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Academic Math Mindset Interventions in First-Year College Calculus

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Academic Math Mindset Interventions in First-Year College Calculus

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Dissertation

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Doctor of Philosophy

The University of Texas at Austin

August 2017

Dedication

To my daughter, Vivien. This work was completed because of you, more than anyone. I love you.

Acknowledgements

After many years working on this, I have accumulated a significant debt of gratitude to several people. I can never repay this debt, though I will try whenever possible. The best I can do for now is acknowledge some of it.

Prof. Uri Treisman, when I met you I was on the brink of leaving graduate school. You gave me a home at UT and served as my mentor in research, in teaching, and in life. I have learned more from you than I can say and probably more than I recognize. Watching you teach your students has been an inspiration, and I hope I can have half the impact on my students that you have on yours. Thank you for your guidance and for always making me feel like I could actually finish this thing.

I have had the pleasure of teaching with or being taught by each of my committee members: Prof. Mark Daniels, Prof. Kathy Davis, Prof. Lorenzo Sadun, Prof. Diane Schallert, and Prof. Michael Starbird. I've learned so much from each of you about the art and science of teaching and learning. Thank you for teaching me the importance of respecting my students' thought processes, goals, and backgrounds. I strive to use the many lessons I've learned from each of you in my teaching.

I acknowledge the debts that can never be repaid to Prof. Efraim Armendariz and Prof. Ted Odell, two former committee members who are now, sadly, deceased. Each of these incredibly kind men treated his students and me with sincere respect and care. They were true models of the teaching profession, and I am grateful to have known them.

I am grateful for the guidance and eternal patience of each of the graduate advisers and graduate coordinators that have supported me: Prof. Lorenzo Sadun, Prof. Dan Knopf, Prof. Thomas Chen, Prof. Kui Ren, Nancy Lamm, Sandra Catlett, and Elisa Bass. Thanks also to Dr. Jane Arledge and Dr. John Meth for accommodating my research as a part of their larger study of undergraduate calculus courses.

My interest in teaching mathematics was sparked by my former boss and tutoring mentor, Rick Gibson. Prof. Cristian Bahrim and Prof. Ted Mahavier, my amazing undergraduate mentors, showed tireless dedication to their students, fueling my interest in teaching and helping me develop as a scholar. Thank you each for opening my eyes to the multiple facets of effective teaching.

Thank you, Lilly Soto, Rachele Siefert, and all the rest of the Dana Center staff, for helping me feel welcome and valued in Prof. Treisman's world and always finding a way to fit me into his schedule. Cyntreva Paige, thank you for helping me get this study off the ground. You were instrumental in coordinating the logistics of the experiment and the tedious data collection. Rahel Kahlert and Francesca Leahy, thank you each for taking on the monumental task of helping me organize my time and work. Marissa Faris, you graciously proofread my work, and without your overall support, I would still be, as I was for so long before I met you, perpetually one more semester away from completion. Stephanie Baker, your fingerprints are all over this dissertation, along with your blood, sweat, and tears. I would not have made it this far without your friendship and countless hours of help, and your persistence through tribulations much like my own was an inspiration. I honestly could never repay you, but I will never stop trying.

My parents, Margaret and Danny Hunt, set me on the path of lifetime learning that has led me to and through this point. My sisters, Karla Cohen and Jessie Hunt, helped me through rough times with their friendship and encouragement. My daughter, Vivien Hunt, encouraged me to finish, inspired me to set a high standard for myself, and let me know that I was loved no matter what. Many more family members and friends encouraged me

to keep working because they knew I could achieve my goal. I am eternally grateful to each of you. Thank you.

Academic Math Mindset Interventions in First-Year College Calculus

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The University of Texas at Austin, 2017

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Freshman calculus is in the policy spotlight. This gateway course's well-documented high failure rates impede students' timely completion of baccalaureate degrees. The Mathematical Association of America launched a large-scale study of calculus instruction documenting the breath and intensity of efforts to increase student success. Concurrently, economic studies reveal high returns on investment for mathematics-dependent majors. This study examines whether brief, low-cost interventions targeting freshman calculus students' beliefs about (1) the nature of intelligence, (2) the course content's relevance to their goals, and (3) whether they belong to the community of successful mathematics students, can increase their academic performance.

To this end, I developed and implemented 3 academic "math mindset" interventions. Each consisted of a video of former calculus students ostensibly reflecting on their experiences and their development and adoption of 1 of the 3 targeted math mindsets: growth ("math intelligence increases with effort"), purpose ("math is relevant to my future"), or belongingness ("I am a valued member of the mathematics community"). The videos lasted between 2 and 4 minutes and were embedded in online homework assignments in 18 first-semester calculus courses. The study included 663 participants.

My measures include a validated test of conceptual understanding of differential calculus and self-report surveys of regulation of cognition, task value, control of learning, and self-efficacy. I observed no large significant effects of the interventions on the outcome measures. Unbeknown to me, a similar intervention was administered to all incoming freshmen during the same year; this could have contributed to the lack of positive results.

A growing research base has demonstrated the effectiveness of academic mindset interventions in raising K-12 students' academic achievement and persistence. This study explored the possible effectiveness of such interventions on college freshman. It provides an important reminder that mindset interventions are not guaranteed to deliver positive results, even when they address crucial student beliefs, and that contextual factors play a considerable role in their effectiveness. It adds to the developing suite of mindset interventions that may produce positive outcomes under other circumstances, and it provides educators with useful insight about the practical applications of academic mindsets in calculus classrooms.

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Chapter 1: Introduction

Rationale

As the world grows more dependent on advancing technologies, the United States grows more dependent on members of its workforce with at least some postsecondary education and training in science, technology, engineering, and mathematics (STEM). In postsecondary education, calculus serves as a gateway to advanced study in many STEM fields, and just as a gateway might block one's path, calculus blocks the educational trajectories of many would-be STEM graduates, often diverting them to other fields. Postsecondary calculus courses provide a unique target for reform, where improvement could lead to substantial benefits for the economy and quality of life in the U.S.

Scientific and technological advances have accelerated over the last several decades. Moore's Law, an empirical law that predicted the doubling of capabilities in computing technology roughly every two years, has held true. Exponentially improving computing technologies have driven accelerated understanding and innovation in all STEM fields. Scientists, engineers, and mathematicians have developed an increased reliance on computing technology for modeling climate change, the design and testing of life-saving medical treatments, development of remarkable new materials, analysis of expansive data sets, and myriad other innovations and areas of study. Technology has become ubiquitous in the everyday lives of U.S. citizens, and consumers have come to expect continual improvements. Although Moore's Law now reaches its end as silicon chips near capacity, innovations will continue to be developed and propagated throughout the workplace and economy in the U.S. The continued evolution and adoption of new technologies demand a workforce composed of a growing number of STEM graduates.

Numerous reports in recent years have stressed the need for more STEM graduates now and in the coming decades. In 2012, the President's Council of Advisors on Science and Technology (PCAST) predicted that, based on the current assumptions, the U.S. would experience a shortfall of approximately a one million STEM graduates[1] over the following decade (Olson & Riordan, 2012). The Bureau of Labor Statistics projected that occupations in STEM fields would increase at a higher relative rate than non-STEM occupations (Lockard & Wolf, 2012; Vilorio, 2014). It is worth noting that the severity of the STEM crisis varies greatly depending on the field, the level of degree, and the geographical location (Xue & Larson, 2015). In particular, Xue and Larson (2015) find that there is a surplus of PhDs in academia and most fields in industry and government, with exceptions such as petroleum engineering, computer engineering, nuclear engineering, materials science, and thermohydraulic engineering. Demand for STEM workers with bachelor's degrees is a bit steadier, especially for software development, data science, and petroleum engineering

Aside from the high but uneven demand in STEM occupations, non-STEM fields have also become much more reliant on workers with some college-level STEM education. A National Science Foundation survey of college graduates showed that although the number of college graduates working in STEM-specific jobs increased only modestly from 2003 to 2010, the number of graduates working in non-STEM jobs that required some postsecondary STEM education nearly doubled (National Science Board, 2015). The

[1] There is not universal consensus on what majors are included under the umbrella term "STEM". In this dissertation, unless I state otherwise, STEM includes Mathematics, Life Sciences (excluding medical sciences), Physical Sciences, Engineering and Engineering Technology, Computer and Information Sciences, and Science Technology. Social Sciences and Behavioral Sciences are not included because the theoretical bases of these sciences rely much less on a deep understanding of mathematics than the other fields, and researchers and educators often treat them as separate from STEM.

consensus is that the demand for workers with a strong postsecondary STEM education is increasing.

Meeting the increasing demand for workers with college-level STEM experience will make U.S. employers more productive, competitive, and prosperous, and this prosperity will in part be passed along to the employees. A report from the U.S. Department of Commerce shows that workers from STEM majors earn about 11% more than workers from non-STEM majors, even outside of STEM careers (Langdon, McKittrick, Beede, Khan, & Doms, 2011). This positions STEM education and careers as drivers of economic success and upward mobility. Furthermore, because the American demographics that have historically earned the lowest wages (U.S. Department of Labor: Bureau of Labor Statistics, 2017) are the same populations that are underrepresented in STEM fields (Landivar, 2013), increasing the representation of these workers in STEM-related careers would also go a long way toward reducing income inequity in the U.S..

Despite the growing demand and economic benefits of increasing the number of STEM graduates, the percentage of postsecondary degrees conferred that are in STEM fields has either changed very little or decreased in recent years (Lindsay, 2012). The problem seems not to be one of recruitment, though, but one of retention. As Figure 1.1 shows, data collected from college-bound seniors taking the SAT indicates that the percentage of decided students intending to major in a STEM field has been increasing over the last several years[2]. Data collected by the Cooperative Institutional Research

[2] This data is aggregated from archived College Board reports (The College Board, 2005, The College Board, 2006, The College Board, 2007, The College Board, 2008, The College Board, 2009, The College Board, 2010, The College Board, 2011, The College Board, 2012, The College Board, 2013, The College Board, 2014, The College Board, 2015, The College Board, 2016).

Program at the Higher Education Research Institute at the University of California, Los Angeles, confirms this trend[3].

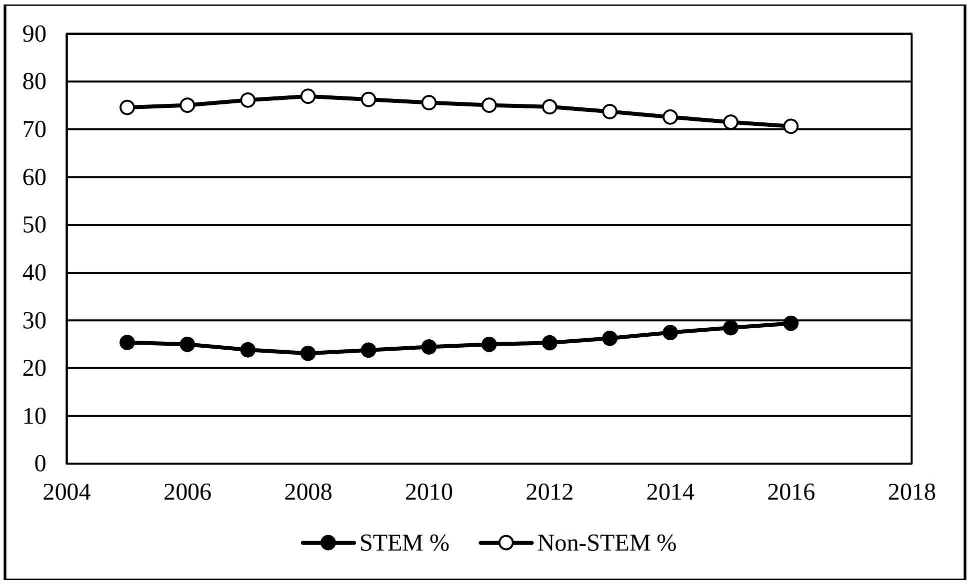

Figure 1.1: Percentage of SAT-takers planning to major in STEM and Non-STEM fields.

STEM majors have some of the worst persistence rates—less than half of students who begin in a STEM major persist until graduation (Chen, 2009; Olson & Riordan, 2012). Olson and Riordan report that many of the students who leave STEM majors do well in introductory courses and would likely have made valuable contributions to their fields had they persisted. Increasing retention in STEM fields presents an effective way to increase the number of students graduating with a STEM degree. Olson and Riordan estimate that increasing retention in STEM majors by 40-50% would meet about three fourths of the projected shortfall over the following decade (2012).

[3] This data is aggregated from archived Higher Education Research Institute reports (Eagan et al., 2014, 2015; Eagan, Lozano, Hurtado, & Case, 2013; Pryor et al., 2012; Pryor, DeAngelo, Palucki Blake, Hurtado, & Tran, 2011; Pryor, Hurtado, DeAngelo, Palucki Blake, & Tran, 2010).

Many studies have sought to determine what factors most commonly lead students in STEM fields to switch to a non-STEM field. Instructor pedagogy and quality of teaching seem to be major contributing factors (Seymour & Hewitt, 1997). Students often do not develop a strong connection with the material or to the faculty, whom they feel are unapproachable or unavailable for academic guidance (Seymour & Hewitt, 1997). These complaints have led to calls from researchers and educators to incorporate active learning, early research experiences, and learning communities in STEM courses to engage students and increase student motivation and confidence (Graham, Frederick, Byars-Winston, Hunter, & Handelsman, 2013).

The PCAST report on STEM identifies three aspects of students' experiences that influence retention: intellectual engagement and achievement, identification with a STEM field, and motivation (Olson & Riordan, 2012). Intellectual engagement concerns the students' individual engagement with course concepts in class. Active learning techniques incorporated in a class are intended to encourage intellectual engagement. Braxton and Lee (2005) point to evidence that active learning leads students to a greater commitment to graduation, which in turn leads to a higher rate of persistence. The second aspect Olson and Riordan (2012) identify, identification with a STEM field, has to do with the degree to which a student feels that they belong to the academic community of their field. The authors point to a growing body of evidence showing that creating opportunities for students to meaningfully interact with peers and faculty in their field increases the likelihood they will persist, especially for demographics historically underrepresented in STEM fields.

The last aspect of students' experiences Olson and Riordan (2012) identify is motivation, a multifaceted construct (Deci, Vallerand, Pelletier, & Ryan, 1991; Dweck & Leggett, 1988; P. R. Pintrich, 2003; Weiner, 1972; Wigfield & Eccles, 2000). Motivation is significantly determined by a student's disposition and prior experiences, but motivation is also impacted by a student's subjective college experience. Olson and Riordan (2012) point to evidence that lack of relatable role models, financial concerns, lack of encouragement from family, and few peers from similar backgrounds all tend to have a negative effect on motivation and persistence. The authors also stress that a student's beliefs about barriers to academic success can influence how motivation is impacted by academic success or struggle. Students who believe that their intelligence is a fixed entity rather than malleable are more likely to view struggle as a sign of inadequacy and are less likely to persist through struggle. Fortunately, with intervention, students can adopt the mindset that intelligence is malleable and can grow (a growth mindset of intelligence) (Dweck, Chiu, & Hong, 1995; Dweck & Leggett, 1988; Farrington et al., 2012). Stereotype threat—being presented with or reminded of negative stereotypes—can also diminish motivation and threaten persistence (Steele, 1997; Steele & Aronson, 1995). Because negative stereotypes tend to be attached to demographics underrepresented in STEM, addressing this threat could do much to retain these populations which are leaving STEM majors at higher than average rates (Chen, 2009).

Students' experiences with mathematics play an important role in their persistence. Chen (2009) reports that students who have taken calculus in high school tend to persist in STEM majors at a rate higher (61.0%) than average (40.7%), and the rate is much lower (< 28.1%) than average for students who have not taken trigonometry or precalculus in high school. This suggests that struggles with college calculus may redirect many students out of STEM fields. This claim is supported by the research of Seymour and Hewitt (1997) who interviewed STEM majors and found that their reasons for leaving often stemmed from feeling overwhelmed and struggling with conceptual understanding, especially in mathematics and chemistry. Bressoud, Carlson, Mesa, and Rasmussen (2013) showed that after passing a first-semester course, students' confidence in mathematics, enjoyment of mathematics, and desire to take more mathematics courses all decreased. Clearly calculus is a major hurdle for many students in STEM majors.

Calculus is often one of the first courses students take when they embark on an education in STEM, and it is nearly universally required for STEM majors. This positions first-year calculus as a gatekeeper course. Nearly all STEM-intending students must either pass through the gateway to continue to advanced study in their intended fields, or they must find other educational paths. First-semester calculus offers a nearly unique point in STEM education where improving students' learning and experience can have a twofold effect of impacting almost all STEM students and deepening their understanding of concepts that are essential to their success in subsequent STEM courses.

Calculus instruction needs to be improved, but reform initiatives can be costly. They generally require additional money to implement, potentially raising the cost of tuition. They require staff time to be spent on logistical changes, and they necessitate instructor training. Fortunately, researchers have begun investigating cost effective ways to address similar reform needs in mathematics education. Reviews by Yeager and Walton (2011) and Snipes, Fancsali, and Stoker (2012) summarize the results of several brief but impactful interventions that have raised students' academic performance and persistence. These results have demonstrated the effectiveness of short-term, minimally intrusive, social-psychological interventions to impact students' academic beliefs and attitudes. These interventions typically address one or more of the following mindsets: a growth mindset of intelligence, a sense of purpose and passion, belongingness and identity as part of the academic community, and the use of deliberate learning strategies. The interventions often involve brief exercises in which participants learn that other similar students have experienced similar worries and struggles but developed productive mindsets and successfully persisted. Many interventions utilize the ostensible testimony of former students or authoritative articles on the science of learning and follow up with writing exercises that allow participants to internalize and take ownership of the intended message. Such exercises might reasonably be made and implemented at very little financial cost and with little time invested, but they can have lasting effects on student performance (Farrington et al., 2012). Yeager and Walton (2011) explain that these seemingly "small" interventions can have surprisingly large lasting effects because they address mindsets that tend to set up either productive or deleterious feedback loops of motivation and behavior.

RESEARCH QUESTIONS

My research addresses the growing need for STEM majors by attempting to improve students' first-semester calculus experience by fostering productive mindsets to enhance learning and persistence. I build upon the social-psychological interventions discussed above by designing and delivering to first-semester calculus students very brief peer-delivered video interventions targeting the following academic mindsets: a growth mindset of mathematics intelligence, a sense of purpose in the calculus course, and academic belongingness in the calculus class and university. My research questions are listed below.

Effects of Interventions on Calculus Understanding

1. What is the effect of a novel growth mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?
2. What is the effect of a novel purpose mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?

3. What is the effect of a novel belongingness mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?

Effects of Interventions on Motivation and Regulation of Cognition

4. What are the effects of a novel growth mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of regulation of cognition, task value, control of learning, and self-efficacy as measured by standard instruments?
5. What are the effects of a novel purpose mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of regulation of cognition, task value, control of learning, and self-efficacy as measured by standard instruments?
6. What are the effects of a novel belongingness mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of regulation of cognition, task value, control of learning, and self-efficacy as measured by standard instruments?

I used the Calculus Concept Inventory (Epstein, 2006) to measure students' gains in calculus conceptual knowledge, and I assessed their regulation of cognition, task value, control of learning beliefs, and self-efficacy for learning with scales of the Metacognitive Awareness Inventory (Schraw & Dennison, 1994) and the Motivated Strategies for Learning Questionnaire (P. Pintrich, Smith, Garcia, & McKeachie, 1991). I performed multiple linear regression analyses to predict these outcome measures using the intervention groups (growth, purpose, or belongingness) as predictor variables. I observed no significant impact of the interventions on any of the outcome measures, due to a combination of limitations and delimitations.

Delimitations and Limitations

I only included in this study subjects who were students in a first-semester college calculus course at a large research. Because the course is required for nearly all STEM majors, it is an ideal course to augment with interventions designed to increase student success. I limited my focus to interventions that addressed students' growth mindset, sense of purpose, and belongingness. The relevant literature points to these academic mindsets as promising targets for brief and effective social-psychological interventions intended to produce favorable academic outcomes. I used only very brief interventions delivered by experienced student peers via video, a purposeful delimitation. Social-psychological interventions have been shown to be effective in other contexts, though they are often delivered by perceived authorities and typically require at least an hour of the subject's time. I wanted to know if brief interventions delivered by peers via videos would be as effective in the context of a calculus course.

