instructor required synchronous online meetings at a formal class time four days per week (Monday through Thursday) for 50 minutes.

After sketching out lecture notes that were based on the corresponding section in the textbook, the instructor created prerecorded video lectures with a Microsoft Surface Pro 7, a high-quality microphone, and several software applications. The instructor selected the Camtasia screen capturing software application for its robust editing capabilities. More than 90% of the video footage consisted of the instructor writing on the screen with a Microsoft Stylus in Microsoft OneNote, while talking as if it were a live lecture. Some lectures included animated graphs with the graphing utility website Desmos.com, some lectures regarding trigonometry included short clips from the NSF-funded video series *ProjectMathematics!*, and some videos included some animated PowerPoint slides. Often, the instructor used the *screenshot* function in OneNote to insert a definition or example problem from the eTextbook. Each video corresponded to a learning objective, in an attempt to keep the videos as short as possible, so the videos varied in length. On average, students needed to watch approximately four hours per week of lecture material, which matched the amount of time students typically spent in class in a face-to-face format. Once the videos were recorded and edited, the instructor rendered the videos into the MP4 video format, and uploaded them to YouTube.com with unlisted links. The instructor chose YouTube for a few reasons. First, YouTube automatically generated close captioning, which provided accessibility compliance with Section 508 of the Rehabilitation Act of 1973. Second, the instructor believed many students may be familiar with YouTube, and could access the videos more easily with their mobile devices compared to options provided by the research site. The instructor compiled a video schedule based on previous pacing experience of the actual class lectures so the students knew when they should watch each video. This video schedule was incorporated onto the calendar in the course syllabus.

The site retained a license for Zoom, a software application designed for meetings, and the instructor created a link the students used to access each live class meeting. The research location created a web-based Learning Management System (LMS) site for the course, and the instructor posted links to all the class materials to the

LMS, including the course syllabus, all the links to the prerecorded YouTube videos, test study guides, keys to prior assignments, etc. In addition, the LMS included an announcement tool and a gradebook tool. The announcement tool allowed the instructor to quickly post an announcement, of which a copy was emailed to each student. The gradebook tool provided an easy way for the instructor to keep track of all the students' grades, as well as providing transparency and feedback to students in real time. Given that each student's account was connected to the LMS, the instructor used the LMS to create student groups, with four or five students included in each group. The instructor attempted to distribute students equitably by gender, age, and race/ethnicity. The instructor exported the list of groups from the LMS into Zoom, so that the instructor could quickly send students into their respective *breakout rooms*, a phrase that describes the virtual meeting place for the students. The course syllabus indicated a webcam and microphone were required equipment for the class, and the university provided the equipment for low-income students.

Each student was graded with a weighted average according to the following categories: (a) online homework/classwork problem sets (15% of the overall numeric average after the lowest two grades were dropped), (b) participation (15%), (c) challenge problems (10%), (d) midterm examination (25%), and (e) the cumulative final examination (35%). Online homework/classroom problem sets were built in a textbook-accompanied online homework system called WebAssign. Each set consisted of digital questions that were connected to the content/textbook and were automatically graded by WebAssign. The length of these assignments matched what was typically used as homework in face-to-face sections of Precalculus; students were encouraged to work on the problems in class and to complete any unfinished work outside of class. Students were always encouraged to work in groups, but WebAssign algorithmically generated different numerical values for each student, and students were individually accountable for their own performance.

The instructor created and distributed a *weekly assignment* each Monday before class, which typically consisted of four exercises similar to examples in the prerecorded lecture videos. A four-point rubric, based on correctness of work shown, was devised and communicated to students in the course syllabus. Given that each assignment typically included four questions, each assignment typically received a score of up to 16. After a class meeting each day, the instructor ran Zoom reports and noted the amount of time each student attended on a given day. To allow for potential disconnection issues, a student was defined as being *present* if they attended at least 25 minutes of a 50-minute class. An attendance grade was entered in the gradebook for each student each week. Each student received a participation grade each week, and the participation grade simply inherited the higher grade of the student's weekly attendance grade and their Weekly Assignment grade.

A collection of 10 *challenge problems* was distributed to all the students at the beginning of the semester. Typically, each question was unlike others in the textbook, and required students to synthesize concepts from multiple sections. The instructor created a message board in the LMS for the entire class, with one thread for each of the ten questions. Students were encouraged to informally divide up the work as a class and post solutions on the corresponding thread. Whenever a student proposed a solution online, the class was to notify the instructor to confirm the correctness of the solution. The instructor would notify the students if they were correct/incorrect within 24 hours. At the end of the semester, every student in the class received the same grade in the challenge problem weight, based on how many correct answers the class collectively solved (100% for 10, 90% for 9, etc.). The midterm examination and final examination (which were both proctored by ProctorU) were graded automatically and students' scores were posted in the LMS gradebook. In a typical class meeting, the instructor would ask if anyone had questions from the prerecorded videos. After any questions were clarified, the instructor would send students to their breakout rooms and encouraged students to do their work in the following order: (a) weekly assignments, (b) online classwork/homework problem sets, and (c) challenge problems. The instructor would visit all of the breakout rooms to interact with the students and address any questions.

Instrumentation

This study involved three instruments. The *Precalculus Self-Efficacy Survey* (PCSES) measured precalculus self-efficacy. The *12-Item Grit Scale* (GS) measured grit (Duckworth et al., 2007). Finally, all students took the same cumulative final examination, which measured mathematics achievement. The remainder of this section describes how each instrument was developed and validated.

Precalculus Self-Efficacy Survey

Research suggests self-efficacy is specific to tasks (Bandura, 1986; Pajares & Miller, 1995); therefore, it is appropriate to measure precalculus self-efficacy with a survey, where an individual self-reports their level of confidence with performing those tasks. Given that no valid instrument existed to measure self-efficacy specifically in terms of precalculus, the researcher developed the *Precalculus Self-Efficacy Survey* (PCSES) for this study. In doing so, the researcher followed the methodology Zakariya et al. (2019) used to develop the *Calculus Self-efficacy Instrument* (CSEI). The remainder of this subsection will describe how Zakariya et al. (2019) developed the CSEI, thereby outlining the process this study followed to develop the PCSES. For the purposes of this study, the PCSES measured students' precalculus self-efficacy (See Chapter IV for more details.)

Calculus Self-Efficacy Inventory

The *Calculus Self-Efficacy Inventory* (CSEI) was developed by Zakariya et al. (2019) to provide a concise measure of calculus self-efficacy. The instrument was needed because there were no instruments that measured self-efficacy as it specifically pertained to Calculus 1, despite self-efficacy researchers having argued that domain-specific instruments are needed to ensure validity (Schunk & Hanson, 1985). Based on Bandura's (1977) theoretical framework of self-efficacy, the final version of the instrument contains 13-items from old final exam questions in Calculus 1 (Zakariya et al., 2019). Rather than actually solving the problems, students are asked to rate their confidence in their ability to solve the problems on a scale from 0 to 100 (0 = *Not Confident, through 50 = Moderately Confident, to* 100 = *Highly Confident*). The higher the score, the higher the self-efficacy (Zakariya et al., 2019).

Consisting of 15-items originally, 110 engineering students and 124 economics students (135 males and 99 females, with an average age between 19-22 years old) piloted the survey by rating their confidence in their ability to solve the problems (Zakariya et al., 2019). The researchers ultimately completed three iterations of EFA (Zakariya et al., 2019). In the first iteration (a two-factor solution based on the mean) Zakariya et al. (2019) removed one of the items for two reasons. First, the item's factor loading was out-of-range, which is suggestive of negative error variance in the factor solution of the item (Zakariya et al., 2019). In addition, the polychoric correlation matrix showed it had negative correlation coefficients with other items (Zakariya et al., 2019). The researchers decided the second iteration should be a one-factor solution of the model based on an optimized parallel analysis from the 95th percentile, which has shown to be more accurate than a two-factor solution based on the mean (Zakariya et al., 2019). The second iteration culled another item because its communality was equal to one; therefore, all its variance was shared with other items. In other words, the item was removed because it did not measure anything independently from the other items (Zakariya et al., 2019). In the third and final iteration, all factor loadings were greater than 42 and the average communality was 0.74 (Zakariya et al., 2019), suggesting the solution was a good model (Pituch & Stevens, 2016). The extracted eigenvalues accounted for a total of 62.55% of the common variance. Shown to be more accurate than Cronbach's alpha, the ordinal coefficient alpha was used to show the instrument is highly reliable (α = .91).

The 12-Item Grit Scale

The *12-Item Grit Scale* (GS) was developed to measure a participant's "perseverance and passion for long-term goals" (Duckworth et al., 2007, p. 1087). After exploring common attributes of highly successful professionals with qualitative interviews, researchers conceptualized the grit construct and drafted a survey with 27 items to measure it (Duckworth et al., 2007). Desiring wide applicability, the researchers took care to construct items that maintained face validity for a general audience (i.e., avoided using words like school or work) (Duckworth et al., 2007). The researchers piloted the instrument draft on a free public website which focuses on psychology research; ultimately, they collected 1,545 participant responses over 18 months (M = 45 years; 73% female) (Duckworth et al., 2007). Upon reviewing the data, the initial revision omitted 10 items to improve internal consistency (i.e., Cronbach's alpha), redundancy, item-total correlations, and to simplify the vocabulary (i.e., decrease cognitive load, thereby increasing response rate) (Duckworth et al., 2007). With 17 items left, the researchers partitioned the dataset into two equal groups (i.e., split-half) (Duckworth et al., 2007). This was done so they could perform CFA with the second half (n = 773) after first using EFA with the first group (n = 772) (Duckworth et al., 2007).