Another delimitation was that I assigned all students in a calculus class to the same treatment group. I did this to avoid cross-intervention effects, but this also makes it difficult to account for the effects of class-level factors such as the quality of instruction. I chose not to collect demographic information to reduce the chance of survey fatigue with an already lengthy survey. Additionally, the interaction of the interventions with demographic characteristics was not a focus of this study. Finally, I used only selected scales of the Motivated Strategies for Learning Questionnaire (task value, control of learning beliefs, and self-efficacy for learning and performance) and the Metacognitive Awareness Inventory (regulation of cognition). I used only these scales so that the survey would not be so long as to discourage response but so that it still addressed relevant noncognitive factors. Furthermore, these scales were being used in evaluations of the redesign of other large-enrollment first-year courses at the same university, and I wanted the option to compare results from my interventions to the effects of other course redesign efforts.

The most significant limitation of this study comes from the unplanned concurrence of my interventions with a large-scale study employing longer interventions to address the same academic mindsets during freshmen orientation. It is likely that most of the participants in my study were unknowingly part of the other study prior to participating in my study. This has made any effects of the two interventions studies impossible to distinguish, and it likely created a ceiling effect for my interventions. I was unaware of the other study until a year after I had administered my interventions.

Another limitation of this study was the small number of classes in each treatment group. There were initially only ten classes included in the study, and each was assigned to one of four treatment groups. Therefore only 2-3 classes were assigned to each of the intervention groups, and the rest were assigned to the comparison group. The small number of classes in each group made more sophisticated modeling that could have controlled for differences between classes and instructors (e.g., hierarchical linear modeling) unlikely to give meaningful results.

Roadmap of This Dissertation

In this chapter, I discussed the rationale, focus, limitations, and delimitations of this research. In Chapter 2, I review the relevant literature. I present the methodology of this study in Chapter 3. In Chapter 4, I describe the results of this research. I conclude in Chapter 5 with a discussion of the implications and limitations of the study and ideas for future study.

Chapter 2: Literature Review

In this chapter, I address three areas of research centrally relevant to this study: undergraduate calculus, academic math mindsets, and social-psychological interventions. In my review of undergraduate calculus, I discuss how the role of mathematics in undergraduate education has changed over time, with a focus on the curriculum and instruction of first-semester calculus courses. I summarize some important findings from recent research on characteristics of calculus course offerings that seem to undermine calculus students' confidence and motivation.

In the second section of this literature review, I discuss the theoretical underpinnings of three academic mindsets—students' growth mindset of intelligence, sense of purpose, and academic belongingness. I review literature that has shown that each of these mindsets is central to academic persistence and success.

In the last section of this chapter, I review research utilizing social-psychological interventions meant to promote productive academic mindsets. I discuss how existing research supports the notion that social-psychological interventions delivered by calculus students' peers could positively impact the academic math mindsets of the targeted students.

UNDERGRADUATE CALCULUS

Postsecondary calculus in the U.S. has evolved since its initial inclusion in mathematics courses of study in the early nineteenth century (Cajori, 1890). Before then college mathematics was considered part of a classical curriculum and typically only included Euclidean geometry and some algebra. In the early- to mid-nineteenth century, only the most interested and capable students studied differential calculus (fluxions). Students and instructors often viewed calculus as too abstruse for the average student. This view, as Cajori (1890) puts it, “worked an untold amount of mischief in mathematical education” (p. 83), but he continues, optimistically, that “the delusion will soon vanish that the average college student is not able to grasp the more advanced branches of exact science” (p. 83). Cajori based this hope on the growing realization that inadequate preparation and instruction were to blame for students’ seeming incapacity to understand. Educators were beginning to recognize the failures of instruction that focused on lecture with no practice, except for practice done with tutors who were as uninterested in the material as the students (Eddy, 1885). The persistence more than a century later of these problems—though now less pervasive—is remarkable.

Throughout the nineteenth century, as college-preparatory instruction became more common, the intellectual level and rigor of college mathematics improved (Tucker, 2013). In the latter half of the nineteenth century, some students were taking calculus in their junior or senior year. However, college enrollment declined in much of the latter half of the century as students grew increasingly dissatisfied with a classical curriculum that had little use after graduation. To appease students, colleges followed the lead of Charles Eliot at Harvard and introduced a free elective system modeled after Germany’s system (W. L. Duren, 1989). The elective system lead to a surge in overall enrollment, but a decline in study of the classics (Tucker, 2013). Along with Latin and Greek, mathematics was so established as one of the classics that mathematics nearly dwindled out, due to lack of interest (E. B. Wilson, 1913). The demand for students in engineering and the new sciences likely saved college mathematics (Tucker, 2013). Thus, mathematics had gone from a central part of a classical curriculum to a subject associated with engineering and science.

The declining role of mathematics in American education spread to high schools, where, in many cases, mathematics became an elective in the early twentieth century (Tucker, 2013). Subsequently, colleges began offering many more precollege mathematics courses in arithmetic and beginning algebra to account for students' minimal mathematics preparation.

This crisis went largely unnoticed until the mid-1910s. Edwin Bidwell Wilson (1913) was one of the first to respond with a call for calculus in the first year of college, citing calculus' utility for a broad student population. Shortly after, the Mathematical Association of America (MAA) was established, and the first president, Earle Raymond Hedrick, made improving collegiate mathematics a central focus (Hedrick, 1916). Hendrick was concerned about the decline in mathematics enrollment as well as the broader problem of students graduating with little more than freshmen level mathematics courses. Educators in all fields increasingly shared this concern, and a counter-movement developed in colleges to establish a system of academic majors and a core curriculum (Tucker, 2013). According to Tucker, despite the calls of mathematics educators such as Wilson and Hedrick, the new core curriculum did not require any mathematics courses, which were grouped with the natural sciences. Many students could take a science course in lieu of mathematics, and when mathematics was required for a major, students often needed extensive remediation. Students who had good mathematics preparation in high school typically took courses in algebra and trigonometry as freshmen and analytical geometry and calculus as sophomores.

In the late 1800s and early 1900s, education specialists made efforts to reform secondary education, calling for extending mandatory schooling to the 12th grade (National Education Association, 1894). Mathematics, however, remained a low priority. An influential report by the National Education Association (1918) makes no explicit mention of mathematics. As states adopted compulsory secondary education, demand for college-educated high school teachers grew (Tucker, 2013). At the same time, the U.S. saw a growing need for professionals in fields that rely heavily on mathematics, such as commerce, infrastructure, and technology. Colleges, eager to accept the growing number of applications, lowered enrollment standards, and students who took mathematics courses increasingly enrolled in remedial mathematics courses.

With the increased enrollment, the number of mathematics PhDs produced also grew from about 25 per year in the 1910s to about 50 per year in 1925 (Richardson, 1936). These doctoral graduates typically went on to teach at colleges. Until then tenured mathematics faculty rarely had more than a Master's degree since most courses were at a low content level. As more PhDs were produced and began teaching, interested students were able to study mathematics at a higher level. Graduates were being produced who would become leaders in their fields by mid-century (Tucker, 2013). Although many students were receiving world-class education, the trend in the early to mid-twentieth century leaned toward a more practical college education, largely in response to world crises. During World War II, mathematicians showed how mathematics could contribute to a wide range of important areas including fluid mechanics, code breaking, and designing the atomic bomb. Mathematical models became an essential part of the study of engineering, economics, commerce, and the physical sciences. Because pure mathematicians were responsible for the success of mathematical models in the war effort, mathematicians became valued in industry almost as much as engineers, and the proportion of students interested in mathematics grew. After the war, the GI Bill bolstered college enrollment, and as overall college enrollment increased, mathematics enrollment flourished at all levels.

Despite the increased interest in mathematics, college course offerings changed very little between the 1920s and 1950s (Tucker, 2013). Even so, students were entering college more adequately prepared to study mathematics because high school mathematics had come to include two years of algebra, Euclidean geometry, and a pre-calculus course.

High school teachers with better mathematical training were increasingly in demand, and teaching colleges expanded from only training primary teachers to also preparing secondary teachers, though the offerings varied greatly among colleges. During this time, most college instructors still did not have doctoral degrees, and teaching was still faculty members' primary responsibility.

In the 1950s, the MAA proposed a common first-year mathematics course called Universal Mathematics, which consisted of one semester of functions and limits and one semester of sets, logic, counting, and probability (W. L. Duren, Newsom, Price, Putnam, & Tucker, 1955). This course was designed around mathematics that was instrumental to the war effort, and it later evolved into what is now taught as finite mathematics. Despite the MAA's efforts, calculus became the standard first-year mathematics course in the mid-1950s when introductory physics courses began incorporating calculus (Tucker, 2013). Calculus came to be seen as foundational for modern technology and commerce and thus found its current place as the primary focus of first-year mathematics instruction.

Despite the ubiquity of calculus courses in science and engineering degree plans, calculus courses were inconsistent among colleges. For example, some mathematics students entered graduate school having not studied topics as fundamental as Riemann integration (Tucker, 2013). The MAA's Committee on the Undergraduate Program in Mathematics (CUPM) attempted to address both these inconsistencies and those in the mathematics major in general (Mathematical Association of America, 1963). The CUPM report, intended as an idealized curriculum for honors students, swung the pendulum far in the other direction with courses that were too difficult for most undergraduate math majors. At the same time, the MAA and the National Council of Teachers of Mathematics created the School Mathematics Study Group to advocate for the "New Math" in grade school which was also met with public resistance for being too abstract (Tucker, 2013).

In response to the backlash, subsequent CUPM proposals attenuated the recommendations of the 1963 report, until the MAA CUPM (1972) published the General Curriculum in Mathematics for Colleges, which was widely accepted by the mid-1970s. This report recommended a core of two semesters of calculus (with some differential equations), linear algebra, multivariable calculus, abstract algebra, and linear algebra. The report suggested course outlines for the two semesters of calculus that are very similar to those in the modern courses. Notable exceptions were the lack of recommended lessons on optimization, related rates, and series in the two courses, and the inclusion of basic differential equations in the second semester of calculus.

Calculus thus established its current place in the undergraduate curriculum. The importance of calculus and calculus instruction increased as the number of students taking the course increased. Between 1950 and 1970, undergraduate enrollment quadrupled, precollege (remedial) mathematics enrollment declined, and calculus enrollment increased significantly (Tucker, 2013). This seems to reflect improvements in secondary mathematics preparation. By the 1970s, the primary focus of mathematics faculty had shifted from teaching to research. Consequently, calculus courses were often taught in large lecture halls with the aid of graduate teaching assistants. This model of instruction is now how over 40% of all students are taught first-semester calculus in the U.S., according to the 2010 survey of mathematics departments and students conducted by the American Mathematical Society (AMS) Conference Board of Mathematical Sciences (CBMS) (Blair, Kirkman, & Maxwell, 2013).

The report from CBMS also shows recent trends in the way calculus is taught (Blair et al., 2013). From 2005 to 2010, the average number of students per section increased by more than 5%. Among all universities and colleges, the average calculus section size grew from 32 to 34 students, and at PhD granting universities, the increase was from 45 to 48 students. At the same time, the number of calculus sections taught by tenured (or tenure-eligible or permanent) faculty declined. The CBMS survey found that the percentage of calculus-level sections (including linear algebra and differential equations) taught by permanent faculty fell from 64% in 2000 to 61% in 2005, then fell again to 59% in 2010. During these years, the percentage of calculus level sections taught by part-time faculty increased from 10% in 2000 and 9% in 2005 to 12% in 2010. Other full-time faculty taught about 15% of calculus level sections during these years, and graduate students taught about 7%. The changes are more dramatic when considering only first-semester mainstream calculus, of which the share of sections going to tenured faculty fell from 63% in 2005 to 53% in 2010, while part-time faculty saw their share roughly double from 7% to 15%. Other full-time faculty and graduate students meanwhile taught, respectively, about 18% and 7% of first-year mainstream calculus sections during both years. These numbers indicate that first-semester calculus courses are more and more being taught in large classes by untenured instructors.

These trends were reflected in a 2009 MAA study of nearly 14,000 students at over 200 universities and colleges in the U.S. that identified characteristics of first-semester calculus students and programs (Bressoud et al., 2013). The researchers found that only 30% of calculus sections at research universities were taught by tenured or tenure-track faculty, as opposed to 60-70% at other institutions. The survey also showed that among faculty teaching first-semester calculus at research universities, only 39% reported having a high interest in teaching the course, and 20% had no interest or only a mild interest in teaching the course. At other institutions, 58-80% of such faculty reported a high interest in teaching the course, and only 8% or less had little or no interest. Students are also feeling the negative effects of college calculus courses—research by Bressoud et al. (2013) indicates that students taking first-semester calculus began with high confidence and strong academic backgrounds but experienced a decline in mathematics confidence, mathematics enjoyment, and in their desire to take more math classes. This decrease was most severe among students at research universities, where students also reported less than average use of good or innovative teaching practices.

Burtner (2005) surveyed and collected data from students ($N = 138$) of an engineering school and found that non-cognitive factors measured at the end of the first year of courses effectively predicted whether students would persist in the program. Burtner found that mathematics and science confidence as well as expectations about job opportunities and pay each had a significant positive correlation with persistence in STEM fields years later. Seymour and Hewitt's (1997) ethnographic study exploring the reasons that students leave STEM fields revealed many nonacademic factors and academic factors. Some of the most common factors that students cite for leaving STEM majors were, in decreasing order of frequency, a loss of interest in the field, change to a more interesting non-STEM major, poor teaching in STEM courses, overwhelming course load, inadequate career rewards, rejection of STEM careers and lifestyles, inadequate advising, and discouraging low grades in early courses. Each of these factors was explicitly cited, by more than 20% of the students interviewed who left their STEM majors, as directly influencing their decisions to quit. Many more STEM students mentioned these issues as sources of concern, though not as reasons for leaving. Among first-year courses, chemistry and calculus were most commonly referenced as being overwhelming and uninteresting.

Ellis, Fosdick, and Rasmussen (2016) showed that first-semester calculus has a disparate negative effect on female students. After taking first-semester calculus, female students are as much as 50% more likely than males to change their initial intention to take second semester calculus. The researchers asked students who left STEM pathways to select from a list of reasons for their decisions, and there was only one significant difference between the responses of the males and females. Specifically, females were significantly more likely to indicate that they lacked adequate understanding of first-semester calculus material to continue to the second semester, even though the authors found no evidence that female students understood calculus any less than their male counterparts. First-semester calculus seems to have a greater negative effect on female students' confidence, which leads to attrition from the calculus sequence and from STEM pathways. The authors go on to estimate that if females would persist at the same rate as males, then the number of women entering the STEM workforce would increase by about 75%.

Students' declining interest and confidence in mathematics is a cause for concern for STEM advocates. Much research has shown that noncognitive factors such as those listed above can have a significant effect on persistence in STEM pathways.

Researchers have found that "good" and innovative teaching practices have a positive impact on students' decisions to persist in majors that required more mathematics (Ellis, Kelton, & Rasmussen, 2014). From case studies of selected institutions with successful calculus programs Bressoud and Rasmussen (2015) identified the following seven best practices:

1. Regular use of local data to guide curricular and structural modifications;
2. Attention to the effectiveness of placement procedures;
3. Coordination of instruction, including the building of communities of practice;
4. Construction of challenging and engaging courses;
5. Use of student-centered pedagogies and active-learning strategies;
6. Effective training of graduate teaching assistants;
7. Proactive student support services, including the fostering of student academic and social integration. (p. 145)

These practices were common among calculus programs with higher levels of success, defined as a combination of increased student interest, enjoyment, and confidence in mathematics, high passing rates in first-semester calculus, high rates of persistence to a second semester calculus course, and high measures of students' calculus understanding. Introductory calculus instructors face many challenges as they attempt to navigate this relatively new landscape. The focus is no longer on whether calculus will be included in the curriculum but rather on how to support students in their calculus education and, ultimately, in their STEM education trajectories.

ACADEMIC MATH MINDSETS

Mathematics education used to focus predominately on content, such as what courses are most needed in the curriculum, and on cognitive outcomes, such as whether students could apply mathematical procedures and use mathematical reasoning to solve problems. Now, researchers and educators are looking for a more complete picture of what it means to know and do mathematics, what it means to be a "math person", and what it means to be a member of the mathematics community. In looking at this bigger picture, researchers have linked several positive noncognitive factors (e.g., mindsets, productive persistence) to cognitive outcomes (e.g., ability to solve complex math problems, math course grades). Much research currently focuses on untangling these links and searching for evidence regarding which noncognitive factors are most essential to develop.

In an attempt to clarify the research landscape of noncognitive factors and support forward momentum in the field, Farrington et al. (2012) surveyed the existing research and created a framework that describes a hypothesis about the interplay between five categories of noncognitive factors and academic performance. Their model, shown in Figure 2.1, illustrates the direct impact of academic mindsets on students' social skills, perseverance, learning strategies, and academic behaviors.

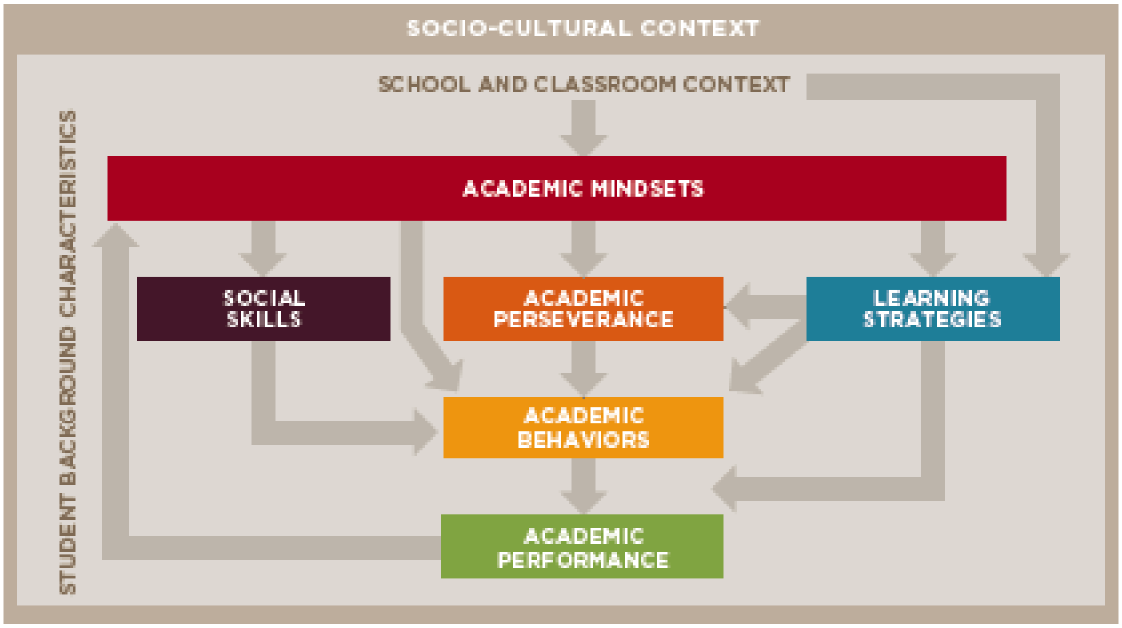

Figure 2.1: A hypothesized model of how five noncognitive factors affect academic performance within a classroom/school and larger socio-cultural context. Reprinted from *Teaching adolescents to become learners: The role of noncognitive factors in shaping school performance—A critical literature review*, by C. Farrington, M. Roderick, E. Allensworth, J. Nagaoka, T. Keyes, D. Johnson, and N. Beechum, 2012, Chicago, IL: University of Chicago Consortium on Chicago School Research. Reprinted with permission.

Academic mindsets are "psycho-social attitudes or beliefs one has about oneself in relation to academic work" (Farrington et al., 2012, p. 11). As such, they play a crucial role in supporting the other categories of noncognitive factors. Figure 2.1 shows that the relationship between mindsets, perseverance, behaviors, and performance is reciprocal. Performance successes can reinforce positive academic mindsets, while actual or perceived performance failures can negatively impact academic mindsets, creating a feedback loop between academic mindsets and academic performance. Farrington et al. (2012) broadly define four academic mindsets using positive mindset statements that reflect research-based noncognitive factors:

1. “My ability and competence grow with my effort.”
2. “This work has value for me.”
3. “I belong in this academic community.”
4. “I can succeed at this.” (p. 11) (Farrington et al., 2012, p. 11)

Growth mindset, advanced most notably by Carol Dweck, is the foundation of the first statement and is intertwined with goal theory, attribution theory, and the concept of learned helplessness. The second statement focuses heavily on *purpose*; it is influenced by research involving goals and utility and research in expectancy-value theory (see, for example, work of Jacquelynne Eccles). The third statement is centered on *belongingness* and is strongly supported by research in stereotype threat theory by Claude Steele and others. The final statement centers on *self-efficacy*, stemming from Albert Bandura’s social learning theory and tying into other expectancy beliefs.

In 2015, 22 social scientists formed The Mindset Scholars Network (MSN) as a next step in advancing the field of mindset research (Ascione, 2015). The MSN currently consists of 28 researching scholars from 14 universities who survey, conduct, and disseminate cross-disciplinary learning mindset research. According to MSN scholars (“The Mindset Scholars Network,” 2015), “Learning mindsets can be thought of as lenses through which students interpret their day-to-day experiences in school, particularly challenges and adversity. They influence whether students engage with challenges productively because they affect the way in which students understand the larger meaning of these challenges” (Mindsets FAQ section, para. 2).

The MSN identifies growth mindset, purpose and relevance, and belongingness as the most critical learning mindsets for motivating students to pursue and persist on difficult tasks and for helping students achieve academic success. As defined by the MSN *growth mindset* is "the belief that intelligence can be developed", *purpose and relevance* is "the belief that one's schoolwork is valuable because it is personally relevant and/or connected to a larger purpose," and *belonging* is "the belief that one is respected and valued by teachers and peers" (Quay & Romero, 2015, p. 1). These three learning mindsets correspond with the first three of Farrington et al.'s (2012) four academic mindsets. Because learning mindsets tend to promote self-efficacy ("The Mindset Scholars Network," 2015) and growth mindset is a causal predecessor to self-efficacy (Yeager, Bryk, Muhich, Hausman, & Morales, 2013), the academic mindset of self-efficacy is not included in the MSN's list of learning mindsets most deserving of researchers' and educators' attention.

My current research and the focus of my interventions are at the intersection of Farrington et al.'s (2012) academic mindsets and the MSN's learning mindsets ("The Mindset Scholars Network," 2015). I devote the next three subsections to discussions of research on the growth, purpose, and belongingness mindsets. I also address how these academic mindsets influence other noncognitive factors, productive persistence, and cognitive outcomes in academic contexts.

Growth Mindset

As I discussed above, difficulty learning calculus is cited by many students who leave STEM majors as a contributing factor to their decision to abandon the field (Seymour & Hewitt, 1997). Avoiding unnecessary misconceptions and fruitless confusion is a major concern addressed by curriculum design, but students will almost certainly grapple with calculus concepts regardless of the quality of the curriculum and instruction. Students will struggle and fail, but their responses to struggle are determined in large part by their beliefs about the nature of intelligence. After encountering an obstacle, students who believe that intelligence is malleable will likely redouble their efforts to improve, but students who believe that intelligence is fixed will likely disinvest effort in an endeavor that seems hopeless ("I'm just not a math person"). The school of thought that students hold these "implicit theories" of intelligence was developed and popularized by the work of early achievement goal theorists (Dweck, 1986; Dweck & Leggett, 1988).

Achievement goal theory (AGT) posits that for any task, a person can hold different types of competency-based goals, and the specific type of goal adopted will influence the person's motivation regarding its attainment. Early AGT theorists identified a dichotomy of goals based on the individual's definition of competence. Nicholls (1984) delineates two definitions of ability that individuals hold—one in which "ability [is] judged high or low with reference to the ability of members of a normative reference group" (p. 329) and one in which "levels of ability and task difficulty are judged in relation to one's own perceived mastery, understanding, or knowledge" (p. 329).

With the former conception, individuals view their ability as a capacity, and this capacity is only revealed when optimum effort is exerted (Nicholls, 1984). Greater effort exerted on normatively easy tasks is therefore viewed as a sign of lower ability. Nicholls uses the term *ego involvement* to refer to a state in which an individual is activating the latter conception of ability. An individual in this state would, according to Nicholls, choose tasks depending on her perceived level of ability and the difficulty of the task. This conception is therefore more differentiated than the former. If an ego-involved individual believes she has above average ability, she will choose normatively difficult tasks since they offer opportunities to demonstrate her ability. If an individual perceives her ability to be low, she will tend to choose normatively easier tasks that can demonstrate her ability but avoid normatively difficult tasks that could demonstrate her lack of ability.

Individuals with the latter conception evaluate their ability according to perceptions of their own learning and mastery, and because more effort leads to greater mastery, they associate greater effort with greater ability. Nicholls uses the term *task involvement* to refer to a state in which one is activating this conception of ability and is concerned with mastering a task. An individual who is task-involved will tend to choose difficult tasks that offer opportunities to grow and deepen her understanding.

A similar dichotomy of achievement goal types was identified by Dweck (1986) and Dweck and Leggett (1988). They identified *performance* goal orientation and *learning* goal orientation. According to their framework, an individual with a performance goal orientation will seek positive judgments and avoid negative judgments of her competence. Thus, her behavior will be differentiated according to her perceived level of ability; high perceived ability will likely lead the individual to seek challenges, and low perceived ability will likely lead her to avoid them. An individual with a learning goal orientation will tend to seek out tasks that increase her understanding, regardless of her present perceived ability. Individuals with high perceived ability, then, would tend to seek challenges regardless of their goal orientation. Behavior among individuals with low perceived ability—who would expect to experience failure on difficult tasks—would be differentiated according to their goal orientation. Dweck and Leggett suggest that a performance goal orientation leads to maladaptive "helpless" behavior in response to obstacles, whereas a learning goal orientation leads to adaptive "mastery-oriented" behavior.

Leggett (as cited in Dweck & Leggett, 1988) revised the achievement goal framework to include two choices of performance goals: "Performance goal (avoid challenge)" and "Performance goal (seek challenge)" (p. 263). Elliot (1999) takes a similar theoretical approach with his trichotomous achievement goal framework that organizes achievement goals as either mastery goals, performance-approach goals, or performance-avoidance goals. Elliot cites research employing dichotomous achievement goal frameworks that yield unclear empirical evidence and argues that the performance goal construct is insufficient, even when perceived ability is included as a moderating factor. According to Elliot, including the approach-avoidance distinction offers a more nuanced classification of goals. Later iterations of this framework distinguish between mastery-approach and master-avoidance (e.g., striving not to misunderstand), establishing a 2×2 framework with dimensions of *definition* (mastery/performance) and *valence* (approach/avoidance) (Elliot, 2001; Elliot & Murayama, 2008). These frameworks assume that an individual adopts an achievement goal in response to several antecedent variables: competence-based, self-based, relationally-based, demographic, environmental, and neurophysiological variables (Elliot, 1999).

In either achievement goal framework, an individual's tendency to adopt mastery or performance goals is determined in part by her implicit theory of intelligence. Each holds that individuals who possess an incremental (i.e., malleable, growth mindset) theory of intelligence are more likely to adopt learning (mastery-approach) goals, and those with an entity (i.e., fixed mindset) theory of intelligence are more likely to adopt performance goals, both approach and avoid (Dweck, 1986; Dweck & Leggett, 1988)[4]. Dweck (1986) argues that students with an entity theory of intelligence attribute failure to stable, unchangeable traits. Failure is therefore a clear signal to entity theorists that they are

[4] Evidence from (Elliot, 2001) indicates that antecedents of having an entity (fixed) theory of intelligence and not having an incremental (growth) theory of intelligence are predictive of mastery avoidance goal adoption. However, the study's results also indicated that adopting mastery avoidance goals, though not predictive of negative performance and health outcomes, is predictive of several potentially negative outcomes such as disorganized study, worry, test anxiety, and emotionality.

incapable of succeeding at a task and further effort would be fruitless. An entity theorist would therefore adopt performance avoidance goals regarding difficult tasks that, she believes, would only demonstrate a lack of ability. According to Dweck, a student with an incremental theory of intelligence would attribute failure to unstable traits and contextual factors such as a malleable intelligence and effort. An incremental theorist would be more likely to adopt learning goals when faced with a difficult task since the task would offer an opportunity to grow her knowledge and demonstrate ability through effort.

This framework of implicit theories and their implications is related to attribution theory (Weiner, 1972, 1985). Attribution theorists study individuals' perceptions of causality and how one's assignment of responsibility influences behavior. Weiner (1972) reviews prior research showing that, on achievement tasks, people distribute (physical and/or affective) rewards and punishments to themselves and others based not only on level of achievement, but also effort. When a task is successfully completed, rewards are greatest when effort, rather than innate ability, is the perceived cause of the outcome; conversely, when a task is not satisfactorily completed, penalties are most severe when a lack of effort is to blame. Weiner (1972) relates this to goal choice: "Inasmuch as perceptions of causality influence the affect experienced in achievement-oriented activities, one's causal biases when interpreting success or failure have important implications for achievement striving. It is reasonable to speculate that achievement strivings are in part determined by causal attribution, and that individual differences in achievement needs are related systematically to disparities in the perception of causality" (p. 206).

In their seminal article, Dweck and Leggett (1988) distinguish their approach from that of attribution theory in two ways. First, the attributional approach did not consider how people develop their attributional styles and Dweck and Leggett aimed to "identify the source of attributional styles" (p. 269) and trace this source through to attributional styles and outcomes. Their model "proposes a chain of processes beginning with individuals' implicit theories and eventuating in response patterns that include attributions and their consequences" (p. 269). The second way in which they differ relates to controllability. In traditional attribution theory, factors are presented as "inherently controllable or uncontrollable, so that ability is considered to be a stable, uncontrollable factor" (p. 269). In Dweck and Leggett's formulation, each individual formulates her own perception about controllability.

Hong, Chiu, Dweck, Lin, and Wan (1999) conducted three studies with undergraduate university students to establish a clearer relationship between attribution theory and Dweck and Leggett's (1988) model. Instead of focusing on the predictive nature of goal orientations (i.e., performance, mastery), the researchers investigated the predictive nature of mindsets (i.e., fixed, growth) on attributions (i.e., ability, effort). They did this because research undertaken by others and themselves since the inception of Dweck and Leggett's original model showed that implicit theories were superior predictors of attributions and behaviors than were achievement goals.

The first Hong et al. (1999) study (*N*=97) involved a manipulation where undergraduate students at a university in the U.S. were allegedly taking a conceptual ability (intelligence) test to establish test norms. The students were to solve 6 blocks of problems with 15 problems per block; they were allotted 4 minutes on each block. An experimenter would present the task to two students at a time, the students would complete the test under standard testing conditions, a computer would reveal the students' scores to both students in the form of a bar chart, and the experimenter would apologize for revealing both students' scores. Each student saw the same bar chart and it showed that he or she had received a lower score on all six blocks than the other student in the room. After the students viewed their results, they completed an attribution measure that was disguised as a test-evaluation questionnaire for improving the test. A manipulation check revealed the manipulation was successful[5]. Prior to the manipulation, as part of an ostensibly unrelated study, the students had also completed an implicit theory measure and a confidence measure.

As Hong et al. (1999) hypothesized in Study 1, students with a growth mindset assigned heavier weight to effort, despite the fact that they had been told the test measured a component of intelligence. Also, fixed mindset students with high confidence were no less likely than fixed mindset students with low confidence to blame substandard performance on ability. This latter finding ran contrary to prior research that showed positive relationships between high confidence and high achievement. Hong et al. explain that stable situations are supportive of a positive correlation between confidence and achievement. However, the concern (and what this study relates to) is when the student is challenged by environmental instability (e.g., transition from elementary school to middle school) or confrontations with failure—theories of intelligence are better predictors of achievement than confidence[6] in such situations.

Hong et al. (1999) conducted Study 2 (*N*=168) and Study 3 (*N*=60) with undergraduate students at a university in Hong Kong. The researchers' hypothesized that students with a fixed mindset would be less likely than students with a growth mindset to remediate when it was in the students' best interest to do so. One reason the authors gave for this hypothesis was that a student with a fixed mindset might view remediation as pointless because it would involve trying to change the unchangeable. Another reason for

[5] Ten students for which the manipulation may not have been successful were excluded from the analyses.
[6] Confidence is related to the Farrington et al. (2012) academic mindset that I did not include in my study (i.e., "I can succeed at this.").

their hypothesis was that, because there is potential to fail post-remediation, a student with a fixed mindset may believe she risks affirming inaptitude.

In Study 2 by Hong et al. (1999), students who were in a program in which English proficiency was essential were asked about the likelihood of them taking a remedial English course with proven effectiveness. For students whose English skills were unsatisfactory, fixed mindset students were less likely to remediate and growth mindset students were more likely to remediate. Study 3 confirmed the same results as Studies 1 and 2 and further demonstrated causation between fixed mindsets and post-failure attributions. These three studies highlight the importance of instilling a growth mindset in students potentially facing failure. Fixed mindset students, both high and low in self-confidence, were less likely to assign weight to effort. It was also the students with a fixed mindset who opted out of remediation when they needed it, perhaps as a helpless response or because of a belief that participating in remediation would verify their low ability.

Researchers have established evidence that implicit theories of intelligence can be responsive to, and are sometimes contingent upon, environment and experience. Several studies have shown that students' implicit theories can be altered by the way their parents interact with them. For example, receiving praise for one's ability can lead a student to develop a fixed mindset and subsequently avoid challenging learning tasks that could lead to failure and demonstration of low innate ability (Kamins & Dweck, 1999; Mueller & Dweck, 1998; Pomerantz & Kempner, 2013; Yeager, Paunesku, Walton, & Dweck, 2013). Numerous intervention studies have demonstrated in educational settings that students' theories of mathematics intelligence can be influenced with even subtle messages and that these changes can lead to substantial improvements in performance and retention; I will discuss these and other interventions below in the Social-Psychological Interventions section of this chapter.

Purpose Mindset

Almost every math teacher has heard the dreaded question, “When am I ever going to use this?” While many students clearly desire to know how the content of their math classes can be useful, it is surprisingly uncommon for teachers to attach purpose to learning objectives (Yeager et al., 2014). Students with high levels of personal interest (“an individual’s relatively enduring disposition to be attracted to, to enjoy, or to like to be engaged in a particular activity or topic”) and/or situational interest (“a psychological state of being interested in a task or activity that is generated by the interestingness of the task or content”) are more likely to interact deeply with the content and have greater learning gains and achievement (Pintrich, 2003, p. 674).

Intrinsic motivation (as defined by self-determination theory (SDT)) is “the motivational instantiation of the proactive, growth-oriented nature of human beings” (Vansteenkiste, Lens, & Deci, 2006, p. 20) and interest is a crucial component of intrinsic motivation (Pintrich, 2003). Early research on intrinsic and extrinsic motivation showed students who were given extrinsic (means-end) motivators for undertaking intrinsically interesting tasks lose interest and are less likely to persist than students who were not provided external motivators (Deci et al., 1991). Competence, autonomy, and relatedness[7] needs underlie intrinsic motivation and researchers initially hypothesized that the extrinsic motivators robbed students of their autonomy through the potentially controlling nature of rewards and punishments (Vansteenkiste et al., 2006).

Vansteenkiste et al. (2006) discuss later research which showed that certain types of extrinsic motivators improved intrinsic motivation, leading researchers to delineate three types of extrinsic motivation: *external regulation* (“behavior is prompted by external

[7] “’Relatedness’ is a psychological concept [that mirrors] sense of personal acceptance or belonging” (Osterman, 2000, p. 326).

contingencies”), *introjected regulation* (behavior stems from “internal pressure...based either in the pursuit of self-aggrandizement and (contingent) self-worth or in the avoidance of feelings of guilt and shame”), and *identification* (behavior based on “foresee[ing] the personal relevance of an activity”) (p. 21). According to the authors, of these three motivators, identification leads to the deepest internalization of one’s reasons for performing behaviors; identification is the most autonomous of the three and is the only extrinsic motivator that approximates intrinsic motivation. Students who identify with the value of an activity “engage in the activity quite volitionally or willingly” (p. 21).

More recently, SDT researchers, who had primarily attended to learners’ intrinsic versus extrinsic motivations for learning, have transitioned to also focus on learners’ intrinsic versus extrinsic goals. In one study by Vansteenkiste et al. (2006) researchers framed an activity about ecological issues in terms of either an intrinsic goal (community contribution) or an extrinsic goal (financial success). They crossed the goal framing conditions with an autonomy supportive condition (e.g., “you can”) and a controlling condition (e.g., “you should”). Students in the intrinsic goal condition and students in the autonomy supportive condition exhibited superior deep processing, test performance, and subsequent task persistence than students in the extrinsic goal condition and students in the controlling condition, respectively. These findings have been replicated with different age groups in various settings, and there are no differences in effectiveness based on whether a student has a personal intrinsic or extrinsic goal orientation. Some researchers have found that students provided with extrinsic goal framing persist on rote tasks at the same levels, but the cost may be too high—an overreliance on extrinsic goal framing diminishes long-term perseverance, enjoyment, and deep understanding. The researchers conclude students are better served when educators support student autonomy and attach intrinsic goals to learning objectives.

Vansteenkiste et al. (2006) note conclusions from the above study were “based on the SDT proposition that different types of motivation and, hence, different qualities of engagement with the learning materials are induced by these different goal-content manipulations” (p. 25). To situate their work relative to other theories, they provide two alternative interpretations[8]: 1) According to the *match* perspective, learning is best realized when a goal frame (intrinsic/extrinsic goal messages) matches a student’s learning goal orientation (intrinsically/extrinsically oriented). In this interpretation, because only intrinsically oriented students are negatively affected by extrinsic goal framing, match perspective researchers could conclude from the same data that the significant main effect of learning and persistence in the intrinsic goal framing condition was due to greater representation of students with high intrinsic learning goals. 2) From instrumentality models and expectancy-valence theory (EVT) perspectives, the positive effect “would be a function of a larger quantity of motivation rather than a different quality of motivation” (p. 25) as the authors had suggested because instrumentality models and EVT would claim intrinsic goal framing added to the students’ perceived value of the learning more than extrinsic goal framing.

Expectancy-value theory (EVT) is one of the most dominant contemporary social-cognitive theories of motivation[9] (Plante, O’Keefe, & Theoret, 2013). Jacquelynne Eccles extended John Atkinson’s work from the 1950s and 1960s in EVT to create and study an education-related achievement model that specifies how cultural factors and prior events impact students’ expectancies and values, how these expectancies and values influence students’ achievement behaviors, and how other factors mediate students’ expectancies and

[8] The authors also provide studies to argue why the SDT explanation is the most plausible.
[9] According to Plante, O’Keefe, and Theoret (2013), the two dominant theories of contemporary social-cognitive theories of motivation are EVT and AGT.

values (Eccles [Parsons], 1983). While Eccles and colleagues refined the model and how its components were conceptualized as research advanced, the foundational structure—of expectancies and values directly influencing achievement behaviors—remained (Eccles [Parsons], 1983; Wigfield & Eccles, 2000).

The expectancy construct of the EVT model is defined as students' "beliefs about how well they will do on upcoming tasks, either in the immediate or longer term future" (Wigfield & Eccles, 2000, p. 70). Researchers have identified a wide array of expectancy constructs (e.g., self-efficacy, expectancy for success, perceptions of competence, self-perceptions of ability, perceived control, and confidence) and developed diverse methods for measuring expectancy-related beliefs (Pajares, 1996; Wigfield & Eccles, 1992). Farrington et al.'s (2012) fourth mindset ("I can succeed at this" (p. 11)) is grounded in self-efficacy theory established by Albert Bandura (1982), likely because of how highly true self-efficacy measures predict performance and choice[10]. Wigfield and Eccles' use more general measures of expectancy than most self-efficacy researchers, but their expectancy construct is more closely related to Bandura's self-efficacy expectancy construct than to an outcome expectancy construct (Wigfield & Eccles, 2000).

The value construct of EVT relates to sense of purpose and forms the basis of Farrington et al. (2012) second academic mindset ("This work has value for me" (p. 11)). Wigfield and Eccles (2000) defined four achievement values: *attainment value* ("the importance of doing well on a given task" (p. 72)), *intrinsic value* ("the enjoyment one gains from doing the task" (p. 72)), *utility value* or usefulness ("how a task fits into an individual's future plans" (p. 72)), and *cost* ("how the decision to engage in one activity (e.g., doing schoolwork) limits access to other activities (e.g., calling friends), assessments

[10] While improving math self-efficacy has been shown to improve mathematical success, I did not utilize a targeted self-efficacy intervention because growth mindset of intelligence is a causal antecedent to self-efficacy (Yeager, Bryk, Muhich, Hausman, & Morales, 2013).

of how much effort will be taken to accomplish the activity, and its emotional cost" (p. 72)). In later work, these four values are referred to as subjective task values (Eccles, 2009).