As part of the EFA, the researchers excluded an additional five items after performing an oblique ProMax rotation, which yielded a two-factor solution (Duckworth et al., 2007). The researchers expected these factors would be positively correlated, which was confirmed (r = .45) (Duckworth et al., 2007). Additionally, by showing the portion of each factor independently accounted for more variance than the error, the researchers provided sufficient evidence to suggest the presence of the factors was not likely due to chance (Duckworth et al., 2007). Ultimately, EFA yielded two subscales with six items each; one subscale represents consistency of interests, and the second represents perseverance of effort (Duckworth et al., 2007). The confirmatory factor analysis with the remaining data (n = 773) fit the two-dimensional solution (comparative fit index = .83) with minimal error (root-mean square error of approximation = .11) (Duckworth et al., 2007). Furthermore, this final form was found to be highly consistent (Perseverance of Effort, a = .85; Consistency of Interests, a = .84; Overall, a = .85) (Duckworth et al., 2007).

Comprehensive Final Examination

Mathematics achievement was measured with a common, comprehensive final examination at the end of the Precalculus course. Students were provided with a review two weeks before the examination. The instructor selected 20 multiple-choice questions with electronic test bank software provided by the textbook publishing company. The instructor purposefully selected the questions to uniformly represent all the content from the semester, and to be as similar as possible to previous paper-based departmental examinations. While creating the examination template, the instructor checked the wording, spacing, and clarity for each question. Given that the examination was administered online, academic integrity (and internal validity) was threatened. Therefore, the instructor created multiple versions of the examination with an automated process included with the test creation software. Specifically, the software changed numeric values in questions between the test versions.

Once the examinations were created, the instructor uploaded them into Blackboard such that students could not begin the exam without a proctor entering a password. The examinations were all proctored with the online service *ProctorU*. ProctorU required all students to have a webcam and microphone. Students registered with a government-issued photo ID and selected times within the test window, which was set for two hours in the evening on the university-assigned final examination day. To begin the test, students signed into their ProctorU accounts, where they connected with their proctor. Once connected, students were asked to move their webcam around their desk to ensure no unauthorized study materials or equipment were used; no calculators were allowed. When the test was ready to begin, the proctor remotely typed in the password for the student to start the test. Once testing began, students could not access any other programs on their computers. Everything was recorded, including the student's screen and their webcam recording. Any irregularities were noted by the proctor and the proctoring software, timestamped, and shared with the instructor for review to determine if academic dishonesty occurred.

Data Collection Procedures

Before any research was conducted, permission was attained through the UHCL Committee for the Projection of Human Subjects (CPHS). The researcher began building electronic surveys with the application *Qualtrics*. To increase survey response rate and internal validity, the researcher followed best practices outlined by Dillman et al. (2014) to create the electronic surveys. For example, given that the study had many research questions involving different surveys (e.g., grit), the researcher created separate Qualtrics surveys to increase response rate overall (Dillman et al., 2014). Therefore, students were ultimately asked to complete five surveys during the course of the semester: three surveys at the beginning of the term (the demographic questionnaire, PCSES, and GS), and two surveys at the end of the semester (PCSES and GS).

The researcher hypothesized that the demographic questionnaire would take the most time to complete, so the researcher encouraged students to take it first; afterward, the researcher explained to the respondents that subsequent surveys would take substantially less time to complete, thereby fostering a sense that students were invested (Dillman et al., 2014). The demographic questionnaire began with the broadest questions to appeal to the widest possible audience, building commitment to the questionnaire (Dillman et al., 2014). With the respondents in mind, the researcher used branched (or filtered) questions, that prompted follow-up questions only salient to a given respondent; this eliminated the need for students to leave questions blank and decreased overall response time (Dillman et al., 2014). Potentially sensitive questions (e.g., identifying race or ethnic background) were asked at the end of the survey (Dillman et al., 2014). Given that the remaining surveys measured affective constructs and were anticipated to take a short time to complete, to maximize consistency, students were not afforded an opportunity to pause and restart the survey later. (The reader can find additional considerations regarding how the PCSES was put into Qualtrics in Chapter IV.)

A cover letter was prepared to be included with the student surveys. The letter notified the students: (a) that their participation was completely voluntary; (b) that the time needed to complete the survey was between 25-45 minutes; (c) that their responses and personal information would be kept confidential; (d) that there were no obvious undue risks they would endure; and (e) that they may stop their participation at any time. The day before classes began, students were sent an email copy of an announcement posted into Blackboard. The announcement included the text of the survey cover letter, along with three links to three surveys: The first survey contained only demographic questions, the second survey contained the GS and another survey that was ultimately not used in this study, and the third survey contained only the PCSES. Students were offered extra credit as an incentive to complete the surveys. Given that the instructor taught all three sections, and was also the researcher, students were assured their individual responses would be kept confidential. Furthermore, students were informed that their participation would only be known to the instructor after all their grades were calculated and viewable in Blackboard, and only for the purposes of assigning extra credit.

In an effort to increase response rate, the researcher reminded the respondents to complete their surveys (Dillman et al., 2014). Specifically, the researcher sent the class: (a) an initial notification on the first day of class; (b) a reminder email on the second day of class; (c) a reminder on the last class meeting of the first week; and (d) a final reminder on Saturday morning of the first week of classes. Submissions for the survey were turned off after Sunday at 11:59 PM, ensuring data collection occurred within the first week of class. In the last week of the semester, the researcher posted a second iteration of the GS and PCSES (demographic information was not surveyed again). The same reminder structure was followed to solicit responses for the posttest surveys. All data were stored on two separate, encrypted drives and the files were password protected with 128-bit encryption. The drives were stored in a locked desk in a locked office. All data will be destroyed five years after publication.

Data Analysis

Following data collection, the researcher input the data into an IBM SPSS spreadsheet for analysis and calculated descriptive statistics. For research question one, the researcher: (a) developed the survey items; (b) asked expert Precalculus instructors to review the survey draft, which established face and content validity; (c) deployed the survey; (d) conducted an iterative EFA process, which established construct validity; and (e) calculated and reported Cronbach's alpha, which measured internal consistency and established reliability. For research question two, the researcher performed a two-tailed paired *t*-test to determine if there was a statistically significant mean difference between pretest and posttest PCSES scores. For research question three, the researcher performed a two-tailed paired *t*-test to determine if there was a statistically significant mean difference between pretest and posttest GS scores.

For research question four, the researcher calculated Pearson product-moment correlations between posttest PCSES scores and mathematics achievement scores. The independent variable was precalculus self-efficacy, a continuous variable, and the dependent variable was mathematics achievement, a continuous variable. For research question five, the researcher calculated Pearson product-moment correlations between posttest GS scores and mathematics achievement scores. The independent variable was grit, a continuous variable, and the dependent variable was mathematics achievement, a continuous variable. For research question six, the researcher performed multiple regression with posttest PCSES scores, posttest GS scores, and mathematics achievement scores. The two independent variables were precalculus self-efficacy and grit, whereas the dependent variable was mathematics achievement; all variables were continuous.

For research question seven, the researcher used regression techniques to determine if grit moderated the relationship between precalculus self-efficacy and mathematics achievement. The two independent variables for level one included precalculus self-efficacy and grit. The independent variable for level two was the product of precalculus self-efficacy and grit. The dependent variable was mathematics achievement. All variables were continuous. Statistical significance was measured using a *p*-value of .05 for this study.

Privacy and Ethical Considerations

Before any research was conducted, permission was obtained through UHCL's CPHS. The name of the research site was not mentioned in the dissertation and all data provided from participants was safeguarded. The researcher electronically provided the students a cover letter. The purpose of the survey cover letter was to make sure all participants understood the purpose of the study, were informed that their participation was voluntary and they may stop participating at any time, and that all the research data would remain confidential. The researcher, who also served as the instructor, notified students that he would be unaware of which students participated until after grades were posted in Blackboard, and only for the purposes of assigning extra credit, which was the incentive for their participation. All data were stored on two separate, encrypted drives and the files were password protected with 128-bit encryption. The drives were stored in a locked desk in a locked office. All data will be destroyed five years after publication.

Limitations of the Study

Given that exams were administered online, potential academic dishonesty threatened internal validity despite the use of an online proctoring service. Given that a survey was developed for this study, concurrent validity could have been achieved if students were given another survey that measured a construct similar to precalculus self-efficacy (i.e., the MSES to measure mathematics self-efficacy); therefore, internal validity could have been more robust. In addition, approximately 10 students changed their schedule (i.e., added/dropped) during the second week of the semester. These second-week changes were salient because virtual groups needed to be rearranged many times, which may have influenced how closely the students bonded in their groups.