Identity, from an EVT perspective, "can be conceptualized in terms of two basic sets of self-perceptions: (a) perceptions related to skills, characteristics, and competencies, and (b) perceptions related to personal values and goals" (Eccles, 2009, p. 78). Eccles (2009) and colleagues used this conceptualization of identity in multiple studies to investigate how gender roles could indirectly influence individuals' subjective values of their academic and career options through parental cues. In their studies, parents provided gender-biased experiences for their children (e.g., boys have more occasions to develop technical skills with computers), conveyed different messages about career options based on gender (e.g., engineering is suitable for boys and biology is suitable for girls), and made gender-based attributions for their children's successes and failures. Eccles described the cues and consequences: the parents provided "gendered experiences and messages [that appeared] to undermine girls' confidence in their own math abilities and interest in applied math-related courses and fields."

Eccles (2009) briefly described studies with her fellow researchers in which the impact of subjective task value beliefs outweighed the impact of expectancy-related beliefs. In one study with gifted elementary children, prospects for success between males and females were equivalent, but the girls deemed math as less enjoyable and less useful. In a longitudinal study, academically prepared females entering college were more likely than their male counterparts to steer clear of advanced mathematics courses "primarily because they felt that math was less important, less useful, and less enjoyable than did the boys" (p. 87). Eccles showed that identity-related beliefs are powerful predictors of academic and career choice. Identity beliefs are malleable and helping students foster a math purpose mindset could potentially reduce the gender career gap.

Achievement goal theory (AGT), discussed in the Growth Mindsets subsection of this section, overlaps with EVT in its attention to students' beliefs about the likelihood of success or failure on future tasks, but values are largely ignored (Pintrich, 2003). Some longitudinal EVT research has shown that achievement values (i.e., attainment value, intrinsic value, utility value, cost) may predict goal choice whereas expectancy predicts achievement once the goal is chosen, and that the strength of the four value components can influence the type of goals adopted (i.e. performance-avoid, performance-approach, or mastery) (Wigfield & Eccles, 1992).

Future time perspective (FTP) theorists have identified *instrumentality* as a unique construct of value (Husman & Lens, 1999). It is similar to utility value, but it is specifically future-oriented, while the time signature for utility value measures are sometimes inconsistent (Husman, Derryberry, Crowson, & Lomax, 2004). FTP researchers use the term *exogenous instrumentality* to refer to utility value that is useful only for the purposes of jumping hurdles toward a more distal future goal. *Endogenous instrumentality* refers to value given to a task in which the future goal is closely related to the current task. Husman et al. (2004) show that endogenous instrumentality is supportive of intrinsic motivation.

Yeager et al. (2014) "define a purpose for learning as a goal that is motivated both by an opportunity to benefit the self and by the potential to have some effect on or connection to the world beyond the self" (p. 560). The authors refer to the former motivational component as "self-oriented" and the latter as "self-transcendent". The researchers conducted four studies to test their hypothesis of a positive correlation between a prosocial self-transcendent purpose for learning and academic self-regulation on "boring" tasks. All four studies, which included more than 2,000 participants, established this connection, and the researchers were further able to demonstrate how instilling such a purpose positively influences persistence and learning. I provide details of these and other purpose studies in the Social-Psychological Interventions section of this chapter.

Belongingness Mindset

Belongingness—also referred to as "'relatedness,' 'support,' 'acceptance,' 'membership,' or 'sense of community'" (Osterman, 2000, p. 326)—is a "basic psychological need…inherent in human life" (Deci et al., 1991, p. 327). There is a long history of studies addressing the importance of developing a sense of community in educational environments and how having such a community relates to learning and socioemotional needs, extending in large part from the works of influential educational reformers such as John Dewey and Lev Vygotsky (Osterman, 2000). Because people's belongingness needs and responses to those needs are situational (e.g., in relation to gender, age, context), research has considered the impact of social belongingness in school settings (Osterman, 2000) and achievement situations (Walton & Cohen, 2007) as well as how belongingness relates to students of varied demographic backgrounds (Steele & Aronson, 1995; Yeager, Walton, & Cohen, 2013). Recent research has begun to consider what it means to "belong to" a domain—described by Good, Rattan, and Dweck (2012) as "one's feelings of membership and acceptance in the [particular] domain" (p. 1). A growing body of research points to the profound importance of belongingness on students' psychological processes, mindsets, academic behaviors, and educational outcomes.

Stereotypes play a large role in students' beliefs about their belongingness. "Stereotype threat is being at risk of confirming, as self-characteristic, a negative stereotype about one's group" (Steele & Aronson, 1995). If a student in a group deemed intellectually inferior underperforms, he or she risks confirming the negative stereotype associated with that group. The experience of stereotype threat has detrimental effects on working memory. Working memory[11] is "a limited-capacity executive process that coordinates cognition and controls behavior to achieve performance goals in the presence of exogenous or endogenous information that competes for attention" (Schmader, Johns, & Forbes, 2008, p. 340). Schmader, Johns, and Forbes (2008) identify three pathways by which occasions of stereotype threat can reduce the working memory of stigmatized individuals: physiological stress response ("increased physiological stress response…in highly evaluative situations" (p. 350)), performance monitoring tendencies ("heighted vigilance [in] monitoring of the performance situation" (p. 350)), and suppression processes ("active attempts to cope with or suppress the phenomenological manifestations of stereotype threat" (p. 351)). Stereotype threats encountered during an academic task can have an immediate negative effect on performance. As will be shown below, stereotype threats can also lead stigmatized persons to disidentify with domains in which they experience chronic stigmatization (Steele, 1997).

Murphy, Steele, and Gross (2007) examined the impact of situational cues on confident, math-identified female math, science, and engineering (MSE) majors. Twenty-five males and 22 females were assigned to watch either a gender-balanced (1:1 ratio of men to women) or gender-unbalanced (3:1 ratio of men to women) video advertisement for a MSE summer conference. Measures included the subjects' memory of the video and MSE items in the room in which they watched the video, physiological factors, MSE conference belongingness, and MSE conference interest. Women in the unbalanced condition remembered more about the video and room, demonstrated more physiological changes, and had a lower sense of belonging and interest in attending the MSE conference than women in the balanced condition. There were no significant condition-based

[11] Working memory is related to, but distinct from, short-term memory (Schmader, Johns, & Forbes, 2008).

differences for the men, except men expressed greater interest in the conference when presented with the gender-balanced video. In other words, social identity threats to MSE identity were applicable only to the traditionally stereotyped demographic (i.e., women in male-dominated fields), even though these persons had strong math identity.

In a study by Walton and Cohen (2007), Black and White students (N=70)[12] read a fake news story about their school's computer science department as part of a belongingness experiment. Afterword, participants were tasked to create a list of either eight or two friends who were a good fit for the department. One third of the Black students were not required to create a list (a control condition the researchers designed in response to findings from a pilot study). The reportedly difficult task of listing eight friends was meant to serve as a cue for potential nonbelonging, and the researchers hypothesized that stigmatized students in the eight-friends condition would exhibit a lower sense of belonging and academic fit. The White students were unaffected by the manipulation, but the Black students in the eight-friends condition rated their belongingness and computer science fit much lower than Black students in the two-friends and the no-list conditions. Participants were also presented with a fabricated situation in which they were to advise potential computer science students. Black students in the eight-friends condition discouraged Black, but not White, students from joining the field.

Members of stereotyped groups can experience stereotype threat even when the stereotype is inconsistent with their self-beliefs (e.g., "I believe I am good at math, but if I fail at math as a woman, I will confirm the stereotype that women are not good at math. If I avoid math, I will not confirm this stereotype") (Steele, 1997). First-generation college students, women, racial minorities, and other traditionally marginalized groups are more

[12] One student was excluded from the analyses.

prone to stereotype threat in math courses (Good et al., 2012; Steele, 1997; Steele & Aronson, 1995; Yeager, Walton, et al., 2013). When stereotyped students receive messages about their academic competence, they may not trust them, attributing them to a perceived prejudice of the one providing the message rather than an honest comment on their abilities. This can occur even with positive feedback if the student believes the positive message is delivered out of a fear of being viewed as prejudiced. This "attributional ambiguity" can lead to detachment from tasks and disassociation from school (Farrington et al., 2012).

Good, Rattan, and Dweck's (2012) conducted a study with students at a selective university in which they showed that, for both male and female students, a strong sense of mathematics belonging is predictive of less mathematics anxiety, stronger perceived usefulness of mathematics, greater mathematics confidence, and stronger intent to pursue mathematics in the future. Furthermore, a longitudinal study in the same article reveals that the perceived pervasiveness of a gender stereotype—that women have less mathematics ability—predicted a lower sense of mathematics belonging for females but not for males. However, if females also perceived the academic environment as supporting a growth mindset rather than a fixed mindset, the negative impact of the perceived gender stereotype was diminished. In other words, growth mindset messages from within the mathematics community may protect stereotype-threatened demographics from stereotypes' negative impacts.

Academic settings that satiate students' need for belongingness[13] facilitate students' self-determined learning (Ryan & Deci, 2000). According to SDT theorists, when extrinsic motivators are "well-internalized, [they] are expected to promote adaptive learning outcomes" (Vansteenkiste et al., 2006, p. 22) and "the groundwork for facilitating

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[13] Ryan and Deci (2000) note that the psychological need SDT theorists refer to as *relatedness* is what others term *belongingness*.

internalization is providing a sense of belongingness and connectedness to the persons, group, or culture disseminating a goal" (Ryan & Deci, 2000, p. 64). Foundational to SDT is the idea that humans have three psychological needs which must be met: a sense of relatedness (i.e., belongingness), a sense of competence, and a sense of autonomy (Vansteenkiste et al., 2006). Relatedness promotes people's feelings of competence and autonomy and, additionally, their sense of identity (Osterman, 2000).

A study by Yeager, Bryk, et al. (2013) further underscores the importance of academic belongingness on persistence in math college courses. The researchers created a short survey to measure developmental math students' statistics and math anxiety, growth mindset, belongingness, stereotype threat, and grit. The belongingness measure predicted course completion significantly more than the other constructs, and it strongly predicted whether students who remained in the course through the end of the semester would be able to move on to the next course in the math sequence.

Sense of belonging to an academic domain and within an academic community has been shown to have significant bearing on students' decisions to persist in the related field of study. Students who perceive negative messages about the alignment of an academic field with components of their social identity will tend to disinvest from work in the domain. Conversely, students who experience academic belongingness "have more positive attitudes toward school, classwork, teachers, and their peers;….they invest more of themselves in the learning process;….and they are more likely to interact with peers and adults in prosocial ways" (Osterman, 2000, p. 343).

SOCIAL-PSYCHOLOGICAL INTERVENTIONS

The academic math mindsets I discussed in the previous section warrant investigation not only because they are highly correlated with student success, but also because they are susceptible to interventions that can lead to significant and lasting improvements in academic outcomes. Social-psychological interventions have proven to be particularly effective tools for creating positive changes in these mindsets. Such interventions target students' thoughts, feelings, and subjective school experiences. The interventions are often very brief, covert treatments that make small changes in students' mental processing that can lead to substantial effects by initiating productive cycles of academic growth and curtailing destructive ones.

According to Yeager and Walton (2011), social-psychological interventions initially change students' academic mindsets by "(a) targeting students' experience in school from the student's perspective and (b) deploying powerful yet stealthy persuasive tactics to deliver the treatment message effectively without generating problematic side effects, such as stigmatizing recipients" (p. 285). Beginning with an understanding of students' subjective school experiences, researchers can deliver relevant, directed interventions to alter students' appraisals of, and reactions to, factors that threaten success. Many of the most effective interventions are "stealthy" in that they avoid direct persuasive appeals to adopt productive mindsets. These characteristics may help minimize both students' resistance and the risk of stigmatizing students who may feel that they required intervention because they are not strong enough students to succeed otherwise.

Yeager and Walton (2011) describe how social-psychological interventions can have lasting effects, despite being so "small", by affecting recursive academic, psychological, and social processes. Instilling or reinforcing the belief that a student's intelligence can grow can lead her to value effort and seek challenges. Increased effort will reasonably lead to a higher likelihood of success, further reinforcing these beliefs. Similarly, having students focus on the purpose or value of their studies can increase their motivation, effort, success, and so on. Fostering belongingness in a school or an area of study can encourage social academic interaction, building an invaluable support structure for future academic achievement (Hausmann, Schofield, & Woods, 2007).

In addition to creating and strengthening productive recursive processes, social-psychological interventions can terminate self-destructive cycles (G. L. Cohen & Garcia, 2008; Yeager & Walton, 2011). Students who attribute academic struggle to low intelligence may consider effort futile and disinvest time and effort in their studies, setting up a self-fulfilling prophecy. Helping students reframe their struggle as a typical part of the learning process can avert this downward spiral. Students who attribute little purpose or social fit to a field or school will often avoid meaningful interactions with the associated people or subject matter, minimizing the potential for academic success and leading to further disassociation. Furthermore, these interventions may mitigate the negative effects (physiological stress, heightened awareness, and suppression processes) (Steele, 1997) of stereotype threat, freeing students' working memory to be focused on their academic goals.

In the remainder of this section, I review research that has utilized social-psychological interventions. I focus on social-psychological interventions meant to target a growth mindset, sense of purpose, and belongingness. Additionally, I summarize influential research targeting students' attribution of struggle, as this is related to each of the other mindsets. Interested readers may refer to Spitzer and Aronson's (2015) article for a broader review of social-psychological interventions.

Growth Mindset Interventions

The focus on social-psychological interventions in academic research was popularized by the work of Wilson and Linville (1982). In their study, the researchers attempted to change participants' attributions of struggle from stable factors to unstable, temporary factors. Participants consisted of 12 male and 28 female second-semester college freshmen who had indicated on a survey that they did not do as well as they could have during their first semester and were worried about doing well in college. Participants were randomly assigned to one of four groups in a 2×2 design. The first factor was inclusion in either the "GPA-information" or "no-information" condition. Participants in the GPA-information condition read survey responses and watched videotaped interviews from upperclassmen that each conveyed that their GPAs had increased after the first year of college. Participants in the no-information condition did not receive information in either form. The second factor was participation in a "reason analysis". Students in the reason analysis condition listed reasons why a student's GPA may increase after their freshman year and indicated which of these reasons applied to them. Students in the control group were asked to list possible reasons why the divorce rate in the U.S. was declining. The reason analysis was performed just before dependent variables were measured, one year after the intervention. The researchers found that the GPA information group performed significantly better on a GRE practice test of reading comprehension and had significantly higher GPAs than the no-information group. One year after the intervention, 5 out of the 20 students in the no-information condition had dropped out of college, while only 1 out of of the 20 students in the GPA information condition had dropped out. There was no significant effect of the reason analysis on the GRE practice test scores, GPA, or retention.

In a randomized control study, Aronson, Fried, and Good (2002) studied the impact of beliefs about the malleability of intelligence on Black ($n = 42$) and White ($n = 37$) undergraduate students at Stanford University. Students of each racial group were assigned to one of three treatment groups. Participants in the first group (malleable group), consisting of Black ($n = 16$) and White ($n = 12$) students, met three times during the study to take part in a presumed mentoring pen-pal program in which they would write responses to letters from middle school students. The researchers instructed participants in this group to stress to the young pen pals that intelligence is malleable. Another group of Black ($n = 12$) and White ($n = 11$) students (entity group) also wrote letters of encouragement to middle school students, but the participants were told to convey the message that intelligence is not a single entity but a conglomerate of many talents and skills and that the young students should find and strengthen their natural talents. Each group of participants watched brief video clips discussing how psychological research has supported their group's adopted theory of intelligence. Participants in these groups returned a second time to write a similar letter to a second middle school student and again to edit their letters into a speech that they recorded, presumably, for future use with at risk middle school students. A third group of Black ($n = 14$) and White ($n = 14$) students did not participate in the pen pal program. Students of each race achieved higher GPAs in the malleable group than in the other two groups. Black students in the malleable group also reported higher levels of academic enjoyment and stronger belief that academics are important. This result was not seen in the group of White students. Notably, Black students' perception of stereotype threat was in fact higher for the malleable group. It seems that these students benefited not from perceiving less stereotype threat, but perhaps by reacting to it more productively than Black participants in the other two groups.

Blackwell, Trzesniewski, and Dweck (2007) conducted a study of low-achieving seventh grade students ($N = 91$). All participants took part in 8 weekly 25-minute classroom sessions comprising discussions and activities involving the brain, anti-stereotyping, and study skills. The experimental group ($n = 48$) also received lessons teaching that intelligence can be grown and that learning changes your brain. The control group ($n = 43$) instead received lessons on memory and academic preferences. Although the students' teachers were blind to the experimental condition, teachers of the students in the experimental group were more likely than teachers of students in the control group to spontaneously report improvement in their students' motivation. The researchers also investigated changes in the participants' mathematics grades, which declined in both groups preceding the intervention. However, the mathematics grades of students in the experimental group recovered following the intervention, while the grades of students in the control group continued to decline.

Another study also targeted the intelligence theories of middle school students, in addition to their attribution of struggle (Good, Aronson, & Inzlicht, 2003). A total of 138 seventh-graders from a rural Texas school district participated. Participants were demographically representative of the community (70% qualified for reduced cost lunches; 67% Hispanic/Latino, 13% Black, 20% White; 45% female, 55% male). All participants were enrolled in a computer skills course, and as a final project, the students designed a web page. The researchers assigned 1 of 25 undergraduate student mentors from The University of Texas at Austin to each student to assist with the web page development and to answer any other questions the participants might have about school. The researchers randomly assigned participants to one of four treatment groups—incremental, attributional, combined, or an anti-drug control group. In each group, the mentors met in person with the students in two 90-minute sessions, once in November and once in January, and mentors maintained contact through weekly emails to the students. In the incremental group, mentors conveyed the incremental nature of intelligence—that the capacity for knowledge increases with work. In the attributional group, the mentors conveyed to participants that most students struggle when they move to a new educational environment and that things become easier after students adjust. Participants in the combined condition group received both messages from the mentors, and in the anti-drug control group, mentors warned students about the health- and academic-related dangers of drug use. The participants' web pages were to reflect the messages they received from their mentors. To assist the development of their web page, students had restricted access to the internet. The internet content each student could access reinforced their mentors' messages and none of the messages received in other groups.

Mathematics and reading scores on the Texas Assessment of Academic Skills, a statewide assessment at the end of the school year, served as outcome measures. Female students experienced a large significant intervention effect on math scores in each of the three non-control treatments. Males experienced a marginally significant treatment effect in the incremental group. In the anti-drug control group, males earned significantly higher math scores than females. Thus, each of the three interventions closed the significant mathematics gender gap. This suggests that females in the control group may have suffered the effects of stereotype threat. Furthermore, students in the incremental and attributional groups scored significantly higher than the control group on the reading portion of the assessment, though there was no significant difference between the combined condition group and the other three groups.

Purpose Mindset Interventions

Grounding their work in EVT, Hulleman and Harackiewicz (2009) implemented an intervention that targeted students' beliefs about the relevance of the material and demonstrated differential effects for students based on their performance expectations. High school science students were instructed by their teachers to write one-paragraph essays before exams. Students in the control group ($n = 126$) received instructions to write summaries of the course material. Students in the experimental group ($n = 136$) were told to write about how the material was useful and valuable in their own lives. Students were also asked at the beginning of the semester to indicate their expectancy for success in the course. For students with lower performance expectations (less than one standard deviation below the mean), the experimental condition led to significantly higher levels of interest in science as well as higher course grades. The intervention had no significant effect for students with high expectations of success. This brief writing intervention therefore reduced the achievement gap between students with low performance expectations and students with high expectations while doing no harm to either group.

In another experiment, Harackiewicz, Rozek, Hulleman, and Hyde (2012) administered an intervention to 181 adolescents and their parents when the students were in 11th grade. Parents of students in the experimental group (39 girls and 42 boys) received two brochures that provided information about the importance of mathematics and science in various careers as well as guidance for discussing this with their teen. The brochures included tips for personalizing the messages to the individual students. Parents of students in the control group (47 girls and 53 boys) received no materials. Students in the intervention group took significantly more math and science courses in high school than students in the control group. The difference amounted to about an extra semester of mathematics and science classes. The impact was larger for students whose parents had not attended graduate school. Similar interventions could be useful for retaining students on STEM trajectories, perhaps especially students whose parents are not highly educated or students who are more likely to leave their fields or schools (Choy, 2001).

In their randomized controlled trial of 338 ninth graders (half male and half female; 60% Asian, 28% White, 9% Hispanic/Latino, and 1% Black) from a Northern California high school, Yeager et al. (2014) administered a self-transcendent purpose intervention. Participants received the intervention through a website during the students' elective periods. Students in the treatment group were primed to think about self-transcendent issues they felt were important by writing about ways that the world could become a better place. Students in the control group were asked to write about how high school is different from middle school. Participants then read results allegedly from a study of other similarly aged students. The treatment group saw results that indicated most students are motivated to succeed in school not only by self-interest (e.g., making money), but also to learn skills that would allow them to make positive contributions to the world. The results were accompanied by quotes supposedly from older students at their school that conveyed the same message. Afterwards, participants in the treatment group wrote brief (2-4 sentences) messages to future students explaining how their high school education would enable them to achieve their prosocial goals. Participants in the control group read and wrote about how high school is different from middle school. They also saw supposed study results and quotes from upperclassmen on this topic. There was a significant positive effect of the treatment on GPA after controlling for pre-intervention grades. The effect size was larger for students with a pre-intervention GPA less than 3.0, and not significant for students with a pre-intervention GPA above 3.0.

To examine the mechanism by which their social-psychological intervention improved academic performance, Yeager et al. (2014) performed two more experiments using similar interventions on university students in a second-year psychology course. In one study, students could earn extra credit by visiting a website linked in an email from the instructor. When students clicked on the link, they were randomly assigned to either the treatment or control group, and they were instructed to read and write about self-transcendent purpose related to their psychology course (treatment) or about the differences between high school and college (control). These materials were similar to those in the previous experiment. The website then presented the students with a tedious test review for the psychology course. The instructor stressed to the students that they would benefit most from the review if they used their notes and textbook to answer the questions, and the website tracked the time spent on each question to assess the students' persistence.

Seventy-one students participated in the intervention and answered some of the review questions. On average, students in the treatment group spent about twice as long on the questions as students in the control group.

A third experiment using a sample of undergraduates in a psychology course ($N = 429$) used the same intervention, but added a third group that read and wrote about self-oriented purpose rather than self-transcendent purpose. After the intervention, students performed an online "diligence task" that gave them the option either to work on tedious math problems—which were promoted as helpful preparation for their future—or to watch entertaining videos or to play a game. Students who received either of the two purpose interventions persisted and answered more math questions correctly than the control group. Even at the highest levels of self-reported boredom, students in the self-transcendent intervention group persisted and answered more questions correctly than the other two groups. These experiments demonstrate that brief interventions reinforcing students' sense of purpose can positively impact their diligence and persistence and lead to improved academic performance.

Belongingness Mindset Interventions

Walton and Cohen (2007) conducted a three-stage study in which they attempted to influence factors affecting college students' social belonging uncertainty through attributional retraining[14]. They hypothesized that the intervention would benefit Black students more than White students because the intervention was set up to "de-racialize both objective adversity and the subjective doubts about belonging it instigates" (p. 88). In the pre-intervention stage (Stage 1), 25 Black and 30 White students participated in questionnaires that assessed their attitudes and experiences at their schools, including their

[14] This attributional retraining intervention is distinct from most prior attributional retraining interventions in that it is focused on belongingness instead of self-perceived ability (Walton & Cohen, 2007).

reactions to perceived rejection based on their race. Within two weeks, a subset of Stage 1 participants (18 Black and 19 White students) participated in Stage 2 (laboratory session) under the guise that it was unrelated to Stage 1—the students were told that they were participating in a study "to investigate 'the experiences and attitudes of freshmen'" (p. 88) and to develop informative materials for future students about what to expect in college. Participants were randomly assigned to a treatment or control group, in which they read supposed findings from a survey of upperclassmen. In the treatment group, survey results indicated that many of the upperclassmen, regardless of race and gender, worried that they did not belong at the college in their first year but that these worries lessened over time. The strength of the quantitative findings was supported by actual quotes from the upperclassmen who had taken the survey. Participants in the control group read survey results that indicated that students' social-political views grew more sophisticated with time. Participants in both groups were subsequently asked to write an essay and deliver a speech on video discussing why college students experience the reported changes and how the participants' own experiences were reflected in the survey results.

Following the social-psychological intervention in Walton and Cohen's (2007) study, all participants completed a questionnaire of academic fit (social fit, academic identification, academic enjoyment, self-efficacy, potential to succeed, possible academic self, and evaluative anxiety). Black participants in the treatment group assessed their academic fit significantly higher than Black students in the control group, while the opposite effect was observed for White participants. The researchers suggested this latter result could be due to the White students' loss of stereotype lift—"the achievement boost that arises from the belief that an out-group is inferior to one's own" (p. 88). To assess participants' challenge-seeking behaviors, they were asked to indicate which of 12 courses they would like to take based on past students' ratings of difficulty and educational benefit.

There was a positive effect of treatment for both races, though the effect was more moderate for the White participants. In Stage 3, participants wrote diary entries and completed two questionnaires daily for 14 days. Black students in the treatment condition sustained higher levels of academic fit than all other participants over the duration of Stage 3. The academic fit of Black students in the treatment group did not fall on days of "high adversity" as it did for Black students in the control group. Finally, the researchers analyzed the effects of treatment and race on GPA at the end of the second year of college. GPAs of Black students in the treatment group increased significantly more than their first-year GPAs predicted. No significant effect was observed for the White participants. Overall results indicated that the intervention had reduced group-based inequality.

In a longitudinal randomized controlled experiment, Walton and Cohen (2011) targeted the belongingness of students in their second semester at a selective college. The participants consisted of 49 Black students and 43 White students. Participants were randomly assigned to either an experimental group or a control group. The groups received a treatment nearly identical to that described in Stage 2 of the previous study (Walton & Cohen, 2007). The intervention led to higher GPAs for Black students in the experimental group and reduced the racial gap between Black students and White students. The impact was still evident 3 years after the intervention was administered. Even after controlling for gender and for preintervention GPA, similar results were seen—Black students in the experimental group were significantly more likely to be in the top 25% of students in their class than other Black students at the school, and they were less likely to be in the bottom 25%. Three years after the intervention, Black students in the experimental group also reported significantly lower levels of belonging uncertainty, accessibility of negative racial stereotypes, and accessibility of self-doubt than Black students in the control group. Furthermore, these students gave significantly higher assessments of their general health and happiness and they reported fewer doctor visits. For White students, there were no significant differences between the experimental and control groups on any of the dependent variables. As in the previous study, the brief intervention had lasting effects that reduced the racial gap between White students and Black students.

Walton, Cohen, Cwir, and Spencer (2012) performed a series of experiments testing the effects of very small "mere belonging" interventions. These experiments are exceptions in this review in that they did not seek to improve students' achievement or motivation in a natural academic setting, but instead measured participants' mathematics motivation, persistence, and social fit in the laboratory. Nonetheless, I include these experiments here because they show the affect that even a very small manipulation of social belonging can have on motivation. Furthermore, the two experiments I review each used mathematics motivation and social connectedness to mathematics as outcome measures, making them even more relevant to my research.

In Walton et al.'s (2012) first experiment, 49 women and 23 men, all of whom were White undergraduate students receptive to the prospect of doing math, read a putative *Chronicle of Higher Education* report by a recent graduate of the school's mathematics department. Students in the "relational-context" condition read a report that indicated that the mathematics department provided many opportunities for positive social interactions and collaborations. Students in the "skill-promotive" condition read a report that indicated that the department provided opportunities to develop personal abilities and explore mathematics. Both reports described a positive experience, and in all cases the author's gender matched the participant's. The researchers randomly assigned male participants to the relational-context group or the skill-promotive group, and the female participants were randomly assigned to one of these two groups or to a third group which read no report.

After the participants in Walton and Cohen's (2012) first experiment were randomly assigned, researchers gave participants a mathematics puzzle that was, unknown to the participants, unsolvable[15]. The researchers told the participants to spend as much or as little time on the task as they wanted, and they measured the time students spent on the task before giving up. In both report conditions, women spent longer on the task than men. After controlling for gender differences and other significant covariates, students in the relational-context group spent significantly more time ($M_{adj} = 11$ min 8 s) on the puzzle than students in the skill-promotive group ($M_{adj} = 7$ min 57 s) and the no report group ($M_{adj} = 6$ min 37 s). Students in the relational-context group also reported significantly higher levels of mathematics motivation than the other two groups. The researchers also showed that students in the relational-context group reported higher levels of social fit in the mathematics department and that the level of social fit significantly mediated the effects of the intervention.

In this same article, Walton et al. (2012) reported on a second experiment ($N = 26$) similar to the one described above. As in the first experiment, participants were students at least moderately interested in doing mathematics. They again read a fabricated article from the *Chronicle of Higher Education* ostensibly authored by a graduate of their school's mathematics department. The article spoke highly of the department, and the author was presented as a role model for the participants. As before, the author's gender matched the participant's. In this experiment, the author's birthday was given, along with other brief personal information such as the author's hometown. In the experimental condition, the author's birthday matched the participant's (though with a different year), and in the control condition, the author's birthday differed from the participant's by 4 to 5

[15] The participants were asked to create a map so that 5 colors would be needed to color it without adjacent regions sharing the same color, an impossible counterexample to the Four Color Theorem.

months. The researchers hypothesized that sharing a birthday with the author would create a social connection—a sense of mere belonging—that would cause the participant to be more motivated to do mathematics. Indeed, participants in the same-birthday condition spent longer ($M_{adj} = 10$ min 4 s) on the unsolvable puzzle than participants in the different-birthday condition ($M_{adj} = 6$ min 6 s). Participants also self-reported significantly higher levels of math motivation and social connectedness to math in the same-birthday condition. As in the first experiment, social connectedness to the mathematics community mediated composite mathematics motivation.

Hausmann et al. (2007) performed a randomized controlled experiment targeting first-year college students' sense of institutional belonging. The researchers invited all Black first-year students ($n = 254$) and a random sample of White students ($n = 291$) to complete surveys measuring social and academic integration, peer and family support, sense of institutional belonging, institutional commitment, and intentions to persist. Participants completed surveys at the beginning of the first semester, the beginning of the second semester, and again near the end of the second semester. The researchers randomly assigned participants into three groups: an enhanced sense of belonging treatment group, a gift control group, and a no-gift control group. The treatment group received written communications from university administrators indicating to the students that they were valued members of the university community and that the students' responses on the survey were highly valued. Students in the treatment group also received small gifts, such as magnets, with the university's colors and logo displayed on them. The gifts served to surround the participants with reminders of the academic community they belonged to. In the two control groups, each participant only received communications from a psychology professor, and the professor did not refer to the student's place in the academic community. To control for any effects that receiving gifts may have on belongingness and motivation, participants in the gift control group received identical gifts to those received in the treatment group, except the gifts did not display the university logo, name, or colors. Students in the no-gift control group received no gifts.

All participants in the Hausmann et al. (Hausmann et al., 2007) study reported a decline in sense of belonging and intentions to persist, though the rate of decline differed by experimental condition, even after controlling for many factors. Students in the enhanced sense of belonging group reported a significantly smaller decrease in belongingness than the control groups combined, though the effect was small. The decrease in belongingness in the treatment group was also slower than each control group individually, though the difference from the gift control group was only marginally significant. The researchers observed a similar marginal intervention effect on the rate of decline in intention to persist.

Combined Mindsets Interventions

To test the relative effectiveness of social-psychological interventions targeting different mindsets and beliefs, David Yeager and colleagues (2016) conducted three double-blind randomized experiments on students leaving high school or entering college. Each experiment had a control group and three experimental groups.

In Experiment 1, 584 seniors from 4 high-performing urban charter high schools were randomly assigned to receive a growth mindset intervention, a belongingness intervention, a combined intervention, or no intervention (Yeager et al., 2016). In the spring of their senior year, participants took a survey to create a baseline measurement of several factors linked to college persistence. The researchers stratified the sample by school, gender, and prior GPA (above median and below median) and randomly assigned students in each stratum to the four groups. This experiment utilized a 2 (social-belonging) × 2 (growth mindset) factor design, so roughly a quarter of the participants received a combination of the two interventions. In May, students received their assigned intervention in their school computer lab. Students wore headphones and had cardboard blinders to avoid treatment contamination. The social-belonging intervention presented putative survey results from upperclassmen indicating that most students worry about fitting in after the transition to college but that these feelings subside. To ensure that the worries expressed in the survey responses were relevant to the students, the researchers designed these materials with assistance from previous students of the school who had been admitted to college. The growth mindset of intelligence intervention had students read a brief scientific article citing research that shows that intelligence grows with mental work. Participants in the control group saw materials similar to the social-belonging group, but the intervention focused on the physical aspects of a college transition such as becoming familiar with the buildings.

After reading the article, survey responses, or both, each participant in Yeager et al.'s (2016) first experiment wrote a brief essay relating the delivered message to their own experiences transitioning to high school. Ostensibly, the essay responses were to help future students in their school transitions. The researchers tracked participants' enrollment in college and found that students who had received the social-belonging intervention were significantly more likely than the rest to have been continuously enrolled full-time during the first year of college. The growth mindset intervention did not have a significant effect on participants' college enrollment. One possible reason the researchers offer for why the growth mindset intervention was ineffective was the fact that the school already taught students to adopt a growth mindset of intelligence and the intervention may have been redundant. The researchers also hypothesize that because the student's selected college did not deliver the message, the participants may not have viewed a growth mindset as something important or accepted by the college, thus reducing its salience and effect.

Yeager and colleagues (2016) conducted Experiment 2 and Experiment 3 during orientation sessions at universities. Experiment 2 ($n = 7{,}335$) was at the same large public 4-year university as my study. The interventions in Experiment 2 were like those in Experiment 1. Participants receiving the growth mindset intervention, the belongingness intervention, or the combined intervention were more likely to remain continuously enrolled for the first year at the university than participants in the control group. Based on pre-manipulation survey results, the researchers found that the intervention had a large significant effect on the persistence of students whose responses indicated that they may be at higher risk of leaving college and no significant effect on students who were not at risk. There were no differences in effects between the three intervention groups.

Yeager et al. (2016) likewise conducted Experiment 3 ($n = 1{,}592$) during an orientation but at a selective private university and with two new interventions: response to critical feedback and cultural fit. Each was similar in form to the social-belonging intervention except that the critical feedback intervention delivered the message that professors give critical feedback because they believe the recipient has high potential for academic success, and the cultural fit intervention conveyed that upperclassmen learned to make interdependent relationships like the ones they have with friends and family members in their hometowns. Participants in Experiment 3 received only one intervention or the control treatment. The interventions had a significant positive effect on participants' cumulative first-year GPA. The effect was larger for students identified as disadvantaged on pre-manipulation surveys, and it was not significant for advantaged students.

This study was published after my data collection, but it is worth special mention for its attempt, as with my study, to differentiate effects from interventions targeting different mindsets (Yeager et al., 2016). Furthermore, without my knowledge, Experiment 2 was conducted at the same institution immediately prior to the semester in which I conducted my study. This almost certainly had a drastic effect on my research results, which I discuss in Chapter 5.

Challenges to Implementation

These studies demonstrate that social-psychological interventions can be a powerful tool for fostering productive academic mindsets that can propagate cycles of improved motivation and success. However, researchers rightly warn that educators must not implement these interventions hastily. Yeager and Walton (2011) caution researchers and educators that social-psychological interventions are not a quick fix for students' academic struggles. The authors use the analogy of the complex forces involved in lifting a plane to describe the study and implementation of these interventions and the complex contexts and psychological forces involved:

> Basic laboratory research helps explain the principles of air flow and shows that the shape and position of wings cause air to flow faster below them than above them, lifting a plane beyond what might seem possible. In a similar way, hidden yet powerful psychological forces, also investigated through basic science, can raise student achievement. An engineer uses theories of fluid dynamics to fine-tune a wing, which, in the context of other factors, makes a plane fly. Analogously, a social-psychological perspective uses basic theory and research to identify educationally important psychological processes and then subtly alters these processes in a complex academic environment to raise performance. (Yeager & Walton, 2011, p. 274)

Just as any aviation enthusiast would be wise not to piece together materials in the shape of an airplane and expect it to fly, educators must not expect guaranteed success from any social-psychological intervention. Snipes et al. (2012) point out that there is very little evidence thus far that academic mindset interventions are effective when scaled up outside of the context of research. Indeed, many of the interventions discussed in this chapter were delivered in controlled laboratory environments, and they are largely unproven in the classroom. Snipes et al. (2012) advise that educators and researchers attend carefully to implementation fidelity. The authors point to a study by Hulleman and Cordray (2009) as evidence that when teachers did not adhere strictly to protocol, the interventions had no positive impact on student success.

Additionally, Snipes et al. (2012) argue that the success or failure of academic mindset interventions depends on several contextual factors. Non-intervention messages that students receive in the classroom from teachers, other students, or course materials may undermine the message of an intervention. Furthermore, academic supports must be available to students. Mindset interventions alone are not enough to teach students; students must also have available the resources and educational supports to learn. The target population may also impact the generalizability of an intervention. An intervention that is successful for one demographic may not be successful for another.

A few related comments on the differential effectiveness of social-psychological interventions are in order. Research described here has shown social-psychological interventions to be especially effective for certain groups of students who are struggling, who have a record of underperformance, or who are stereotype threatened. Advantaged students and students with a record of high achievement did not receive as much benefit from many of the studies mentioned in this review. However, even when the interventions showed no achievement effects or were only minimally effective for such students, the interventions also did not appear to cause them to underperform. This was even the case in the Walton and Cohen (2007) study where White students reported decreases in belongingness (hypothetically due to a loss of stereotype lift).

Finally, Snipes et al. (2012) stress that teachers and students must have organizational support from the school and community in order for mindset interventions to be effective. School leaders must ensure that teachers have proper training and that there is generally buy in and acceptance of the intervention. Similarly, messages and support from students' families and peer groups can influence the extent to which students adopt the target mindset. The complex web of influences shapes students' attitudes and beliefs and has the potential to render the effects of a mindset intervention comparatively miniscule.

Chapter 3: Methodology

This chapter describes the methods of data collection and analysis I used to answer my research questions. I performed an exploratory study to observe the effects (on student academic performance, motivation, and regulation of cognition) of peer-led social-psychological interventions delivered through videos embedded in online homework assignments as part of a first-semester calculus course at a large research university. In this study, I address the six research questions listed below. The null and alternative hypotheses follow each research question.

Effects of Interventions on Calculus Understanding

1. What is the effect of a novel growth mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?

   $H_0 1$: Participants receiving the growth mindset intervention exhibit no greater gains on a calculus assessment than participants in the comparison group.

   $H_a 1$: Participants receiving the growth mindset intervention exhibit greater gains on a calculus assessment than participants in the comparison group.

2. What is the effect of a novel purpose mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?

   $H_0 2$: Participants receiving the purpose mindset intervention exhibit no greater gains on a calculus assessment than participants in the comparison group.

   $H_a 2$: Participants receiving the purpose mindset intervention exhibit greater gains on a calculus assessment than participants in the comparison group.

3. What is the effect of a novel belongingness mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?

   $H_0 3$: Participants receiving the belongingness mindset intervention exhibit no greater gains on a calculus assessment than participants in the comparison group.

   $H_a 3$: Participants receiving the belongingness mindset intervention exhibit greater gains on a calculus assessment than participants in the comparison group.

Effects of Interventions on Motivation and Regulation of Cognition

4. What are the effects of a novel growth mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of regulation of cognition, task value, control of learning, and self-efficacy as measured by standard instruments?

   $H_0 4$: Participants receiving the growth mindset intervention exhibit no greater changes in self-reports of regulation of cognition task value, control of learning, and self-efficacy than participants in the comparison group.

   $H_a 4$: Participants receiving the growth mindset intervention exhibit greater changes in self-reports of regulation of cognition task value, control of learning, and self-efficacy than participants in the comparison group.

5. What are the effects of a novel purpose mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of regulation of cognition, task value, control of learning, and self-efficacy as measured by standard instruments?

   $H_0 5$: Participants receiving the purpose mindset intervention exhibit no greater changes in self-reports of regulation of cognition task value, control of learning, and self-efficacy than participants in the comparison group.

H_a5: Participants receiving the purpose mindset intervention exhibit greater changes in self-reports of regulation of cognition task value, control of learning, and self-efficacy than participants in the comparison group.

6. What are the effects of a novel belongingness mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of regulation of cognition, task value, control of learning, and self-efficacy as measured by standard instruments?

   H_06: Participants receiving the belongingness mindset intervention exhibit no greater changes in self-reports of regulation of cognition task value, control of learning, and self-efficacy than participants in the comparison group.

   H_a6: Participants receiving the belongingness mindset intervention exhibit greater changes in self-reports of regulation of cognition task value, control of learning, and self-efficacy than participants in the comparison group.