An obvious limitation was that the research was conducted during the first fall semester that was planned to be online due to the COVID-19 pandemic. That point should be underscored because many of these students were 18-year-old freshmen and, although everyone was impacted by the pandemic, half of these students' senior year was abruptly cut short, causing them to miss senior proms and graduations. The types of events Tinto (2012) recommends for first-year experience (e.g., face-to-face orientation) were limited. Given that affective constructs are concerned with social and emotional phenomena, and are therefore particularly sensitive to changes, it is likely the pandemic influenced or modified their relationship. Another limitation is the small sample size. Unfortunately, it was infeasible to include the spring 2021 data in the analysis for research questions two through seven because too many confounding variables were introduced; specifically, the courses could not be offered completely online, there were two instructors, the final examination questions and format were different, in addition to the introduction of time period bias.

At the time of the study, the Zoom software application was limited such that the researcher would only know if a student raised their hand in a breakout group (to request help) if the researcher was in the main room (and not in a breakout room helping another group). For that reason, the researcher checked on students in the virtual breakout rooms randomly fewer times than planned; therefore, this influenced the extent to which the researcher could utilize the teaching model as it was designed.

Conclusion

The purpose of this correlational study was to examine the relationships among self-efficacy, grit, and mathematics achievement in undergraduate Precalculus classes taught with an OFM. In this chapter, the researcher described the methodology. The researcher purposefully selected university Precalculus students at a regional university in the southeastern region of Texas to take surveys (PCSES and GS). In addition, students' final examination scores were used to measure mathematical achievement and demographic data for the student participants was collected and reported. After establishing content and face validity for the PCSES, validating the instrument through an iterative EFA process, and calculating Cronbach's alpha to establish reliability, the researcher analyzed these data using two-tailed paired *t*-tests, Pearson product-moment correlations, and regression techniques. With these statistics, the researcher examined the relationship between precalculus self-efficacy, grit, and mathematics achievement in undergraduate Precalculus classes taught with an OFM. The next chapter presents the findings of the study.

CHAPTER IV:

RESULTS

The purpose of this correlational study was to investigate the relationships among self-efficacy, grit, and mathematics achievement in undergraduate Precalculus classes taught with an Online Flipped Model (OFM). This chapter presents the findings of the quantitative data analysis. To begin, the participants' demographics are presented, followed by results for each of the seven research questions. The chapter concludes with a summary of the findings.

Participant Demographics

Given that validating the *Precalculus Self-Efficacy Survey* (PCSES) required a large sample size, the researcher solicited 190 students from all three Precalculus classes that were offered at the research site in fall 2020 (n = 112) and both Precalculus classes that were offered at the research site in spring 2021 (n = 78). This resulted in a dataset with 220 responses, which included 79 duplicated responses (some students completed both the pretests and posttests). The researcher imported all data into the IBM Statistical Package for Social Sciences (IBM SPSS) to analyze the data. Using IBM SPSS, the researcher purposefully removed duplicates by only retaining the first response given by each participant. Ultimately, this final dataset resulted in 141 responses (n = 87 fall 2020; n = 54 spring 2021). Regarding class rank, most students were freshman (n = 44) or juniors (n = 39). Other class ranks included sophomores (n = 24), post-baccalaureates (n = 5), and seniors (n = 2). A total of 27 students were unsure of their rank or did not provide a response. Table 4.1 further describes the participant demographics for the collection of students whose responses were used to validate the PCSES. The majority of the students were 18-years-old (22.7%), Hispanic (31.2%), and majoring in mathematics, engineering, or computer science (36.2%). An equal number of male and female students (39.7%) self-reported their gender identity.

Table 4.1

Student Demographics for PCSES Validation

Total (*n* = 141)	Frequency (*n*)	Percentage (%)
1. Gender		
Male	56	39.7
Female	56	39.7
Other	4	2.8
Not Reported (Missing Data)	25	17.7
2. Race/Ethnicity		
Asian	5	3.5
Black	7	5.2
Caucasian	38	27.0
Hispanic	44	31.2
Other	23	16.3
Not Reported (Missing Data)	24	17.0
3. Age		
17	2	1.4
18	32	22.7
19	19	13.5
20-21	22	15.6
22-24	17	12.1
26-29	15	10.5
30-38	10	7.0
Not Reported (Missing Data)	24	17.0
4. Major		
Arts & Humanities	2	1.4
Education	19	13.5
Mathematics, Engineering, or Computer Science	51	36.2
Biology, Chemistry, or Physics	39	26.2
Occupational Safety or Industrial Hygiene	4	3.5
Other	2	2.1
Not Reported (Missing Data)	24	17.0

In fall 2020, two confounding variables were controlled at the research site. Specifically, the researcher served as the same instructor for all three Precalculus courses. Also, given that the research site responded to the COVID-19 pandemic by offering all classes online, it provided an appropriate setting to examine classrooms taught with an OFM. It was not possible to control for these confounding variables at the research site in spring 2021. Put explicitly, both Precalculus courses that were offered at the research site were taught by different instructors; in addition, the research site transitioned courses to a hybrid format, where students took turns attending face-to-face. Therefore, for the purposes of examining the relationships among self-efficacy, grit, and achievement in Precalculus classes taught with an OFM, the researcher purposefully selected 81 Precalculus students from the fall 2020 cohort participant data only (excluding spring 2021). The researcher taught the courses with an OFM (see Chapter III for more information). All courses met synchronously through Zoom, four times per week, for 50 minutes each, over a 15-week semester. Students were typically assigned prerecorded videos to watch on YouTube and were broken into breakout groups to complete assignments during class.

Students' Self-Reported Demographics

Regarding class rank, most students were freshman (38.3%) or juniors (30.9%). Other class ranks included sophomores (21.0%), post-baccalaureates (6.2%), and seniors (2.5%); one student was unsure of their rank (1.2%). Table 4.2 includes more demographics for this purposeful sample of participants.

Table 4.2

Background Demographics for Sample Participants

Total (*n* = 81)	Frequency (*n*)	Percentage (%)
1. Gender		
Male	36	44.4
Female	42	51.9
Other	3	3.7
2. Race/Ethnicity		
Asian	5	6.2
Black	7	8.6
Caucasian	35	43.2
Hispanic	28	34.6
Other	6	7.4
3. Age		
17	2	2.5
18	28	34.6
19-20	16	19.7
21-24	19	23.5
25-28	9	11.1
30-41	7	8.6
4. Major		
Arts & Humanities	1	1.2
Education	3	3.7
Mathematics, Engineering, or Computer Science	32	39.5
Biology, Chemistry, or Physics	39	48.1
Occupational Safety or Industrial Hygiene	4	4.9
Other	2	2.5

The age of the students spanned from 17 to 41; however, the mode age was 18 (34.6%). As a percentage, the number of males were overrepresented in the sample (44.4%) when compared to the university as a whole (36.4%). Additionally, the sample consisted of more white students (43.2%) compared to the university as a whole (34.9%). Most students were majoring in Biology, Chemistry, or Physics (48.1%). Student demographics related to previous academic preparation are included in Table 4.3.

Table 4.3

Academic Preparation Demographics for Sample Participants

Total (*n* = 81)	Frequency (*n*)	Percentage (%)
1. College Credits Earned in High School		
By Advanced Placement (AP) Only	12	14.8
By Dual Enrollment (DE) Only	21	25.9
Through Both AP and DE	7	8.6
Other	2	2.5
Not Applicable	39	48.1
3. Classroom Climate for High School AP		
Lecture	15	18.5
Alternative Methods	4	8.6
Not Applicable	62	76.5
3. Classroom Climate for High School DE		
Lecture	24	85.7
Alternative Methods	1	3.6
Unable to Determine	2	7.1
Other	1	3.6
Not Applicable	53	65.4

Most students had earned some college credits while still attending high school (51.9%). Interestingly, some students did earn college credits through both the Dual Enrollment (DE) program, and the Advanced Placement (AP) program (8.6%). Excluding the students that took both AP and DE courses, more students earned college credits through DE (25.9%) rather than through AP (14.8%). Given that a student earned credits through the DE program, students self-reported that most classes were taught with lectures (85.7%). Similarly, students who earned credits through AP also self-reported most classes were lecture-based (78.9%). Student demographics related to employment are included in Table 4.4.

Table 4.4

Employment Demographics for Sample Participants

Total (n = 81)	Frequency (n)	Percentage (%)
1. Employed		
Yes	44	54.3
No	37	45.7
2. Type of Employment		
Part-Time	25	30.9
Full-Time	15	18.5
Other (e.g., Self-Employed)	4	4.9
3. Type of Unemployment		
Seeking Employment	10	12.3
Not Seeking Employment	14	17.3
Would Consider Employment Given the Opportunity	13	16.0

Generally, most students were employed (54.3%). Given they were employed, most worked part-time (30.9%). Given the students that were unemployed, most were not seeking employment (17.3%); however, many would have considered working given an employment opportunity (16.0%). It is important to note that these data were collected in the fall of 2020, during the COVID-19 pandemic, before any vaccinations were granted Federal Emergency Use Authorization.

Research Question One

The researcher addressed research question one, *Is the Precalculus Self-Efficacy Survey (PCSES) a valid and reliable instrument?*, with a four-phase process. First, some validity for the precalculus self-efficacy construct was achieved by developing the items with guidance from Bandura's (1977) theoretical framework and the process Zakariya et al. (2019) utilized when developing the CSEI. Second, a panel of three expert Precalculus teachers provided content and face validity. Third, multiple iterations of exploratory factor analysis (EFA) provided more construct validity. Finally, Cronbach's alpha statistics provided reliability for the survey as a whole, as well as its subscales. The next few paragraphs will provide more description of each component of the process.

Item Development

Using self-efficacy as a theoretical framework (Bandura, 1977), Toland and Usher (2016) suggested self-efficacy is most accurately measured with an instrument that includes task-specific items. Therefore, in the process of developing a valid instrument to measure calculus self-efficacy, Zakariya et al. (2019) began by identifying a set of Calculus 1 problems that represented as many learning outcomes from Calculus 1 as possible. Using the same procedure to develop a survey to measure precalculus self-efficacy, the researcher began by reviewing Student Learning Outcomes (SLOs) for collegiate Precalculus courses. Given that the study was set in Texas, the researcher accessed the spring 2020 edition of the Academic Course Guide Manual (ACGM), the standard published by the Texas Higher Education Coordinating Board (THECB, 2020) that stipulates SLOs for all freshman- and sophomore-level courses.

The ACGM cross-listed two versions of *Precalculus Mathematics*; specifically, a 3-credit format (MATH 2312) and a 4-hour format (MATH 2412) (THECB, 2020). The courses only differed in the amount of instruction time because they included the same SLOs, all of which included topics related to algebraic and trigonometric functions (THECB, 2020). The prerequisite for this course is College Algebra (or equivalent preparation) and generally assumes students have not previously taken a course in trigonometry (THECB, 2020). Broadly, the SLOs have remained virtually unchanged since 2012, which was confirmed by reviewing older editions of the ACGM from the THECB website. Generally, the first half of Precalculus reviews concepts from College Algebra (a prerequisite course), and the second half covers trigonometry (THECB, 2020). The goal of the course is to prepare students for the calculus sequence (THECB, 2020).

Given that the university research site had offered the 4-credit hour Precalculus course for many years, the researcher purposefully selected problems from past departmental final exams. Specifically, the researcher selected questions according to the following two principles. First, the researcher selected questions that equitably represented all the Precalculus SLOs. Second, the researcher ensured approximately half the problems focused on algebra, with the remaining half focusing on trigonometry, so that the mixture of problems mirrored the emphasis of the course content. The researcher settled on 25 examination problems (12 were algebra-focused; 13 were trigonometry-focused), forming the basis for the 25-item survey.

Face Validity and Content Validity

Having developed the items, the researcher sought content and face validity by consulting a panel of content experts. All three instructors were currently teaching freshman-level and sophomore-level college mathematics courses exclusively; one worked at the university where the research was conducted, and two worked at a local community college. Two instructors had over 15 years of cumulative experience teaching mathematics at the postsecondary level, and the third instructor had over 30 years of cumulative experience teaching mathematics at the postsecondary level. All instructors also had experience teaching high school mathematics. Each instructor had previously taught at least 10 sections of Precalculus at a college with approximately the same SLOs as the current version of Precalculus from the ACGM. The textbook from the research institution was provided to the instructors to confirm the language of the questions matched the language from the written curriculum. All instructors confirmed the selection of items for the PCSES: (a) represented each of the SLOs; (b) could reasonably be used to form a comprehensive final examination for Precalculus; (c) were not overly redundant; and, (d) matched the language in the written curriculum. The instructors recommended no edits and confirmed the item selection was reasonable.

Survey Development

After attaining face and content validity for what the survey items would cover, the researcher built the survey electronically using Qualtrics. The survey included 25 items, such that each item corresponded to one of the panel-approved Precalculus questions. The researcher modeled the PCSES after the CSEI, which asks students to indicate their confidence level (0 to 100) to solve a particular Precalculus problem at that moment (Zakariya et al., 2019). Therefore, the PCSES asks students to drag a horizontal slider (on their screen) to indicate how confident they are that they could solve the Precalculus problems at that moment (0 = *Not Confident,* through *50 = Moderately Confident,* to 100 = *Highly Confident*). Students were instructed to assume they had no additional resources (i.e., a graphing calculator). Following Zakariya et al. (2019), the researcher planned for the composite score (sum) to measure precalculus self-efficacy such that the higher the score, the higher the self-efficacy. Now that each item had been designed, the researcher considered how to compile them.

In the final stage of development, the researcher followed guidelines outlined by Dillman et al. (2014) to determine how to fit all the items together. For example, to increase response rate, the researcher included only one item per page, as well as a navigation button so respondents could review prior responses (Dillman et al., 2014). In terms of item sequencing, the researcher purposefully sequenced the items to follow the curriculum sequencing (i.e., the order with which the problems appeared in the textbook chronologically). The reason for this was that Dillman et al. (2014) recommends survey items related to events (i.e., learning moments) be asked in the same order with which the events occurred. Furthermore, Dillman et al. (2014) recommends that surveys begin with items relevant to as many respondents as possible and, by sequencing the items to follow the order they appeared in the curriculum, items at the beginning of the survey would pertain to prerequisite algebra content that the course theoretically teaches again, as opposed to trigonometric content that the course theoretically teaches for the first time.

In addition to item sequencing, the researcher carefully considered the overall appearance of the survey. For example, the researcher was careful to include images (e.g., graphs) that were clear across all platforms and screen sizes, thereby optimizing the survey for all mobile and desktop browsers (Dillman et al., 2014). Finally, the researcher tested the survey on multiple platforms, including different mobile devices (requiring interaction through touchscreen) and desktop browsers (requiring interaction through a mouse). Dillman et al. (2014) generally recommends researchers conduct cognitive interviews to identify survey design flaws (e.g., poorly worded questions). In this case however, cognitive interviews were not likely to improve wording for items on the PCSES because the researcher utilized questions from final examinations verbatim, which were constructed with the same phrasing that was used for similar exercises in the textbook. Therefore, altering the item phrasing could have negatively influenced internal validity. In Chapter III, the reader can find more design techniques the researcher used that applied to every survey in the study.

Data Analysis

After designing and testing the survey in Qualtrics, the researcher deployed the survey to all three Precalculus classes offered at the site in fall 2020. From these classes, 81 students provided demographic information, which formed the basis for the sample. Similar to the development of the CSEI by Zakariya et al. (2019), the researcher collapsed the 101-point scale two times in the following way. First, the researcher coded the values to an 11-point scale (0 to 10), such that 0 was coded as 0, 1-10 was coded as 1, 11-20 was coded as 2, …, 91-100 was coded as 10 (Zakariya et al., 2019). Second, the researcher coded the 11 values to a 5-point scale, such that 0-2 was coded as 1, 3-4 was coded as 2, …, 9-10 was coded as 5 (Zakariya et al., 2019). All items were positively coded; therefore, the researcher formed the composite score by calculating the sum of all items; the greater the score, the more self-efficacious the respondent. In an effort to establish some construct validity, the researcher chose to use EFA (Zakariya et al., 2019). Therefore, to confirm EFA was appropriate for those data, the researcher used Bartlett's sphericity test to check the multicollinearity of the sample correlation matrix, as well as a Kaiser-Meyer-Olkin (KMO) test for sample adequacy (Zakariya et al., 2019). Findings suggested the sample were sufficient for EFA, $\chi^2(300, n = 141) = 2905.801, p < .001,$ and the sample was sufficiently large (KMO = .935 > .5) (Cerny & Kaiser, 1977). Once confirming the multicollinearity and sample adequacy, the researcher performed the EFA.

Exploratory Factor Analysis (EFA)

Although the researcher followed Zakariya et al. (2019) when developing the items of the PCSES, given the differences in the data, the researcher could not follow the same process of analysis. Specifically, given the excessive skewness and kurtosis, the data Zakariya et al. (2019) analyzed were not approximately normal. In contrast, the researcher checked the skewness and kurtosis of the composites (Peters et al., 2017) and found their underlying distribution was approximately normal. Specifically, the absolute value of both statistics was less than 1, indicating the underlying distribution was approximately normal (Skew[X] = .122; Kurt[X] = - .777). Given that the data were confirmed to have an approximately normal distribution, the researcher continued to follow the analysis procedures found in Peters et al. (2017).

To observe how well the factors fit, the researcher performed a preliminary principal component analysis (PCA) extraction method with unrotated factor loadings to observe factor loadings greater than one (Thompson, 2010). Table 4.5 shows the eigenvalues and their corresponding proportion of explained variance. Additionally, the researcher produced a scree plot to visually determine the number of factors above the *elbow* (Zwick & Velicer, 1986). Figure 4.1 shows the scree plot.