PARTICIPANTS

The participants are students at a large research university who were enrolled in one of two first-semester calculus courses during the 14-week fall semester of 2013. The two courses did not focus deeply on theory and were designed for students who had not taken calculus before. The courses covered the same topics of differential calculus of one variable, including limits, continuity, differentiation, mean value theorem, and applications. One course (Course I) was intended only for students in the natural sciences and introduced more applications relevant to the natural sciences. All of the Course I classes were flipped—students studied online learning modules outside of class and class time was spent solving problems individually or in groups with occasional lectures as needed. The other course (Course II) was intended for students in the natural sciences, business, and engineering. Some of the Course II classes were flipped, and some were taught as traditional lecture courses. All the flipped classes in each course used the same online learning modules. With the help of colleagues, I contacted 12 instructors (coded A through L) of 18 classes to get permission to recruit participants from their classes. The breakdown of these classes by instructor and course is shown in Table 3.1. Each class had between 96 and 120 students enrolled. Students in each class also attended discussion sessions twice per week with a graduate student teaching assistant. There were two or three discussion sections per class, and all students in a class met with the same teaching assistant.

During the third week of the semester, a colleague and I visited each class during lecture to discuss the study and request informed consent from students. Visits lasted 10 to 15 minutes. During the visits, we distributed consent forms, described the study, and collected the consent forms. Students did not receive compensation of any kind for their participation. A total of 754 students gave consent to participate, but only 633 provided data on the measures described in the Data Collection Measures section of this chapter. The 121 students who did not provide data withdrew from their calculus courses or transferred to a course not included in this study soon after we gained their consent. Only consenting participants who provided some data were included in the data analysis. The distribution of participants among the three different course types is shown in Table 3.1.

Table 3.1

Distribution of Consenting Participants for Whom Some Data were Collected.[a]

	Course I (flipped)	Course II (flipped)	Course II (traditional)	Total
	A (*n*=50)	E (*n*=39)	C (*n*=31)	
	B (*n*=54)	G (*n*=31)	D (*n*=20)	
	E (*n*=26)	G (*n*=54)	D (*n*=8)	
	F (*n*=51)	I (*n*=30)	J (*n*=23)	
	H (*n*=28)	L (*n*=27)	J (*n*=44)	
	K (*n*=40)			
	K (*n*=47)			
	L (*n*=30)			
Total	8 classes (*n*=326)	5 classes (*n*=181)	5 classes (*n*=126)	18 classes (*N*=633)

a. Instructor codes A through L indicate which instructors taught which courses.

INTERVENTION

I created three different intervention videos, each targeting one of the following mindsets: growth, purpose, or belongingness. Each video had the same two former calculus student actors ostensibly discussing their experiences in their first-semester calculus course. The actors, a White male and a White Hispanic/Latina female, were both about 20 years old. I scripted each video so that the actors discussed a transformation in the targeted mindset from an unfavorable and demotivating mindset to a favorable and motivating mindset. In the growth video, the actors discussed how they were initially discouraged by the difficulty of the course but later understood that struggle is a necessary part of learning, and that struggling leads to growth in the brain. For example, near the beginning of the growth video, the male actor said:

> I started out really confident and was sure I'd get an A because I got good grades in math in high school. But I got stuck on some of the first [online homework] problems…I kinda started to wonder if I was smart enough to be at [the university].

The female actor talks in the growth video about how she almost dropped a course at one point and how her thinking ability is innate was illogical:

> Yeah, I probably nearly dropped that class for the wrong reasons. I was embarrassed by not getting A's, and I worried that my family would be so disappointed in me. It's so funny that we know that struggle and effort matter in some subjects and in others we think its natural talent, like genetics, you know?

The male actor responded to the female actor, saying:

> Yeah, it doesn't really matter how smart you are coming into college. It's going to be hard for anyone–that's the point. In one of my psychology classes last year we learned about how struggling with a difficult subject or a challenging problem actually physically changes your brain. It creates new connections between different parts of your brain and that's how you learn new things. That's definitely been my experience at [the university]– the more I struggle with something, the more I learn.

In the purpose video, the actors discussed how they did not always see the utility of calculus in their areas of study and interest but saw many applications in later courses. An example comment from the female actor talking about the importance of seeing the purpose of her calculus class in the intervention video is below:

> I eventually learned that if you didn't connect the studying and the coursework to something important, it would just exhaust you and really grind you down. I definitely felt that early on. But the people who were actually trying to get ready

for something they cared about, like their career, would have more energy when things got difficult.

In the belongingness video, the actors discussed how they felt they did not belong in their course, field of study, and/or university at the beginning of their freshman year but later felt that they did belong. During the belongingness intervention video, the female actor discussed how she eventually felt a sense of belonging even though she did not initially feel that way:

> Now that I have lots of friends, like from my discussion sessions, from my FIG, and from my major, it all seems kinda silly that we were worried about it. Everyone wonders how they'll fit in, and we all do. It's just that your friends in college will probably be a lot more different than your friends in high school.

The final videos differed slightly from the scripts after the student actors gave input and due to small recitation errors. See Appendix A for transcripts of each video.

I embedded the videos in freshmen calculus students' online homework during the third week of class. Due to the nature of the online homework platform in which the videos were embedded, all students in a class had to be assigned to the same treatment group. I assigned participating classes to one of four groups: growth, purpose, belongingness, and comparison. The Growth group viewed the growth video, the Purpose group viewed the purpose video, the Belongingness group viewed the belongingness video, and the comparison group did not view a video that I filmed. Students in the flipped classes viewed several other videos unrelated to the intervention within their online learning modules. All students in each intervention group had the opportunity to view a treatment video, regardless of whether they consented to participate in the study. If a student in an intervention group did not attempt homework the week of the intervention, then they probably did not receive the intervention. I considered including these students in the comparison group, but it is possible that some of the students may have viewed the intervention video while studying with a classmate. Since it was impossible to determine whether these students had seen the intended intervention video, I excluded their data from the analyses. I was unable to coordinate with the instructors of the traditional Course II classes to include any intervention videos within their online homework assignments. Therefore, I assigned all the traditional lecture classes to the comparison group. I randomly assigned all other classes to a treatment or comparison group. Table 3.2 shows the number of classes and students in each of the groups.

Table 3.2

Distribution of Consenting Participants for Whom Some Data were Collected and Who Viewed Assigned Intervention Video.[a]

Treatment Group	Course I (flipped)	Course II (flipped)	Course II (traditional)	Total
Growth Group	H (*n*=26), K (*n*=19)	G (*n*=40)		3 classes (*n*=85)
Purpose Group	A (*n*=50) K (*n*=18)	I (*n*=25)		3 classes (*n*=93)
Belongingness Group	E (*n*=17)	G (*n*=26)		2 classes (*n*=43)
Comparison Group	B (*n*=54) F (*n*=51) L (*n*=30)	E (*n*=39) L (*n*=27)	C (*n*=31) D (*n*=20) D (*n*=8) J (*n*=23) J (*n*=44)	10 classes (*n*=327)
Total	8 classes (*n*=265)	5 classes (*n*=157)	5 classes (*n*=126)	18 classes (*N*=548)

a. Instructor codes A through L indicate which instructors taught which courses.

DATA COLLECTION MEASURES

Calculus Concept Inventory

Students took an in-class Calculus Concept Inventory (CCI) during the first week of the semester and during the last two weeks of the semester and submitted answers via Scantron. The CCI is a 22-item multiple choice test of students' conceptual understanding of differential calculus that was developed and validated by Jerome Epstein and a panel of experts (2006, 2013). Because the exam must remain secure, I cannot include it here. Figure 3.1 shows the question that the CCI author provided as an example similar to actual CCI questions. I used the CCI as a pre- and post-test of calculus understanding to determine if the interventions had any impact on student learning. Epstein (2013) validated the instrument with a set of cognitive labs that showed students who missed items indeed held the misconceptions the items were designed to target. The study also reported moderate reliability (Cronbach's alpha = 0.7). Recently, the validity of the CCI as a measure of calculus concept knowledge has been called into question (Gleason, Thomas, et al., 2015; Gleason, White, Thomas, Bagley, & Rice, 2015) as it may measure calculus vocabulary rather than calculus concept knowledge. I discuss the possibility of alternative measures in Chapter 5.

If you know that a function $f(x)$ is positive everywhere, what can you conclude from that about the derivative $f'(x)$?:

a) the derivative is positive everywhere

b) the derivative is increasing everywhere

c) the derivative is concave upward

d) you can't conclude anything about the derivative

Figure 3.1: Example question similar to those in the CCI.

Surveys

Every student in all classes in the study received access to a survey comprised of items from the Metacognitive Awareness Inventory (MAI), developed by Schraw and Dennison (1994), and the Motivated Strategies for Learning Questionnaire (MSLQ), developed by Pintrich, Smith, Garcia, and McKeachie (1991), during the second week of class and again during the second-to-last week of class. Students had at least one week to complete the survey online each time. In the interest of receiving more complete responses from participants, I shortened the survey to include only the scales deemed most relevant.

The MAI consists of eight scales, each designed to assess a different component skill: *planning*, *monitoring*, *information management*, *evaluation*, *debugging strategies*, *declarative knowledge*, *procedural knowledge*, and *conditional knowledge*. Schraw and Dennison (1994) performed a factor analysis and concluded that the survey reliably assesses two constructs. The first five scales assess a construct they named Regulation of Cognition (Cronbach's alpha = 0.91), and the last three scales reliably assess a construct they identified as Knowledge of Cognition (Cronbach's alpha = 0.91). To validate the instrument, they presented empirical support for the two-component model of metacognition and showed that the respective components of Regulation of Cognition and Knowledge of Cognition were related to one another and to empirical measures of cognitive and metacognitive performance.

Young and Fry (2008) showed that both components were modestly correlated with academic performance as measured by grades and GPA. This study also revealed that graduate students scored significantly higher on Regulation of Cognition but not on Knowledge of Cognition, indicating that the former component is more closely correlated with academic persistence. As such, my survey excluded Knowledge of Cognition scales and included all Regulation of Cognition scales (*planning*, *monitoring*, *information management*, *evaluation*, and *debugging strategies*). The *planning* scale assesses students' capacity for planning, goal setting, and allocating resources prior to learning. The *monitoring* scale gauges students' assessments of their own strategy use and learning. The *information management* scale assesses students' use of skills and strategies to process information more effectively. The *evaluation* scale assesses students' analysis of their own performance and strategy use after a learning experience. The *debugging strategies* scale assesses strategies used to correct comprehension and performance errors.

The MSLQ is comprised of Motivation scales (organized into *Value*, *Expectancy,* and *Affective* components) and Learning Strategies scales (organized into the *Cognitive and Metacognitive* and *Resource Management* components). My survey included the *task value* scale of the *Value* component, the *control of learning beliefs* scale of the *Expectancy* component, and the *self-efficacy for learning and performance* scale of the *Expectancy* component. The *task value* scale evaluates each student's assessment of how interesting, important, and useful the course is. The *control of learning beliefs* scale assesses students' beliefs about whether and to what degree their learning is dependent on their own effort. The *self-efficacy for learning and performance* scale measures each student's assessment of her ability to perform a task correctly and her ability to master the task. Credé and Phillips (2011) performed a meta-analysis of 19,000 college students' responses to the MSLQ and found moderate to high reliability of the *task value* scale (Cronbach's alpha = 0.87), the *control of learning beliefs* scale (Cronbach's alpha = 0.65), and the *self-efficacy for learning and performance* scale (Cronbach's alpha = 0.91). The authors further concluded that these scales showed reasonable predictive validity of course grades and GPA and that scales of the same components were reasonably correlated with one another.

I did not include the remaining Motivation scales (*intrinsic* and *extrinsic goal orientation* scales of the *Value* component and the *test anxiety* component of the *Affective* component). The three scales of *task value, control of learning beliefs,* and *self-efficacy for learning and performance* are the motivational scales most predictive of grades and GPA (Credé & Phillips, 2011). I also chose these motivational scales because I expected them to be most responsive to interventions targeting the closely related academic mathematics mindsets—students' growth, purpose, and belongingness mindsets. Further, I excluded the Learning Strategies scales of the MSLQ in my questionnaire because the Regulation of Cognition scales of the MAI include learning strategies.

The items appeared as one survey with 53 questions. The 35 MAI items were first, followed by the 18 MSLQ items. Table 3.3 gives a sample of the items from the survey. See Appendix C for the complete survey.

Table 3.3

Sample Items from Motivation and Metacognition Survey.

Source	Scale	Item
MAI	Regulation of Cognition	
	Planning	I pace myself while learning in order to have enough time.
	Information Management Strategies	I slow down when I encounter important information.
	Monitoring	I ask myself periodically if I am meeting my goals.
	Debugging Strategies	I ask others for help when I don't understand something.
	Evaluation	I know how well I did once I finish a test.
MSLQ	Task Value	I think I will be able to use what I learn in this course in other courses.
	Control of Learning Beliefs	If I study in appropriate ways, then I will be able to learn the material in this course.
	Self-Efficacy for Learning and Performance	I believe I will receive an excellent grade in this class.

Exams

Students in Course II took multiple-choice exams with very similar questions. Each question on the exams had several versions in which only numbers, functions, and figures varied slightly. All versions of each question were approximately equally difficult. Students completed three exams during the semester and one comprehensive final exam at the end of the semester. Students answered each exam on a Scantron form, and a Scantron machine scored each exam as a percentage of problems correct.

Exams in Course I varied between classes. I attempted to have common items on each exam in Course I classes, but instructors did not consistently comply. Because the exam scores are not a reliable measure, I did not include exam data in my analyses.

METHODS OF DATA ANALYSIS

Independent and Dependent Variables

The independent variables for each participant are group assignment: Growth, Purpose, or Belongingness. The dependent variables are normed changes on the CCI and changes on MAI and MSLQ scales measuring planning, information management strategies, monitoring, debugging strategies, evaluation, task value, control of learning beliefs, and self-efficacy for learning and performance. I calculated normed gains on the CCI as

$$\text{CCI Normed Gain} = \frac{\text{posttest score} - \text{pretest score}}{22 - \text{pretest score}},$$

where pretest and posttest scores are number of problems answered correctly out of a total of 22. I calculated changes on the MAI and MSLQ scales as differences between posttest and pretest averages of scale items self-reported on a 7-point discrete visual analog scale. This is the same measurement recommended in the MSLQ manual except that I listed answer choices vertically rather than horizontally because the online homework platform could not list them horizontally. See Figure C.1 in Appendix C for an example item with response options. The MAI uses a 100mm continuous visual analog scale, but it was not possible to use continuous scales on the online homework platform. Furthermore, it was important that the combined survey be consistent in style.

Research Questions 1-3 Analysis Plan

1. *What is the effect of a novel growth mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?*
2. *What is the effect of a novel purpose mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?*
3. *What is the effect of a novel belongingness mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?*

To answer these questions, I performed a multiple regression analysis using CCI normed gains as the dependent variable and intervention groups (Growth, Purpose, or Belongingness) as the independent variables. Due to the sparseness of data at the class and course level, a multilevel model is not appropriate.

Research Questions 4-6 Analysis Plan

4. *What are the effects of a novel growth mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of regulation of cognition, task value, control of learning, and self-efficacy as measured by standard instruments?*
5. *What are the effects of a novel purpose mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of regulation of cognition, task value, control of learning, and self-efficacy as measured by standard instruments?*
6. *What are the effects of a novel belongingness mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of*

regulation of cognition, task value, control of learning, and self-efficacy as measured by standard instruments?

To answer these questions, I performed four multiple regression analyses using as the dependent variable gains on the regulation of cognition component (MAI), the task value scale (MSLQ), the control of learning beliefs scale (MSLQ), and the self-efficacy for learning and performance scale (MSLQ), and intervention group membership (Growth, Purpose, or Belongingness) as the independent variables. I compared outcomes in each treatment group to outcomes in the comparison group. Due to sparsity of data at the class and course level, a multilevel model is not appropriate.

Because I used one data set to test twenty hypotheses, a Bonferroni correction is appropriate. However, because my research is in part exploratory, I set the significance level for all hypothesis tests at $\alpha = .05$ so that my analyses would identify any possible significant effects. For effects statistically significant at this level, I examined whether a Bonferroni correction altered this conclusion. Using G*Power 3.1.9.2, I performed a power analysis for each planned analysis (Faul, Erdfelder, Lang, & Buchner, 2007). To check whether the sample size was large enough to identify significant effects with a conservative Bonferroni correction, I performed the power analysis with $\alpha = \frac{.05}{20} = .0025$ and a power of $1 - \beta = .95$. For a multiple regression analysis with three predictors, to detect effects of a medium size ($f^2 = 0.15$) (J. Cohen, 1988), a sample of at least 188 subjects is necessary. My sample size is adequate to identify any such effects in each of my analyses. In the next chapter, I present the results of the analyses outlined here.

Chapter 4: Results

In this study, I created and administered three short video interventions, each targeting a different math mindset—math growth mindset, math purpose mindset, and math belongingness mindset. Prior research has demonstrated the effectiveness of these mindsets in enhancing students' achievement levels, metacognitive strategies, and motivation. My dependent measures assessed each of these outcomes and, broadly speaking, I was unable to detect the desired changes, and my interventions appear to have been ineffective in this context. My initial analyses pointed to a negative effect of watching the belongingness video on students' academic performance on a calculus assessment, but this effect disappeared when I took the appropriate statistical measures to control for the likelihood of Type 1 errors (i.e., false-positive results).

I address possible explanations for these seemingly dismal results in Chapter 5, but one potential explanation deserves special recognition at the outset of this chapter. A portion of my participants unknowingly participated in a mindset intervention (Yeager et al., 2016) during their freshman orientation mere weeks before I collected my baseline data. This study likely included students in all three of my intervention groups and my comparison group. I did not modify my study because I was unaware of the confounding (confidential) intervention. I do not know which students, or even how many students, in my study received the large-scale intervention; hence, I cannot parse results or determine the extent of the contamination in my dataset. This makes it impossible for me to draw any definitive conclusions, and the results I present below should be interpreted with caution.

Independent and Dependent Variables

For each analysis, the independent variables are group assignment—Growth, Purpose, or Belongingness. Each independent variable has a value of 0 (not assigned to the group) or 1 (assigned to the group). The dependent variables are normed gains on the CCI and difference scores on the MAI and MSLQ scales: regulation of cognition (planning, information management strategies, monitoring, debugging strategies, evaluation), task value, control of learning beliefs, and self-efficacy for learning and performance. Normed changes on the CCI are defined as

$$\text{CCI Normed Gain} = \frac{\text{posttest score} - \text{pretest score}}{22 - \text{pretest score}}$$

where pretest and posttest scores are calculated as the number of problems answered correctly. Because there are 22 items on the CCI, CCI normed gains have theoretical values of undefined (indicating a perfect pretest score) or between -21 and 1, where a normed gain of 0 indicates no change in score, and a normed gain of 1 indicates a perfect posttest score. Post-survey minus pre-survey difference scores on MAI and MSLQ scales range between -7 and +7.

DESCRIPTIVE STATISTICS

Tables 4.1 through 4.5 summarize the descriptive statistics of each dependent variable for each of the intervention groups and the comparison group. Table 4.1 and Table 4.2 show that mean CCI normed gains and regulation of cognition difference scores are positive for all groups. Tables 4.3, 4.4, and 4.5 show that mean task value, control of learning, and self-efficacy difference scores are negative for all groups. Normed gains and difference scores that are statistically significantly different from zero (2-tailed Student's t-test) are indicated in the tables.

Table 4.1

Descriptive Statistics for CCI Scores.

	Pre			Post			Normed gains		
Group	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*
Comparison	8.6	3.2	305	10.8	3.8	258	.16*	.23	239
Growth	7.7	2.8	79	10.6	3.6	73	.21*	.23	68
Purpose	8.4	3.1	87	10.4	3.5	79	.14*	.23	73
Belongingness	8.2	3.1	42	9.4	3.4	34	.07	.21	33
Total (*n*=544)	8.4	3.1	513	10.6	3.7	444	.16*	.23	413

Note. CCI scores can range between 0 and 22.

*Statistically significantly different from zero ($p < .05$)

Table 4.2

Descriptive Statistics for Regulation of Cognition Self-Reports.

	Pre			Post			Difference Scores		
Group	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*
Comparison	4.77	.80	155	4.88	.77	117	.21*	.62	101
Growth	4.71	.70	80	4.72	.89	54	.01	.78	53
Purpose	4.68	.76	92	4.71	.85	60	.07	.59	60
Belongingness	4.83	.80	40	4.83	.78	26	.05	.62	26
Total (*n*=384)	4.74	.77	367	4.80	.81	257	.11*	.65	240

Note. Regulation of Cognition scores can range between 0 and 7.