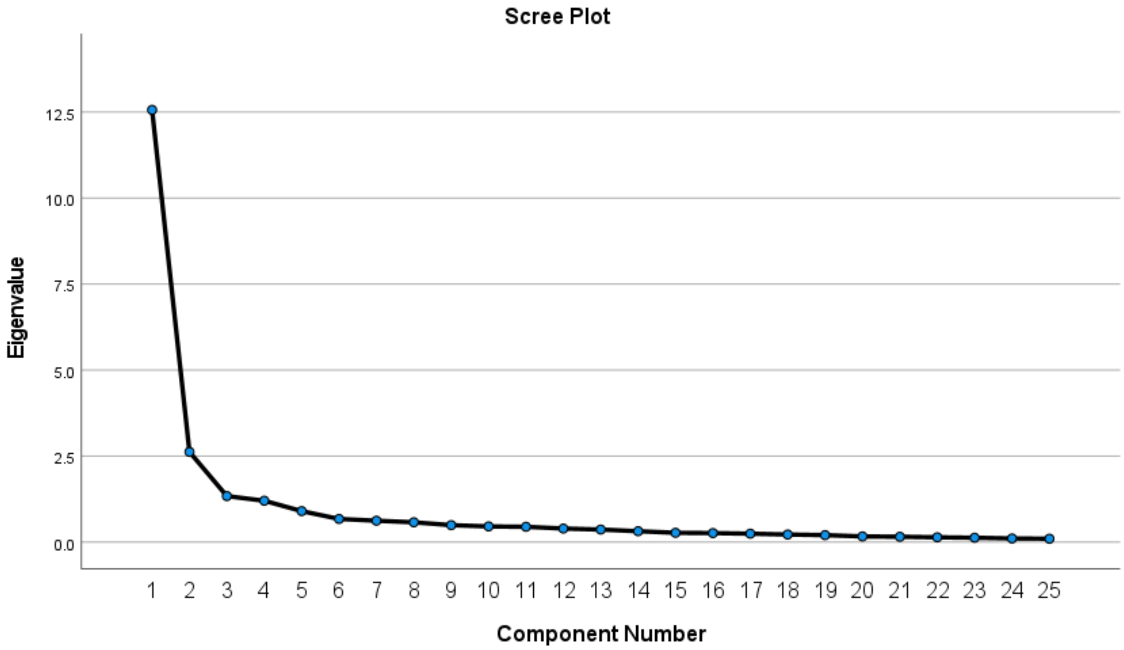
Table 4.5

Factor Extractions, Eigenvalues, and Total Variance Explained

Factor Extractions	Eigenvalue	Percentage of Variance	Cumulative Percentage
One Factor	12.564	50.256	50.256
Two Factors	2.624	10.494	60.705
Three Factors	1.339	5.357	66.107
Four Factors	1.204	4.816	70.923

Figure 4.1

Scree Plot Suggesting Two Factor Extraction Model



The preliminary PCA extracted four factors with an eigenvalue greater than one; however, the scree plot indicated two factors would more appropriately fit the data. Given that roughly half of the Precalculus course focuses on trigonometric functions (in keeping with the ACGM SLOs for MATH 2412), the researcher hypothesized that a two-factor model would be more appropriate, where one subscale focused on algebra, and the other focused on trigonometry. However, in an effort to exhaust all possibilities, the researcher performed three subsequent PCA extractions with varimax rotation, considering four-factor, three-factor, and two-factor models.

The four-factor solution placed only two items on the fourth factor, which was unexplainable with the theoretical framework, indicative that too many factors were extracted (Thompson, 2010). Losing only 4.8% of variance, the researcher considered the three-factor solution. Given that Precalculus fundamentally is the study of elementary functions, the researcher carefully considered whether the three-factor solution could generate a third subscale related to function-related concepts, or another aspect of Precalculus. Given that each item arguably involved functions to some extent since the concept permeates all aspects of the course, no obvious function-related concept clearly connected the items on the third subscale (e.g., use of notation). Likewise, no other obvious themes could explain the third subscale. Finally, the researcher calculated the two-factor solution, which agreed with analysis of the scree plot and best aligned with the SLOs in Precalculus. Table 4.6 shows the loadings distributed over two factors.

Table 4.6

Final Iteration of PCA with Varimax Rotation (2-Factors)

PCSES	Algebra Subscale	Trigonometry Subscale
Item 01	**0.754**	0.015
Item 02	**0.670**	0.091
Item 03	**0.722**	0.146
Item 04	**0.741**	0.305
Item 05	**0.733**	0.225
Item 06	**0.660**	0.231
Item 07	**0.646**	0.437
Item 08	**0.569**	0.432
Item 09	**0.686**	0.320
Item 10	**0.549**	0.489
Item 11	**0.652**	0.454
Item 12	**0.658**	0.398
Item 13	0.218	**0.806**
Item 14	0.177	**0.800**
Item 15	0.359	**0.798**
Item 16	0.477	**0.615**
Item 17	0.377	**0.619**
Item 18	0.339	**0.421**
Item 19	0.247	**0.829**
Item 20	0.327	**0.519**
Item 21	0.323	**0.785**
Item 22	0.345	**0.788**
Item 23	0.143	**0.839**
Item 24	0.107	**0.888**
Item 25	0.216	**0.856**

The first factor clearly aligned items that focused on algebra content (items 1-12), and the second factor clearly aligned items that focused on trigonometry content (items 13-25). Therefore, the two-factor solution most accurately modeled the data, accounting for 60.7% of the variance. Each value was greater than 0.4, indicating that all items produced a model with a reasonable fit (Guadagnoli & Velicer, 1988). To measure internal consistency within these data, the researcher calculated three Cronbach's alpha statistics; for the algebra subscale ($n = 12$; $a = .923$), for the trigonometry subscale ($n = 13$; $a = .951$), and for the complete survey as a whole ($n = 25$; $a = .957$).

Given that the EFA ultimately yielded two subscales, the researcher calculated two new composite variables. Each composite variable was calculated by taking the sum of all the item scores for each corresponding subscale. The researcher reviewed the skewness and kurtosis for the subscales. The calculations indicated the distributions were approximately normal (Algebra: Skew[X_A] = −0.133, Kurt[X_A] = −0.842; Trigonometry: Skew[X_T] = 0.122, Kurt[X_T] = −1.014) (Zakariya et al., 2019).

Research Question Two

Research question two, *Is there a statistically significant mean difference in students' precalculus self-efficacy prior to and following the completion of an online flipped Precalculus course?*, was addressed by using a two-tailed paired *t*-test to determine if there was a statistically significant mean difference in precalculus self-efficacy before and after students took the online flipped Precalculus course. Table 4.7 shows the results of the two-tailed paired *t*-test comparing pretest and posttest PCSES scores, which indicated a statistically significant mean difference in precalculus self-efficacy, $t(48) = -7.798$, $p < .001$, $d = 1.01$ (large effect size), $r^2 = .204$. Specifically, precalculus self-efficacy increased from the beginning ($M = 79.90$) to the end ($M = 102.41$) of the semester. The class model had a large effect on the students' precalculus self-efficacy and 20.4% of the variance in their precalculus self-efficacy can be explained by the class model.

Table 4.7

Paired T-Test: PCSES Pretest and Posttest

Self-efficacy	N	M	SD	*t*-value	df	*p*-value	d	r^2
Pretest	49	79.90	24.25	-7.798	48	< .001*	1.01	.204
Posttest	49	102.41	20.02					

*Statistically significant ($p < .05$)

Research Question Three

Research question three, *Is there a statistically significant mean difference in students' grit prior to and following the completion of an online flipped Precalculus course?*, was addressed by using a two-tailed paired *t*-test to determine if there was a statistically significant mean difference in grit before and after students took the online flipped Precalculus course. Table 4.8 shows the results of the two-tailed paired *t*-test comparing pretest and posttest GS scores, which indicated a statistically significant mean difference in grit, $t(52) = 2.600$, $p = .012$, $d = .254$ (small effect size), $r^2 = .016$. Contrary to expectation, for students enrolled in the online flipped Precalculus class, grit decreased from the beginning ($M = 3.70$) to the end ($M = 3.56$) of the semester. The class model had a small effect on the students' grit and 1.6% of the variance in their grit can be explained by the class model.

Table 4.8

Paired T-Test: Grit Pretest and Posttest

Grit	N	M	SD	*t*-value	df	*p*-value	d	r^2
Pretest	53	3.70	.501	2.600	52	.012*	.254	.016
Posttest	53	3.56	.597					

*Statistically significant ($p < .05$)

Research Question Four

Research question four, *What is the relationship between precalculus self-efficacy and mathematics achievement?*, was addressed by calculating Pearson product-moment correlations between precalculus self-efficacy (at the end of the course) and mathematics achievement (measured by final exam scores 0-100%). Results of the Pearson's product-moment correlation indicated that a statistically significant positive relationship existed between precalculus self-efficacy and mathematics achievement, $r(56) = .591,\ p < .001$, $r^2 = .337$. As a student's precalculus self-efficacy increases, so does their mathematics achievement. The proportion of variation in mathematics achievement attributed to precalculus self-efficacy was 33.7%.

Research Question Five

Research question five, *What is the relationship between grit and mathematics achievement?*, was addressed by calculating Pearson product-moment correlations between grit (at the end of the course) and mathematics achievement (measured by final exam scores 0-100%). Results of the Pearson's product-moment correlation indicated that a statistically significant positive relationship existed between grit and mathematics achievement, $r(55) = .289$, $p = .032$, $r^2 = .066$. As a student's grit increases, so does their mathematics achievement. The proportion of variation in mathematics achievement attributed to grit was 6.6%.