*Statistically significantly different from zero ($p < .05$)

Table 4.3

Descriptive Statistics for Task Value Self-Reports.

	Pre			Post			Difference Scores		
Group	M	SD	n	M	SD	n	M	SD	n
Comparison	5.1	1.1	134	4.9	1.4	105	-.2*	.9	85
Growth	5.0	1.3	79	4.8	1.5	51	-.3	1.2	51
Purpose	5.1	1.4	89	4.6	1.5	58	-.4*	1.2	56
Belongingness	5.3	1.3	39	5.1	1.3	24	-.2	1.0	24
Total (*n*=363)	5.1	1.3	341	4.8	1.4	238	-.3*	1.1	216

Note. Task Value scores can range between 0 and 7.

*Statistically significantly different from zero ($p < .05$)

Table 4.4

Descriptive Statistics for Control of Learning Self-Reports.

	Pre			Post			Difference Scores		
Group	M	SD	n	M	SD	n	M	SD	n
Comparison	5.6	1.0	134	5.3	1.3	105	-.2	1.1	85
Growth	5.5	1.1	79	5.1	1.4	51	-.4*	1.1	51
Purpose	5.5	1.4	89	5.0	1.4	58	-.3*	1.1	56
Belongingness	5.8	.9	38	5.5	1.2	24	-.3	1.1	24
Total (*n*=316)	5.6	1.1	340	5.2	1.3	238	-.3*	1.1	216

Note. Control of Learning scores can range between 0 and 7.

*Statistically significantly different from zero ($p < .05$)

Table 4.5

Descriptive Statistics for Self-Efficacy Self-Reports.

	Pre			Post			Difference Scores		
Group	M	SD	n	M	SD	n	M	SD	n
Comparison	5.1	1.2	134	4.8	1.4	105	-.1	.9	85
Growth	4.8	1.4	79	4.6	1.4	51	-.4	1.2	51
Purpose	4.9	1.4	89	4.7	1.5	58	-.1	1.2	56
Belongingness	5.4	.9	39	5.0	1.1	24	-.4	1.1	24
Total (n=363)	5.0	1.3	341	4.8	1.4	238	-.2*	1.1	216

Note. Self-Efficacy scores can range between 0 and 7.

*Statistically significantly different from zero ($p < .05$)

ASSUMPTIONS

All of my analyses involve multiple regression. There are eight assumptions of a multiple regression: 1) the model has a continuous dependent variable; 2) the model has two or more independent (continuous or categorical) variables; 3) observations are independent; 4) there is a linear relationship between the dependent variable and the independent variables individually and collectively; 5) the data show homoscedasticity of residuals; 6) the data does not show multicollinearity; 7) there are no significant outliers, high leverage points, or highly influential points; 8) the residual errors are approximately normally distributed.

I verified the first two assumptions prior to running any analyses. My CCI dependent variable is a scale variable. The MAI and MSLQ difference score dependent variables can be treated as scale variables because they are ordinal and consist of five or more categories.

I verified each of the other six assumptions after running my regression analyses using IBM SPSS Statistics (Version 23.0). In each analysis, there was linearity as assessed by partial regression plots and a plot of studentized residuals against the predicted values. There was independence of residuals, as assessed by a Durbin-Watson statistic of between 1.5 and 2.5. There was homoscedasticity, as assessed by visual inspection of a plot of studentized residuals versus unstandardized predicted values. There was no evidence of multicollinearity, as assessed by tolerance values greater than 0.1. There were some studentized residuals greater than ±3 standard deviations, but no leverage values greater than 0.2, and no values for Cook's distance above 1; so no data points qualified as unusual. My data met the assumption of normality, as assessed by P-P Plot.

RESEARCH QUESTIONS 1-3 RESULTS

Effects of Interventions on Calculus Understanding

1. What is the effect of a novel growth mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?

   $H_0 1$: Participants receiving the growth mindset intervention exhibit no greater gains on a calculus assessment than participants in the comparison group.

   $H_a 1$: Participants receiving the growth mindset intervention exhibit greater gains on a calculus assessment than participants in the comparison group.

2. What is the effect of a novel purpose mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?

   $H_0 2$: Participants receiving the purpose mindset intervention exhibit no greater gains on a calculus assessment than participants in the comparison group.

   $H_a 2$: Participants receiving the purpose mindset intervention exhibit greater gains on a calculus assessment than participants in the comparison group.

3. What is the effect of a novel belongingness mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?

   $H_0$3: Participants receiving the belongingness mindset intervention exhibit no greater gains on a calculus assessment than participants in the comparison group.

   H_a3: Participants receiving the belongingness mindset intervention exhibit greater gains on a calculus assessment than participants in the comparison group.

To answer these questions and test my hypotheses, I performed a multiple regression analysis using CCI normed gains as the dependent variable and intervention group membership (Growth, Purpose, or Belongingness) as the independent variables. The regression model for this question is

$$\text{CCI Normed Gains} = \beta_0 + \beta_1 \cdot \text{Growth} + \beta_2 \cdot \text{Purpose} + \beta_3 \cdot \text{Belongingness}.$$

The multiple regression model significantly predicted CCI Normed Gains, $F(3, 409) = 2.835$, $p < .05$, adj. $R^2 = .013$. Regression coefficients and standard errors can be found in Table 4.6. Only the Belongingness group exhibited CCI Normed Gains statistically significantly different from the comparison group ($p < .05$). The CCI Normed Gains in the Belongingness group increased significantly less than the comparison group.

Table 4.6

Summary of Multiple Regression Analysis with CCI Normed Gains as the Dependent Variable.

Variable	B	SE_B	β
Intercept	.159	.015	
Growth	.048	.032	.078
Purpose	-.022	.031	-.036
Belongingness	-.088	.043	-.104*

Note. $B =$ unstandardized regression coefficient, $SE_B =$ Standard error of the coefficient, $\beta =$ standardized coefficient.

* Statistically significantly different from zero ($p < .05$)

RESEARCH QUESTIONS 4-6 RESULTS

Effects of Interventions on Motivation and Regulation of Cognition

4. What are the effects of a novel growth mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of regulation of cognition, task value, control of learning, and self-efficacy as measured by standard instruments?

   $H_0$4: Participants receiving the growth mindset intervention exhibit no greater changes in self-reports of regulation of cognition task value, control of learning, and self-efficacy than participants in the comparison group.

   H_a4: Participants receiving the growth mindset intervention exhibit greater changes in self-reports of regulation of cognition task value, control of learning, and self-efficacy than participants in the comparison group.

5. What are the effects of a novel purpose mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of regulation of

cognition, task value, control of learning, and self-efficacy as measured by standard instruments?

$H_0 5$: Participants receiving the purpose mindset intervention exhibit no greater changes in self-reports of regulation of cognition task value, control of learning, and self-efficacy than participants in the comparison group.

$H_a 5$: Participants receiving the purpose mindset intervention exhibit greater changes in self-reports of regulation of cognition task value, control of learning, and self-efficacy than participants in the comparison group.

6. What are the effects of a novel belongingness mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of regulation of cognition, task value, control of learning, and self-efficacy as measured by standard instruments?

   $H_0 6$: Participants receiving the belongingness mindset intervention exhibit no greater changes in self-reports of regulation of cognition task value, control of learning, and self-efficacy than participants in the comparison group.

   $H_a 6$: Participants receiving the belongingness mindset intervention exhibit greater changes in self-reports of regulation of cognition task value, control of learning, and self-efficacy than participants in the comparison group.

To answer this question and test my hypotheses, I performed four multiple regression analyses, one for each dependent variable (difference scores on self-reports of regulation of cognition, task value, control of learning, or self-efficacy). I used intervention groups (Growth, Purpose, and Belonging) as the independent variables in all four models.

Regulation of Cognition as Dependent Variable

The regression model for Research Questions 4-6 with regulation of cognition difference scores as the dependent variable is

$$\text{Regulation of Cognition} = \beta_0 + \beta_1 \cdot \text{Growth} + \beta_2 \cdot \text{Purpose} + \beta_3 \cdot \text{Belonging.}$$

The multiple regression model did not significantly predict regulation of cognition difference scores, $F(3, 236) = 1.299$, $p > .05$, adj. $R^2 = .004$. Regression coefficients and standard errors can be found in Table 4.7. None of the intervention groups exhibited regulation of cognition difference scores that were statistically significantly greater than the comparison group.

Table 4.7

Summary of Multiple Regression Analysis with Regulation of Cognition Difference Scores as the Dependent Variable.

Variable	B	SE_B	β
Intercept	.206	.065	
Growth	-.195	.110	-.125
Purpose	-.140	.106	-.093
Belongingness	-.151	.143	-.072

Note. B = unstandardized regression coefficient, SE_B = standard error of the coefficient, β = standardized coefficient.

No coefficients were statistically significant ($p > .05$).

Task Value as Dependent Variable

The regression model for Research Questions 4-6 with task value difference scores as the dependent variable is

$$\text{Task Value} = \beta_0 + \beta_1 \cdot \text{Growth} + \beta_2 \cdot \text{Purpose} + \beta_3 \cdot \text{Belongingness.}$$

The multiple regression model did not significantly predict task value difference scores, $F(3{,}212) = 0.319$, $p > .05$, adj. $R^2 = -.010$. Regression coefficients and standard errors can be found in Table 4.8. No intervention group exhibited task value difference scores that were statistically significantly greater than the comparison group ($p > .05$).

Table 4.8

Summary of Multiple Regression Analysis with Task Value Difference Scores as the Dependent Variable.

Variable	B	SE_B	β
Intercept	-.217	.117	
Growth	-.107	.192	-.042
Purpose	-.142	.186	-.058
Belongingness	.057	.250	.017

Note. B = unstandardized regression coefficient, SE_B = standard error of the coefficient, β = standardized coefficient.

No coefficients were statistically significant ($p > .05$).

Control of Learning as Dependent Variable

The regression model for Research Questions 4-6 with control of learning difference scores as the dependent variable is

$$\text{Control of Learning} = \beta_0 + \beta_1 \cdot \text{Growth} + \beta_2 \cdot \text{Purpose} + \beta_3 \cdot \text{Belongingness}.$$

The multiple regression model did not significantly predict control of learning difference scores, $F(3, 212) = .310$, $p > .05$, adj. $R^2 = -.010$. Regression coefficients and standard errors can be found in Table 4.9. None of the intervention groups exhibited control of learning difference scores that were statistically significantly greater than the comparison group.

Table 4.9

Summary of Multiple Regression Analysis with Control of Learning Difference Scores as the Dependent Variable.

Variable	B	SE_B	β
Intercept	-.202	.119	
Growth	-.164	.195	-.064
Purpose	-.143	.189	-.058
Belongingness	-.076	.254	-.022

Note. B = unstandardized regression coefficient, SE_B = standard error of the coefficient, β = standardized coefficient.

No coefficients were statistically significant ($p > .05$).

Self-Efficacy as Dependent Variable

The regression model for Research Questions 4-6 with self-efficacy difference scores as the dependent variable is

$$\text{Self-Efficacy} = \beta_0 + \beta_1 \cdot \text{Growth} + \beta_2 \cdot \text{Purpose} + \beta_3 \cdot \text{Belongingness}.$$

The multiple regression model did not significantly predict self-efficacy difference scores, $F(3, 212) = .848$, $p > .1$, adj. $R^2 = -.002$. Regression coefficients and standard errors can be found in Table 4.10. None of the intervention groups exhibited self-efficacy difference scores statistically significantly greater than the comparison group ($p > .05$).

Table 4.10

Summary of Multiple Regression Analysis with Self-Efficacy Difference Scores as the Dependent Variable.

Variable	B	SE_B	β
Intercept	-.125	.118	
Growth	-.226	.192	-.089
Purpose	-.011	.187	-.004
Belongingness	-.297	.251	-.086

Note. B = unstandardized regression coefficient, SE_B = standard error of the coefficient, β = standardized coefficient.

No coefficients were statistically significant ($p > .05$).

Summary of Chapter 4

Assignment to the Belongingness intervention group is a statistically significant predictor of CCI normed gains with a standardized coefficient of $-.104$ ($p < .05$). However, since I used this data to test twenty hypotheses, a Bonferroni correction leads me to test each hypothesis at the $\alpha = \frac{.05}{20} = .0025$ level. With this correction, the regression coefficient is no longer statistically significant. Assignment to one of the other two intervention groups (Growth and Purpose) was not a statistically significant predictor of CCI normed gains ($p > .05$). Assignment to an intervention group was not a statistically significant predictor of motivation and regulation of cognition difference scores ($p > .05$).

In Chapter 5, I discuss what conclusions may be drawn from the results of my analyses. I discuss the limitations of my study and analyses as well as directions for future research.

Chapter 5: Discussion

My research was guided by a desire to improve student success in first-semester calculus. To that end, I designed interventions that prior research suggested could lead students to have beneficial interpretations of stressors that otherwise might undermine their performance. I understood that shaping students' perceptions of their calculus classroom experiences might be useful in supporting higher performance, but that it certainly could not be sufficient. Learning mathematics requires extended engagement with meaningful mathematical problems, and my interventions were meant to supplement high quality instruction.

As a mathematics instructor, I care deeply about helping my students realize their hopes for their futures. I am committed to contributing both to the research base on teaching and learning and to the corpus of practice wisdom that comprises expert professional knowledge. I have learned so much throughout the process of conducting this study, analyzing the results, and writing this dissertation. As they say, "hindsight is twenty-twenty," and there are many things I would do differently if I could do it over. Despite the setbacks, I am forever changed by this experience and feel fortunate that I have developed insights that will guide me as I strive to improve my teaching and my understanding of how students learn effectively.

In this chapter, I begin with a broad overview of the rationale behind my study. I then provide a summary of my study design and results of my investigation. I discuss the strengths and merits of my research, the impact of my delimitations, and how limitations may have contributed to the initially surprising lack of positive impact. I discuss what these results teach us about the use of social-psychological video interventions in calculus homework and in education more generally. I conclude with a discussion of potential directions for future research.

MINDSETS, CALCULUS, AND A STEM-EDUCATED WORKFORCE

The goals I have for my mathematics students are, at least implicitly, goals shared by nearly all collegiate mathematics and science educators, but they grow more salient as societies become increasingly reliant on science and technology. The world faces many challenges—such as feeding a growing population, satisfying energy needs, treating and curing diseases, meeting demands for ever-improving personal technology and security, and confronting the automatization of jobs—that call for a well-educated STEM workforce. Economies in turn grow more dependent on workers with some STEM education. To maintain its prosperity and global relevance, the United States must increase the number and quality of college graduates with STEM degrees. Furthermore, as the value of STEM workers grows, STEM careers present a path of upward socioeconomic mobility to United States citizens. Unfortunately, historically underrepresented groups tend to persist in STEM majors at lower rates than they do in other fields and at lower rates than historically advantaged students (Landivar, 2013). Improving the retention of students in calculus courses, especially those students who are on STEM trajectories, could therefore make the United States more economically competitive, help address the world's myriad technological challenges, and reduce income inequality.

First-semester calculus courses, a necessary challenge for nearly all STEM students, promises to be a fruitful area of focused improvement. Calculus is often cited by students as a daunting obstacle, and poor experiences in first-semester calculus can prime students to leave STEM trajectories (Seymour & Hewitt, 1997). Improving the success and retention of calculus students could go a long way toward meeting the larger goals of increasing STEM graduates.

Calculus instruction undoubtedly has many pedagogical niches to be explored and improved. Students struggle with many first-semester calculus concepts. Numerous efforts to reform and improve students' calculus experiences have centered on the delivery of content and the way students interact and struggle with it (Schoenfeld, 1995), including the relatively recent development of flipped classrooms (McGivney-Burelle & Xue, 2013). In this study, however, I decided to explore the ways students approach and react to their struggles. Psychological research indicates that a person's perception and attribution of an academic or social challenge is central to whether they prevail or fail. Over the last three decades, many experiments have revealed the potentially large and lasting impacts that brief interventions targeting students' mindsets can have on performance, motivation, and retention. I sought to bring this growing body of research on academic mindsets into practice in the calculus classroom to bolster students' motivation and foster academic success. I also hoped to add to the mindset intervention research by creating, implementing, and studying very brief, cost-effective video interventions outside of a laboratory environment with a relatively large number of students.

I designed my interventions to target and influence three mindsets that prior psychological and educational research has shown are predictive of greater motivation and constructive perseverance in the face of adversity. Specifically, I focused on a growth mindset of intelligence, a sense of academic and mathematical purpose, and belongingness to the mathematics and college community. These mindsets have repeatedly been correlated with academic persistence and success in broad contexts, with especially large effects for historically disadvantaged students. I hypothesized that implementing interventions directed at these mindsets within the context of a first-semester calculus class would initiate productive recursive processes and terminate self-destructive cycles, thereby motivating students to success and cementing a mathematics foundation for students' STEM education and careers.

SUMMARY OF STUDY AND RESULTS

I investigated the impact of brief academic math mindset interventions delivered via video by calculus students' peers. I wanted to determine whether interventions of this type targeting one of three academic math mindsets—math growth mindset, math purpose mindset, and math and college belongingness mindset—could improve student learning, regulation of cognition, and motivation in a first-semester calculus course.

I scripted and filmed three videos, one targeting each academic mindset, of former calculus students discussing their experiences in their first-semester calculus courses. In the fall semester at a large research university, I randomly assigned 18 first-semester calculus courses to a comparison group or one of three intervention groups. In each intervention group, I embedded the corresponding mindset video within the students' online homework assignments, along with a multiple-choice follow-up question to ensure that the students thought about the targeted message. I also included pre- and post-test questionnaires, adapted from the MAI (Schraw & Dennison, 1994) and MSLQ (P. Pintrich et al., 1991), within online homework assignments at the beginning and end of the semester to measure students' regulation of cognition, task value, control of learning beliefs, and self-efficacy for learning and performance.

Each student completed the Calculus Concept Inventory (Epstein, 2006) at the beginning and end of the semester to assess their learning in the course. Using SPSS, I performed multiple regression analyses with membership in intervention groups as the independent variables and, separately as dependent variables, CCI normed gains and beginning-to-end of semester changes on measures of control of learning beliefs, self-efficacy for learning and performance, task value, and regulation of cognition.

My research questions, along with a brief discussion of how this study answers each, are as follows:

Effects of Interventions on Calculus Understanding

1. What is the effect of a novel growth mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?

   The results of this study indicate that the intervention targeting the growth mindset did not lead to a statistically significant increase in student performance.

2. What is the effect of a novel purpose mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?

   The results of this study indicate that the intervention targeting the purpose mindset did not lead to a statistically significant increase in student performance.

3. What is the effect of a novel belongingness mindset intervention, delivered via video embedded in course homework, on students' calculus understanding as measured by standard instruments?

   The results of this study indicate that the intervention targeting the belongingnesss mindset had a statistically significant negative effect on student performance. This effect was not significant after a Bonferroni correction.

Effects of Interventions on Motivation and Regulation of Cognition

4. What are the effects of a novel growth mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of regulation of

cognition, task value, control of learning, and self-efficacy as measured by standard instruments?

5. What are the effects of a novel purpose mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of regulation of cognition, task value, control of learning, and self-efficacy as measured by standard instruments?
6. What are the effects of a novel belongingness mindset intervention, delivered via video embedded in course homework, on calculus students' self-reports of regulation of cognition, task value, control of learning, and self-efficacy as measured by standard instruments?

These results were at first unexpected and disheartening. I did not observe the impacts I initially hypothesized. This led to much reflection on the factors that may have diminished the interventions' impact, on what could be improved in future studies, and on the merits of this research despite the lack of positive results. In the remainder of this chapter, I discuss the strengths of my research, the limitations, the delimitations, and directions for future research.

MY HOPES FOR THIS STUDY

The goal of this study was to develop and assess brief social-psychological interventions that are low-cost and easy to implement and that could have positive impacts on student learning, motivation, and regulation of cognition in a first-semester calculus course. Video interventions embedded into regular online homework assignments offer an inexpensive alternative to interventions administered by researchers and instructors. Aside from the initial cost of producing the videos, the interventions cost nothing to implement and required only an online homework platform for delivery rather than a special session during freshman orientation, class time, or time in a laboratory setting. The video interventions were easy to implement with many students in several classes, and they could be scaled up further with very little additional effort.

The interventions in this study had the potential to have substantial impacts on calculus students' experiences because they targeted academic math mindsets that have been shown to be strong predictors of performance, motivation, and regulation of cognition. A growth mindset of intelligence, academic sense of purpose, and academic belongingness have each been targets of interventions that have effectively improved students' academic performance and motivation (Farrington et al., 2012; Snipes et al., 2012; Yeager et al., 2013; Yeager & Walton, 2011). Furthermore, since these videos contained messages delivered by former calculus students, they had the potential added benefit of being viewed as authentic peer-delivered interventions (T. D. Wilson & Linville, 1982).