Research Question Six

Research question six, *Does precalculus self-efficacy and grit predict mathematics achievement?*, was answered with multiple regression, by calculating the *F* statistic from posttest PCSES scores, posttest GS scores, and comprehensive final examination scores (on a scale of 0-100%). Results of the multiple regression indicated that precalculus self-efficacy and grit explained 32.8% of the variance, $F(2,52) = 14.2$, $p < .001$, $r^2 = .328$. Furthermore, precalculus self-efficacy was a significant predictor of mathematics achievement ($\beta = .538$, $p < .001$), whereas grit was not ($\beta = .148$, $p = .207$).

Research Question Seven

Research question seven, *Does grit moderate the relationship between precalculus self-efficacy and mathematics achievement?*, was answered by using regression techniques. The results of the regression analysis indicated that grit did not moderate the relationship between precalculus self-efficacy and achievement ($t = .575$, $p = .568$). In other words, regardless of the amount of a student's grit, it will not impact the relationship between their precalculus self-efficacy and achievement.

Conclusion

This chapter presented the results of the quantitative data analysis in this study. In the next chapter, findings from this study will be compared, contrasted, and synthesized with the results of aforementioned studies from the review of literature. In addition, recommendations for future research will be discussed.

CHAPTER V:

SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

The purpose of this study was to investigate the relationships among self-efficacy, grit, and mathematics achievement in Precalculus classes taught with an OFM. Recent studies have researched the relationship between the FM and achievement; however, findings have been mixed (Collins, 2019; Mkhatshwa, 2021; Sahin et al., 2015; Spotts & Gutierrez de Blume, 2020; Ziegelmeier & Topaz, 2015). Significantly fewer studies have considered an OFM, and their findings are mixed (Stöhr et al., 2020; Swart & Macleod, 2020). Finally, studies that have considered the relationships among self-efficacy, grit, and achievement have been mixed (Alhadabi & Karpinski, 2020; Dixson et al., 2016). More research was needed to help clarify previous findings and tie these constructs together.

Given that no precalculus self-efficacy survey existed, the researcher developed the *Precalculus Self-Efficacy Survey* (PCSES) in the summer of 2020. In the fall 2020 and spring 2021 semesters, 141 students completed the PCSES for the purposes of validating the survey. Of those 141 students, the researcher purposefully selected students enrolled in all three sections of Precalculus in fall 2020 to examine the relationships among self-efficacy, grit, and achievement in a class taught with an OFM. At the beginning and end of the semester (i.e., pretest/posttest), students completed the *12-Item Grit Scale* (GS) (Duckworth et al., 2007) and the PCSES (which was developed and validated in this study). Comprehensive final examinations were used to measure mathematics achievement. This chapter discusses the findings from the study and synthesizes those findings with current and salient educational research literature. The chapter concludes with implications and the researcher's recommendations for future research.

Summary

Results from research question one yielded a valid and reliable survey used to measure precalculus self-efficacy. Validity was established by developing the items with guidance from Bandura's (1977) theoretical framework, following the process used to develop a similar survey (Zakariya et al., 2019), consulting with a panel of highly experienced teachers, and performing multiple iterations of exploratory factor analysis (EFA). Reliability was established by calculating Cronbach's alpha statistics for the survey as a whole, as well as both its subscales.

Findings from research question two indicate that there was a statistically significant mean difference in precalculus self-efficacy after students took the Precalculus course taught with an OFM. Specifically, students' precalculus self-efficacy increased by the end of the semester. The findings from this study agree with those from Swart and Macleod (2020), which found that increased student satisfaction from classes taught with the FM transferred to classes taught with an OFM. In addition, these findings partially agreed with Peters (2013) and partially disagreed with Sonnert et al. (2015). The findings from Peters (2013) suggested classroom climate influenced achievement, which partially agreed since student-centered classroom climate is related to active learning pedagogies, which would include the OFM used in this study. However, the findings from Sonnert et al. (2015) suggested that the use of ambitious teaching methods (defined similarly to the use of active learning pedagogies) had a negative relationship with student attitudes (an affective construct similar to self-efficacy). Therefore, this study partially disagrees with the findings from Sonnert et al. (2015).

Results from research question three show there was a statistically significant mean difference in grit from the beginning and end of the Precalculus course taught with the OFM. Surprisingly, students' grit decreased by the end of the semester. Although few studies considered changes in grit over the course of a study specifically, this finding affirms Alhadabi and Karpinski (2020), in that they found grit to be an important component of their predictive model. However, these findings partially disagree with Bowman et al. (2015), who found the Persistence of Effort (PE) scale from grit had a positive relationship with student outcomes. Although results related to other research questions will be discussed later in this chapter, several research questions in this study were concerned with grit, and findings were somewhat mixed (RQ5 and RQ6 versus RQ3 and RQ7). Ultimately, that fact could agree with the spirit of the findings from Credé et al. (2017), which suggests the grit construct may be problematic as its defined and measured. Statistically, it would be incorrect to say that the findings completely agree, since Dixson et al. (2016) studied correlation and regression. However, the results of this study agree in terms of their findings' general theme—grit did not have a positive relationship.

Results from research question four show precalculus self-efficacy predicted mathematics achievement in Precalculus courses taught with an OFM. This finding is not aligned with Stöhr et al. (2020), which found there was not sufficient statistical evidence to suggest the OFM influenced student achievement. However, Stöhr et al. (2020) compared results from different students over a period of six years, which may have introduced time period bias. Also, aside from differences in population (Sweden versus the U.S.), both studies had different research designs and asked different research questions. Furthermore, findings in research question three disagree with A. S. Burke and Fedorek (2017), which found negative student outcomes increased in classes taught with the FM. This could be possible because of fundamental differences between the studies; for example, A. S. Burke and Fedorek (2017) studied the population of sociology students by considering a sample of criminal justice courses, whereas the research in this dissertation studied the population of STEM students by considering samples of mathematics courses.

This finding disagrees with Ferguson (2020), which found negative student outcomes increased when Precalculus was taught online. One possible reason for the discrepancy is that online classes in Ferguson (2020) may have been taught asynchronously whereas the OFM considered in this study was taught synchronously. In terms of concurrent results, the findings from research question three agree with Swart and Macleod (2020) since both studies found OFMs were associated with positive student outcomes.

Findings from research question five show grit moderately predicted mathematics achievement in the Precalculus courses taught with an OFM. This result partially agrees with Bowman et al. (2015) and Credé et al. (2017), but for different reasons. Both Bowman et al. (2015) and Credé et al. (2017) concurred that Persistence of Effort (PE) was the most important component of grit; however, Credé et al. (2017) argued that grit was so strongly correlated with conscientiousness, that it may not be a distinct construct. The current study agrees with Bowman et al. (2015), which found that grit predicted many academic student outcomes. Also, the current study agrees with Credé et al. (2017), because grit was a relatively weak predictor. Results from research question six indicated that precalculus self-efficacy and grit predicted mathematics achievement in the Precalculus course that used the OFM. This finding partially agrees with Alhadabi and Karpinski (2020), which constructed a multivariable model of how self-efficacy and grit influenced achievement.

Findings from research question seven show that grit did not moderate the relationship between precalculus self-efficacy and mathematics achievement in Precalculus courses taught with an OFM. This was not explicitly addressed in the review of literature; however, it partially disagrees with Alhadabi and Karpinski (2020), which found the relationship between self-efficacy, grit, and achievement was multidimensional.

Implications

This study produced a few important implications including instrumentation and precalculus self-efficacy, their relationships among affective constructs, and an OFM. First, although self-efficacy is a well-established general construct, this study developed and validated the PCSES, which introduced the more specific precalculus self-efficacy construct. Therefore, more robust research is needed to confirm that precalculus self-efficacy is reliable and independent from other constructs; in other words, to confirm this study did not fall victim to what the psychological researchers refer to as the jingle-jangle fallacy (Pedhazur & Schmelkin, 1991). If precalculus self-efficacy is confirmed, the PCSES could foster more studies in precalculus. Another important implication regarding the development of the PCSES was that it included an Algebra subscale and a Trigonometry subscale. Therefore, these subscales alone could spawn future research in Algebra 2, College Algebra, Trigonometry, or other college entry-level mathematics courses.

Second, the study found some of the benefits of the face-to-face FM transferred when adapted to an OFM. Few studies have explicitly researched OFMs (Stöhr et al., 2020; Swart & Macleod, 2020), and results from each of these studies suggest OFMs are effective online pedagogical designs that incorporate active learning. A. S. Burke and Fedorek (2017) noted that a potential barrier for asynchronous online mathematics courses is students' difficulty to understand the use of notation compared to their face-to-face counterparts. However, the technology at the time of this writing enables synchronous online options that are arguably similar to face-to-face classes in that regard because the instructor can lecture with a shared screen in the same way that they can lecture in a face-to-face environment. Furthermore, students can share their screen while asking for clarification about their understanding of mathematical notation.

In terms of technology specifically, there are some adjustments students must make when interacting amongst themselves in an OFM. One specific way technology can impact the social dynamic is by negatively impacting communication. For example, when users have different quality of network service or experience lagging delays, interruption becomes more common. Another example is with both known and unknown technological difficulties. Consider the case where someone may not realize their microphone is malfunctioning. If they have their webcam off or if they have it on but their groupmates are looking down at their own work, the user with the malfunctioning microphone may feel they are being ignored. If a situation like that occurred at the end of a class before they realized they simply had a technological issue, it could negatively influence the group dynamic in a way that is not possible face-to-face.

Another element of communication is nonverbal communication, which introduces another challenge. Elements of interpersonal communication like social mores and doxa generally govern face-to-face social interactions; for example, when people are in a room together face-to-face, someone can tell if another person is making eye contact as they are speaking or are staring at them if neither of them are speaking. In a virtual meeting environment, that is not the case and users may feel self-conscious. Finally, talking in a small group is different with a webcam compared to face-to-face interaction. When engaged in discussion in a small group, users may be more comfortable with their webcam turned on; however, group work frequently includes periods where students are quiet as they go back to their work after helping each other. Because the social interactions are different online, students may be uncomfortable falling in and out of conversation as they interact with webcams. Some researchers have suggested that students may feel more self-conscious about their own appearance when they can see themselves in an online class session (Gherheș et al., 2021). Ultimately, more research is needed and new social norms will likely develop and evolve as online meetings become more common. Also, technologies need to adapt to specifically accommodate educational environments.

Finally, in terms of affective constructs, few studies considered in the Review of Literature checked grit toward the beginning and end of the study. This study serves as one example where grit decreased. Recall that these data were collected during the fall 2020 semester during the height of the COVID-19 pandemic, before vaccination was possible. With grit being a construct of the affective domain, a significant time of societal stress was not the ideal time to take a measurement. In addition to an increased possibility of measurement bias, Duckworth and Quinn (2009) developed a second instrument to measure grit, which may have yielded different results. Finally, in light of the research from Credé et al. (2017), and considering this study confirmed small effect sizes, more research is needed to clarify affective constructs.

Recommendations for Future Research

In terms of future research, the PCSES affords many opportunities. First, a study could attempt to show concurrent validity by giving the PCSES and another valid instrument that measures similar self-efficacy. For example, students in Calculus 2 should have high-levels of precalculus self-efficacy and calculus self-efficacy, so the results of both instruments should be highly correlated if both accurately measure their constructs. In addition, one benefit of the PCSES is that both the algebra and trigonometric subscales have been validated, providing the opportunity to measure self-efficacy in college algebra and trigonometry more accurately than with a more general instrument, like the Mathematics Self-Efficacy Survey (MSES). First however, it is recommended that a much larger study be conducted, with a nationally representative sample of Precalculus students. Perhaps CFA could be utilized instead of EFA, or if a sufficiently large sample is collected, a split-half design could be utilized, where EFA is performed with one half of the data, and the other half is later analyzed with CFA. More studies would help triangulate the validation of the PCSES in this study.

In terms of affective constructs, the findings from Credé et al. (2017) demonstrate the need for a comprehensive revalidation of grit as a construct. This researcher recommends a comprehensive examination of differences between self-regulation, conscientiousness, perseverance, and grit. In addition, a careful literature review of the differences between mathematical confidence and mathematical self-efficacy is warranted. Given that mathematical identity and mathematical mindset (related to growth mindset) are all interesting research areas, a large mixed methods study could be warranted to investigate the differences between these constructs, so as not to propagate the jingle fallacy or jangle fallacy referenced by Credé et al. (2017).

In terms of the OFM, the findings from Stöhr et al. (2020) related to increased polarization are fascinating. It seems reasonable that, if a student develops strategies that work in face-to-face classes that do not work in online classes, the student's perception of the alternative pedagogical design would be skewed and could be perceived negatively (Alhadabi & Karpinski, 2020). Although it was not brought up in this study, it may relate to what Herbst and Chazan (2012) refer to as the *didactic contract*. Related to a point made by Alhadabi and Karpinski (2020), student-centered classes empower students, but in the case of the FM, the burden of pacing the material shifts from the instructor to the student. Therefore, the terms of the didactic contract differ from the norm. This could be especially difficult for entry-level mathematics courses like Precalculus and Calculus 1, which are notoriously content-driven, and often taken by freshman that may not have adjusted to higher education.

Conclusion

This study investigated the relationship between affective constructs and achievement in Precalculus taught with an OFM. Some components of the study were well researched, like the FM, self-efficacy, and grit, whereas few studies exist regarding OFMs. This study provided an important early step in growing the body of research; however, more studies are needed to truly understand OFMs and its implications for the future.

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APPENDIX A:

SURVEY COVER LETTER

University
of Houston
Clear Lake

August 2020

Dear Precalculus Student:

Greetings! You are being solicited to complete three surveys this semester. The first will consist of standard demographic questions (e.g., age, ethnicity, educational background, etc.). The second will be a combined survey including the Mathematics Self-Efficacy Scale (MSES), and the 12-Item Grit Scale (TIGS). Finally, the third survey will be the Precalculus Self-Efficacy Survey (PCSES). The data obtained from this study will not only allow UHCL's Mathematics Department to improve student learning and achievement, but also contribute to the body of research in mathematics education. These surveys should take approximately 10-20 minutes to complete (each).

All of your responses will be kept completely confidential. No obvious undue risks will be endured and have the right to stop your participation at any time. You will not be asked to complete the demographic survey again, but you will be asked to complete the second two surveys again at the end of the semester. As an incentive for your participation, you will receive up to 2.5% extra credit on your overall average at the end of the semester for completing all surveys. I will know who has completed the surveys (but not individual results) only after final exam grades have been posted, and only to award the gift cards. Your participation in this study will not influence your grade.

Your willingness to participate in this study is implied if you proceed with completing the survey. Your completion of the survey is not only greatly appreciated, but invaluable. If you have any further questions, please feel free to contact me (carter@uhcl.edu). Thank you!

Sincerely,
Nelson L. Carter
Doctoral Student, UHCL
281-283-3730

APPENDIX B:

THE PRECALCULUS SELF-EFFICACY SURVEY (PCSES)

Cover Letter

Greetings! You are being solicited to complete five surveys this semester; this is a Pre-Calculus Self Efficacy Instrument (PCSEI) The data obtained from this study may not only allow UHCL's Mathematics Department to improve student learning and achievement, but also contribute to the body of research in mathematics education. This survey should take approximately 10-20 minutes to complete.

All of your responses will be kept completely confidential. No obvious undue risks will be endured and you have the right to stop your participation at any time. Your grade will not be lowered in any way if you decide not to participate. If you complete all five surveys, you will receive extra credit I will know who has completed the surveys (but not individual results), only after all the final exams have been graded, to award the extra credit for final averages.

Your willingness to participate in this study is implied if you proceed with completing the survey. Your completion of the survey is greatly appreciated. If you have any further questions, please feel free to contact me (carter@uhcl.edu). Thank you!

Identification Information

What is your First Name?

What is your Last Name?

What is your Student ID Number?

PCSEI

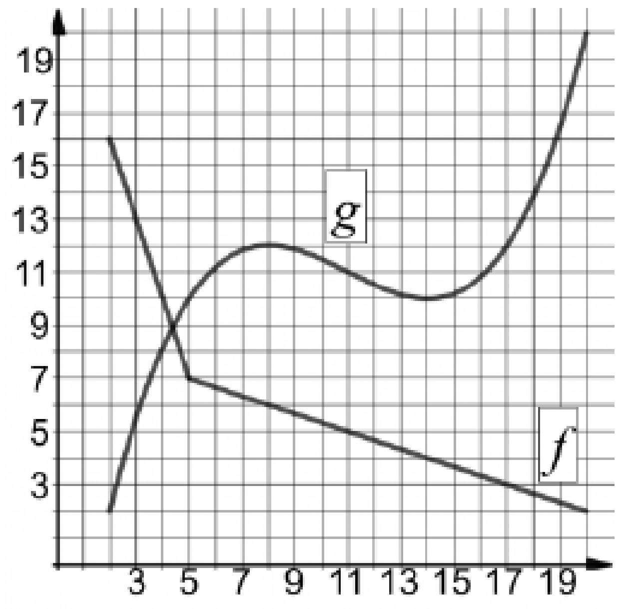
#1 Find the domain of the function $f(x)=\dfrac{x}{\sqrt{x+1}}$.

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 100)											

#2 If $f(x)=2x^2-3x+1$, evaluate $\dfrac{f(a+h)-f(a)}{h}$, $h\neq 0$.

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#3 Given the graphs of the functions f and g,
find $(f \circ g)(14)$.



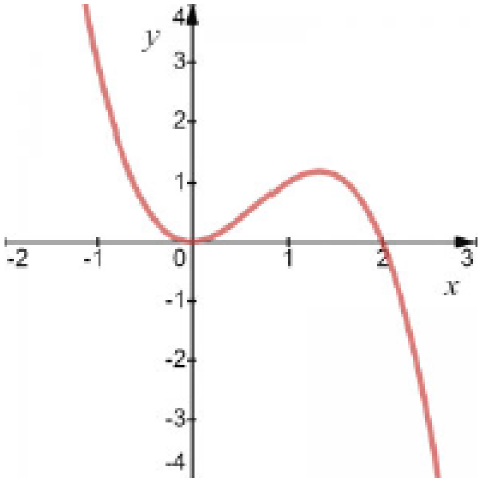
	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#4 Find the vertex of the quadratic function

$$f(x) = 3x^2 - 6x + 1.$$

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#5 The graph of $f(x)$ (below) could be expressed with which of the following algebraic/symbolic representations?



a) $f(x) = -x^3 + 2x^2$

b) $f(x) = -x^3 - 2x^2$

c) $f(x) = -x^2 + 2x$

d) $f(x) = -x^2 - 2x$

e) $f(x) = x^3 - 4x^2 + 4x$

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#6 Divide $6x^2 - 26x + 12$ by $x - 4$.
Express your answer in the form:
$P(x) = D(x) \cdot Q(x) + R(x)$

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#7 Find a polynomial $P(x)$ of degree 3 that has integer coefficients and zeros $\frac{1}{2}$ and $3-i$.

0 10 20 30 40 50 60 70 80 90 100

Confidence (0 - 100)

#8 Let $r(x)=\dfrac{3x^2-12x+13}{x^2-4x+4}$.
Find the intercepts and asymptotes, then sketch its graph.

0 10 20 30 40 50 60 70 80 90 100

Confidence (0 - 100)

#9 Solve $\dfrac{1}{x}+\dfrac{1}{x+1}<\dfrac{2}{x+2}$.

0 10 20 30 40 50 60 70 80 90 100

Confidence (0 - 100)

#10 Evaluate the expression: $\log_3\left(\frac{1}{27}\right)$.

0 10 20 30 40 50 60 70 80 90 100

Confidence (0 - 100)

#11 Use logarithmic properties to combine the following expression into a single logarithm:
$3\log x + \frac{1}{2}\log(x+1)$

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#12 Solve the equation $e^{2x} - e^{x} - 6 = 0$.

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#13 Evaluate $\cos\left(\frac{2\pi}{3}\right)$.

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#14 Evaluate $\sin\left(135^{\circ}\right)$.

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

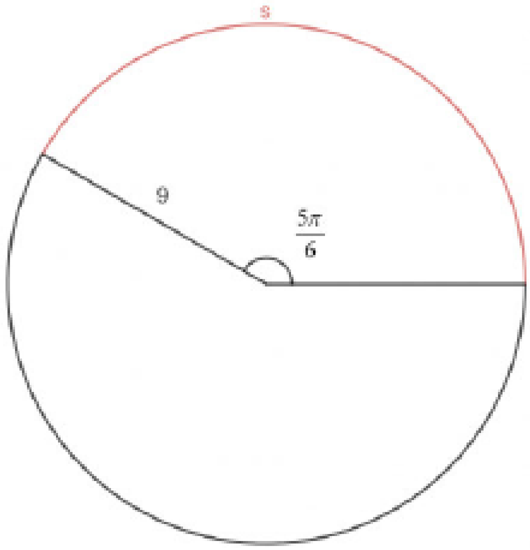
#15 Sketch one period of the graph of $y = 1 + \cos\left(3x + \frac{\pi}{2}\right)$.

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#16 Given that $\sin t = -\frac{4}{5}$, such that the terminal point determine by t is in Quadrant IV, find the values of the other five trigonometric functions determined by t.

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

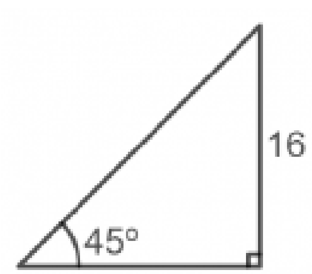
#17 Find the length s of the circular arc, with the given central angle.



0 10 20 30 40 50 60 70 80 90 100

Confidence (0 - 100)

#18 For the given triangle (below), find the lengths of all sides, and the measure of all angles.



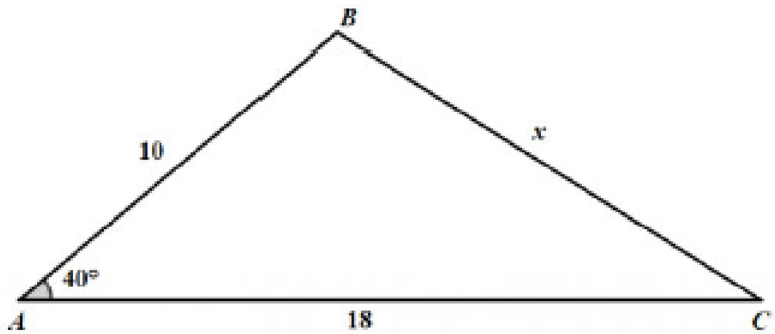
0 10 20 30 40 50 60 70 80 90 100

Confidence (0 - 100)

#19 Evaluate $\cos\left(\sin^{-1}\left(\frac{3}{5}\right)\right)$.

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#20 Using either the Law of Sines or the Law of Cosines (as appropriate), find the length of the side of length *x* of the triangle shown below.



	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#21 Simplify the trigononmetric expression:

$$\frac{\sin x}{\cos x}+\frac{\cos x}{1+\sin x}$$

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#22 Prove that $\frac{1}{1-\sin^2(x)}=\frac{1}{\tan^2(x)}$.

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#23 Calculate the exact value of $\cos\left(75^{\circ}\right)$.

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#24 Calculate the exact value of $2\sin\left(15^{\circ}\right)\cos\left(15^{\circ}\right)$.

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

#25 Solve $\sqrt{3}\tan\left(\frac{x}{2}\right)-1=0$.

	0	10	20	30	40	50	60	70	80	90	100
Confidence (0 - 100)											

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APPENDIX C:

THE 12-ITEM GRIT SCALE

12- Item Grit Scale

Directions for taking the Grit Scale: Please respond to the following 12 items. Be honest – there are no right or wrong answers!

1. I have overcome setbacks to conquer an important challenge.
   - ❑ Very much like me
   - ❑ Mostly like me
   - ❑ Somewhat like me
   - ❑ Not much like me
   - ❑ Not like me at all

2. New ideas and projects sometimes distract me from previous ones.*
   - ❑ Very much like me
   - ❑ Mostly like me
   - ❑ Somewhat like me
   - ❑ Not much like me
   - ❑ Not like me at all

3. My interests change from year to year.*
   - ❑ Very much like me
   - ❑ Mostly like me
   - ❑ Somewhat like me
   - ❑ Not much like me
   - ❑ Not like me at all

4. Setbacks don't discourage me.
   - ❑ Very much like me
   - ❑ Mostly like me
   - ❑ Somewhat like me
   - ❑ Not much like me
   - ❑ Not like me at all

5. I have been obsessed with a certain idea or project for a short time but later lost interest.*
   - ❑ Very much like me
   - ❑ Mostly like me
   - ❑ Somewhat like me
   - ❑ Not much like me
   - ❑ Not like me at all

6. I am a hard worker.
   - ❑ Very much like me
   - ❑ Mostly like me
   - ❑ Somewhat like me
   - ❑ Not much like me
   - ❑ Not like me at all

7. I often set a goal but later choose to pursue a different one.*

- ❑ Very much like me
- ❑ Mostly like me
- ❑ Somewhat like me
- ❑ Not much like me
- ❑ Not like me at all

8. I have difficulty maintaining my focus on projects that take more than a few months to complete.*

- ❑ Very much like me
- ❑ Mostly like me
- ❑ Somewhat like me
- ❑ Not much like me
- ❑ Not like me at all

9. I finish whatever I begin.

- ❑ Very much like me
- ❑ Mostly like me
- ❑ Somewhat like me
- ❑ Not much like me
- ❑ Not like me at all

10. I have achieved a goal that took years of work.

- ❑ Very much like me
- ❑ Mostly like me
- ❑ Somewhat like me
- ❑ Not much like me
- ❑ Not like me at all

11. I become interested in new pursuits every few months.*

- ❑ Very much like me
- ❑ Mostly like me
- ❑ Somewhat like me
- ❑ Not much like me
- ❑ Not like me at all

12. I am diligent.

- ❑ Very much like me
- ❑ Mostly like me
- ❑ Somewhat like me
- ❑ Not much like me
- ❑ Not like me at all

Scoring:

1. For questions 1, 4, 6, 9, 10 and 12 assign the following points:
   5 = Very much like me
   4 = Mostly like me
   3 = Somewhat like me
   2 = Not much like me
   1 = Not like me at all

2. For questions 2, 3, 5, 7, 8 and 11 assign the following points:
   1 = Very much like me
   2 = Mostly like me
   3 = Somewhat like me
   4 = Not much like me
   5 = Not like me at all

Add up all the points and divide by 12. The maximum score on this scale is 5 (extremely gritty), and the lowest scale on this scale is 1 (not at all gritty).

Duckworth, A.L., Peterson, C., Matthews, M.D., & Kelly, D.R. (2007). Grit: Perseverance and passion for long-term goals. *Journal of Personality and Social Psychology, 9*, 1087-1101.