Another goal of this research was to assess the interventions' potential to lead to greater retention and success in STEM majors and career trajectories. By targeting students in a first-semester calculus course and delivering messages tailored to the typical calculus student's experiences, struggles, and concerns, this research reached STEM students at a critical juncture in their educational journeys. A poor experience in first-semester calculus is cited by many former STEM students as a contributing factor in their decisions to leave their fields (Seymour & Hewitt, 1997). Developing and reinforcing productive academic mindsets within first-semester calculus courses could increase motivation and self-regulation in a challenging and often demoralizing course. Increased motivation and self-regulation would in turn lead to deeper understanding of calculus concepts that are foundational to nearly every STEM field.

Many students not going into STEM fields are also required to take first-semester calculus, and failure in these courses can block students from receiving a post-secondary degree. Because these interventions were targeted at students in first-semester calculus, not just STEM majors, the interventions could promote positive math mindsets and behaviors in students going into non-STEM fields, thereby deepening their mathematics knowledge and simultaneously increasing their chances for success in their pursuits.

The lack of statistically significantly positive results, though initially troubling, presents an important lesson to be learned from this study. It serves as a counterpoint to the body of research in recent years that has espoused the benefits of brief social-psychological interventions targeting noncognitive factors and academic mindsets. These results serve as a cautionary reminder about the threat of publication bias, the overreliance on laboratory studies, and the importance of replication studies. The study outcomes recall the warning communicated by Yeager and Walton (2011) that social-psychological interventions, though potentially powerful, are not magic bullets that will universally lead to academic improvement. The results of this study attest to the influence of contextual factors on mindset interventions.

Limitations and Delimitations

There were a few limitations and delimitations in this study that may have led to the finding of no discernable positive effects of the interventions. One delimitation of this study and my statistical analysis is that the regression models do not control for effects of class sections, discussion sections, instructors, or teaching assistants. Because I could not feasibly randomize group assignment within a class, participants in each treatment group were students in one of only two or three classes. Many characteristics of the class, the instructor, and the teaching assistants—student involvement, teaching style, content knowledge, etc.—could therefore have had nonnegligible effects on the dependent variables in this study (Bressoud, 2015). This makes it difficult to conclude that any statistically significant results were due to my intervention and not to class level effects.

Another delimitation that may have diminished the effectiveness of my interventions was their brevity. It was my intention to design brief interventions that would be easy for educators to implement and for students to receive, but it is possible that the interventions were in fact too short to have a lasting effect on students' mindsets. Students may not have had ample opportunity to internalize the messages.

I did not collect demographic information from the subjects. I made this choice to avoid survey fatigue and because I did not believe my interventions would have deleterious effects on any students, regardless of their demographics. However, much of the research on social-psychological interventions has shown differential effects based on demographic characteristics. In many social-psychological intervention studies, the students who appear to have the greatest gains are students who are part of historically academically disadvantaged groups or members of groups prone to stereotype threat (Aronson et al., 2002; Good et al., 2003; Walton & Cohen, 2007, 2011). At the university where the study was conducted, nearly half of the undergraduate population is White. There is a possibility that the interventions in this study are less effective for White students (perhaps due to loss of stereotype lift (Walton & Cohen, 2007)), and the overall results may have been negatively impacted. It is also possible that the interventions were in fact beneficial to students who faced stereotype threat, but I did not obtain the data to check this hypothesis. Were I to conduct another study such as this one, I would search for shorter surveys of my dependent variables (e.g., self-efficacy) so I may collect pertinent demographic data and still keep survey fatigue to a minimum.

The use of the Calculus Concept Inventory as an outcome measure for academic progress is another delimitation that may have complicated my analyses. The validity of the CCI as a measure of calculus concept knowledge has recently been called into question (Gleason, Thomas, et al., 2015; Gleason, White, et al., 2015). Critics point out that the instrument uses language and notation that would be unfamiliar to students who had not taken a calculus course. Therefore, CCI scores may not be a valid measure of concept knowledge but rather of familiarity with calculus vocabulary and notation.

As I briefly described at the beginning of Chapter 4, a considerable factor that may have greatly diminished the possibility of observing positive results is the fact that, unbeknown to me, another mindset intervention was given to some of the students during freshmen orientation (Yeager et al., 2016). This intervention was administered several weeks before my intervention and before students answered their motivation and regulation of cognition questionnaires. This previous intervention likely disrupted the baseline responses on the questionnaires, making it difficult to interpret any beginning-to-end changes in measures of motivation and self-regulation. Furthermore, students who received both the large-scale intervention and one of my interventions likely experienced a ceiling effect, and it is impossible to know what marginal effect my interventions had or what impact they had on students who were not part of the larger study. Finally, the interventions of the larger study created a contamination within my treatment groups. Many of the students in my comparison group likely received one of the interventions from the larger study, and comparisons may not be meaningful. It is therefore not surprising, in retrospect, that the interventions in this study had no statistically significant impact, compared to the comparison group, on difference scores on any of the outcome variables.

DIRECTIONS FOR FUTURE RESEARCH

The delimitations of this study included several design features that I considered necessary but not ideal, leaving several areas for improvement. Perhaps the feature of the research design that most notably led to difficulty finding results is that each class, rather than each student, was randomly assigned to a treatment group. Because student interactions within calculus classes are common, it seems unlikely that individuals in a class could receive an intervention in an online homework assignment without it being shared with classmates outside of their intervention group. Therefore, it seems necessary that an entire class must receive a common intervention. Consequently, the class, and not the student, should be the unit of analysis. A continuation of this study with several more classes and instructors would be required for such an analysis. Furthermore, data should be collected from many classes for each instructor so that a multilevel model can be applied to include random effects at the instructor level. This would account for the effects of instructors on student performance, regulation of cognition, and motivation.

Because of the concerns with the validity of the CCI (Gleason, Thomas, et al., 2015; Gleason, White, et al., 2015), alternative measures of calculus concept knowledge should be considered for future research. For example, the Calculus Concept Readiness instrument developed by Carlson, Madison, and West (2010) could serve as a guide for a new inventory that better assesses students' conceptual understanding of calculus rather than their calculus vocabulary.

Additional research could identify areas for possible improvement within the brief video interventions I used in this study. Follow-up interviews with participants could assess the believability and relatability of the student actors in the video. Each of the student actors used in my video interventions could be considered White—though some viewers may have considered the female to be Latina or Hispanic. It is possible that using student actors who more closely represent the ethnic and cultural diversity of the targeted classes could improve the effect of the interventions. Also, since the student actors followed a script, it is possible that the study participants did not find their delivery believable. Additional research with authentic student interviews could lead to more believable and impactful interventions.

The interventions could be further improved by eliciting more active processing from the participants. One way to do this would be to have students write a brief paragraph about their academic mindsets. This is a common tool utilized by many of the social-psychological interventions reviewed in Chapter 3 that was absent from my research. I felt that having students answer a brief multiple-choice question following the video interventions would be enough to ensure that the participants would think carefully and deeply enough about the message to truly internalize it, but I fear this may have been a naïve hope. Future iterations of this research may prompt students to write a paragraph about an experience that corroborates the delivered mindset message. Yeager and Walton (2011) put forth that, "these strategies can induce deep processing and prepare students to transfer the content to new settings" (p. 284).

Another area for future research is in the study of the long-term effects of these brief interventions. A longitudinal study could determine whether and to what extent video interventions targeting math academic math mindsets have lasting effects on students' performance, motivation, and regulation of cognition. Such a study could show whether any of the interventions have effects that are only evident after a longer period.

SUMMARY AND RELEVANCE

This was an exploratory quantitative study of the effects of brief social-psychological mindset interventions on calculus students' regulation of cognition, motivation, and performance on a calculus concept test. I developed video interventions that addressed students' mindset of intelligence, sense of purpose, and belongingness, each in the context of first-semester calculus. It was my belief that these interventions would encourage the development of productive academic mindsets and lead to improvements on the outcome variables of interest. I performed multiple linear regression analyses to determine whether any of the interventions had an effect on the outcome variables and to determine which interventions were most impactful. My data analyses showed that none of the interventions had a significant effect on any of the outcome variables. I have discussed some possible reasons for the lack of significant results. Most notably, many of the participants were likely also participants in a large-scale intervention that targeted similar mindsets.

This experience has taught me a great deal that I intend to apply to my future work. Despite the lack of positive results, I believe the format and delivery method of the video interventions I produced have merit and promise. The videos have the potential to normalize the struggles and concerns students face in calculus and other STEM courses that often lead to disinvestment and attrition. Destigmatizing the common feelings of academic inadequacy, lack of purpose or relevance, and presumed isolation could ease the burden these concerns place on students' cognitive resources, freeing them for learning and regulation of cognition. Furthermore, removing the stigma of these struggles could mitigate their demotivational impacts and lead to higher retention rates in STEM fields. I hope to improve upon these interventions and study their impacts further. I believe that brief peer-delivered video interventions paired with brief reinforcement tasks (e.g., short essay questions) throughout the semester can be valuable supplements to high-quality mathematics curriculum and instruction.

This research is therefore relevant to both educators and educational researchers. It provides educators with a potential means of instilling productive academic mindsets in their students. Many social-psychological interventions are administered outside of the classroom and may be difficult for students to connect to specific contexts. Embedding the interventions into online calculus homework assignments is a practical and cost-effective method to deliver targeted messages that students can immediately internalize and contextualize within their calculus coursework. Although the results of my work have not born out this hypothesis, I believe that the circumstances surrounding this study justify further research and improvement of these and similar domain-specific, social-psychological interventions.

Also of relevance to education researchers is the potential interaction between social-psychological interventions. By chance, this study was conducted during the same semester as another similar study. Although none of my interventions had significant effects on the outcome variables, there were several effects that were insignificantly negative. This may be random noise in the data, but it may alternatively be an indication of the dangers of too much intervention. As social-psychological interventions become more widely utilized in research and in schools, it is important to study the possibility that multiple interventions may not just lead to a ceiling effect, but perhaps even have the opposite of the intended effects. Although past research has shown that these kinds of interventions can have large, lasting positive effects on students' motivation and academic success, it may be possible to have too much of a good intervention.

As a researcher, I learned a lot from the intricacies of research; I encountered unexpected issues and discovered things I would do differently. I would try to coordinate more with other researchers in the field to make sure we aren't doing overlapping studies. I learned about the complexities of creating interventions and the importance of the context in which students experience them. I never expected them to be a cure all and for people to make magical gains in their conceptual understanding, but I did expect them to have some effect. So not getting those effects made me look much more carefully at the study.

First and foremost, I am a math instructor, and I learned a lot from this experience that has and will continue to impact my teaching and interactions with my students. My overarching drive is to empower students to better their lives and the lives of others with the aid of mathematics. My goal is to guide students to and through the development, exploration, application, and appreciation of mathematical ideas and tools. As a corollary, in addition to providing my students with high-quality instruction and learning opportunities, I am also devoted to helping my students become motivated, strategic, and effective learners. Through previous experiences teaching and working with the Emerging Scholars Program, I had uncovered anecdotal evidence of growth, purpose, and belongingness mindsets affecting my students and their persistence in my classes. This experience and learning about academic mindsets from the psychological literature and using the resources from the Mindset Scholars Network affirmed my beliefs about the importance of instilling these mindsets in students.

My students are people with experiences and their experiences matter. I have learned how important it is to consider, not only their experiences, but also how they interpret those experiences. If I can do anything to help them view their experiences with struggle in a more productive way, I believe they will benefit academically. I will not necessarily be giving interventions in all of my classes, but this research has influenced my daily interactions with my students.

I started this work with hopes of developing practical, effective tools that I and other instructors could use within the classroom to help students grow as scholars. I believe that this research has taken several steps toward achieving this, though there is still much to improve. Instilling productive mindsets in students is a difficult but worthwhile challenge, and although they are nontrivial, there exist solutions.

Appendices

Appendix A. Video Transcripts

Growth Video

Interviewer (I): What do y'all remember most about your first calculus course at [the university]?

Male (M): I started out really confident and was sure I'd get an A because I got good grades in math in high school. But I got stuck on some of the first [online homework] problems. It was just so much different from the way I learned math in high school, and I just couldn't figure them out. It really freaked me out. I kinda started to wonder if I was smart enough to be at [the university].

Female (F): Yeah, sort of the same thing happened to me. I got a C on my first quiz and I really studied for it. When I asked the TA about it, he told me that that was the average grade—then I really freaked out. I actually called my high school math teacher, who told me college math was going to be like training for a sport: it's gonna be a grind. The prof was trying to get us to learn by making us struggle.

I: Can you say more about that?

F: Yeah, well the idea really helped me. I played a lot of sports in high school, and I knew that real mastery only comes through struggle. I had never really connected that to math. My high school teacher called it productive struggle.

M: It took me ‘til my sophomore year to get that the professors are purposely making you struggle and that no matter how prepared you are, they will throw problems at you that make you work outside your comfort zone. Realizing that changed how I went through school. Now, when I feel confused, I know that I’m just getting closer to learning something.

F: Yeah, I probably nearly dropped that class for the wrong reasons. I was embarrassed by not getting A’s, and I worried that my family would be so disappointed in me. It’s so funny that we know that struggle and effort matter in some subjects and in others we think its natural talent, like genetics, you know?

M: Yeah, it doesn’t really matter how smart you are coming into college. It’s going to be hard for anyone–that’s the point. In one of my psychology classes last year we learned about how struggling with a difficult subject or a challenging problem actually physically changes your brain. It creates new connections between different parts of your brain and that’s how you learn new things. That’s definitely been my experience at [the university]–the more I struggle with something, the more I learn.

F: Oh yeah, my high school math teacher sent me an article about that. I still have it in my cell phone and I read it every now and then. And I see it playing out in my classes. Like even now after a few years, I still remember all of that stuff from chemistry and calculus that I thought was so hard at the time. I guess because it took so much work to understand it, when it finally clicked, it stuck for good.

Purpose Video

I: When you look back at freshman calculus and what you learned about studying, how did your studying change, and what would you say were the biggest lessons.

M: At first I studied pretty much like I did in high school. I did the homework and crammed for the tests. I tried to learn everything for the tests because a good grade seemed like the most important thing at that point. I'm pre-med and I was worried about how a B or C would affect my med school chances. Unfortunately, with the way I was studying, I'd forget most of it two days later. I had a couple of study mates who'd tease me about this. They were always really good at remembering all of the stuff we studied, even long after the exam. One time we were studying though, I realized that they were asking themselves how what they were learning could be connected to their goals. I had never really thought about this kind of thing, and I was amazed at how their self-reflections motivated them.

F: Yeah, I saw the same thing. I eventually learned that if you didn't connect the studying and the coursework to something important, it would just exhaust you and really grind you down. I definitely felt that early on. But the people who were actually trying to get ready for something they cared about, like their career, would have more energy when things got difficult.

M: Honestly, competing for grades, and fear, drove a lot of my work early on, like the fear of not doing well and not getting into med school. But when I saw how others were more motivated, were retaining things better, I tried to start thinking about how this stuff related to my goals and my future.

F: If I didn't believe that what I was studying really mattered to my economics courses, I wouldn't be able to go that extra mile. So many of my classmates are so serious. You really have to care about the material to be on that level.

I: Is it easy to connect the material to something you care about?

M: It was kind of hard at first because I just didn't know enough about calculus to know how it could be connected to biology and medicine, so I just kinda tricked myself into believing that I'd need to know the stuff later. Eventually it did become easier to see how it was true. Either I'd start seeing connections myself or think of ways to actively find connections. With calculus, I started looking online to how it could be applied in medicine. I had a biology professor who would always show us how math could be used in the field. I didn't always understand the applications, but it helped a lot to know that I'd be using math eventually.

F: Yeah, my calculus professor made us write down how what we were learning might be connected to our personal goals. It was a pain the first couple of times, but now I do it on my own for myself a few times a semester in almost every class. There are still some things that I feel like are just like another hoop to jump through, but I feel like most of what I study really matters, and that helps motivate me a lot.

Belongingness Video

I: What do you remember most about the first few weeks in your calculus course?

M: I felt pretty confident because I had had a little calculus before, but mostly excited. That was my first semester, and I was really looking forward to being at college and away from home.

F: Yeah, me too, especially the part about being away from home. But I was a bit homesick, and that surprised me.

M: I remember being really intimidated by the size of [the university] and all the people, especially in that class. I came from a pretty small town and my high school was good but not great. I think I got into [the university] because I was high up in my class, but my class was really small. And here at [the university] everyone in my class seemed to be working so hard, and there already seemed to be groups of people that already knew each other and studied together. I started to wonder how I would ever really make friends here.

F: Yeah, that was one of my biggest classes freshman year, and it's weird how there are like so many people around but they all seem completely different from me. Most of the students at my high school felt pretty similar to me, not just physically, but culturally and the way we thought and acted. Like a lot of my close friends went to my church, and we all felt pretty much the same way about school. I had never been competing with people who were so different from me, and there were some freaking smart people in there.

M: Yeah, the professor gave a quiz really early on, and a few people finished in about three minutes and left early. I heard one of them say that he had learned that stuff in 9th grade. I had seen that stuff before, but it still wasn't that easy.

F: It was a tougher adjustment than I thought it'd be.

I: What are your reflections on those early experiences now?

F: Now that I have lots of friends, like from my discussion sessions, from my FIG, and from my major, it all seems kinda silly that we were worried about it. Everyone wonders how they'll fit in, and we all do. It's just that your friends in college will probably be a lot more different than your friends in high school.

M: Yeah, I think the other students are one of the best parts about [the university] for me. A lot of my friends came from other backgrounds, and I really like that. And on the other hand, because [the university] is so diverse, there's always someone who you can relate to and share interests with. And study with, of course. That's pretty much the way I stopped worrying so much about the overachievers. I found a couple of people to study with who were at about my level, plus one or two above my level to help make sense of the harder stuff. It was easier to find people to work with than I thought it would be. I realized that most of the people that seemed like they knew each other really didn't. All I had to do was ask, and most people were pretty open to the idea of studying and hanging out together.

F: Yeah. It was a little harder in second semester calculus, because then there really were groups of people coming into that class together. But still, most of them were really cool about letting me join them. It took me a few semesters to be comfortable with trying to join other groups and talk to new people, but now it's like nothing at all. I eventually learned how to do things at [the university]. Now I feel like I can succeed at any major and do whatever I want.

M: Yeah, now it's kind of fun to meet new people who are completely different from me and who have different academic interests and sort of try out the whole new perspective. It gives me a chance to try on different identities, try out being different kinds of people. It's kinda just a fun thing to do, but also it helps a lot to get a clearer idea of what kind of stuff I'm interested in doing and learning.

APPENDIX B. ADDITIONAL TABLES

Table B.1

Number and Percentage of Participants in Each Group.

	Growth	Purpose	Belonging-ness	Comparison (no video)	Total
Number of participating Classes	3	3	2	10	18
Number of students in participating classes	341	333	239	1124	2037
Number of consented students in participating classes	155	139	74	386	754
Percent of consented students in participating classes	45%	42%	31%	34%	37%

Table B.2

Distribution of Consenting Participants for Whom Some Data were Collected.[a]

Treatment Group	Course I (flipped)	Course II (flipped)	Course II (traditional)	Total
Growth	H (*n*=28) K (*n*=47)	G (*n*=54)		3 classes (*n*=129)
Purpose	A (*n*=50) K (*n*=40)	I (*n*=30)		3 classes (*n*=120)
Belongingness	E (*n*=26)	G (*n*=31)		2 classes (*n*=57)
Comparison	B (*n*=54) F (*n*=51) L (*n*=30)	E (*n*=39) L (*n*=27)	C (*n*=31) D (*n*=20) D (*n*=8) J (*n*=23) J (*n*=44)	10 classes (*n*=327)
Total	8 classes (*n*=326)	5 classes (*n*=181)	5 classes (*n*=126)	18 classes (*N*=633)

a. Instructor codes A through L show which instructors taught which courses.

APPENDIX C. SURVEY

The survey was presented as a learning module with 8 slides. The first slide was an introduction to the survey, the next 6 slides consisted of 8 or 9 survey questions, and the last slide had one "Yes" or "No" question that instructors could use to give credit for completing the survey if they chose to. Each item in the survey was presented with 7 answer choices listed vertically as shown in Figure C.1. The full survey follows, along with the source, survey construct, and subscale for each item in parentheses. The source, survey construct, and subscale were not present on the survey that the participants viewed.

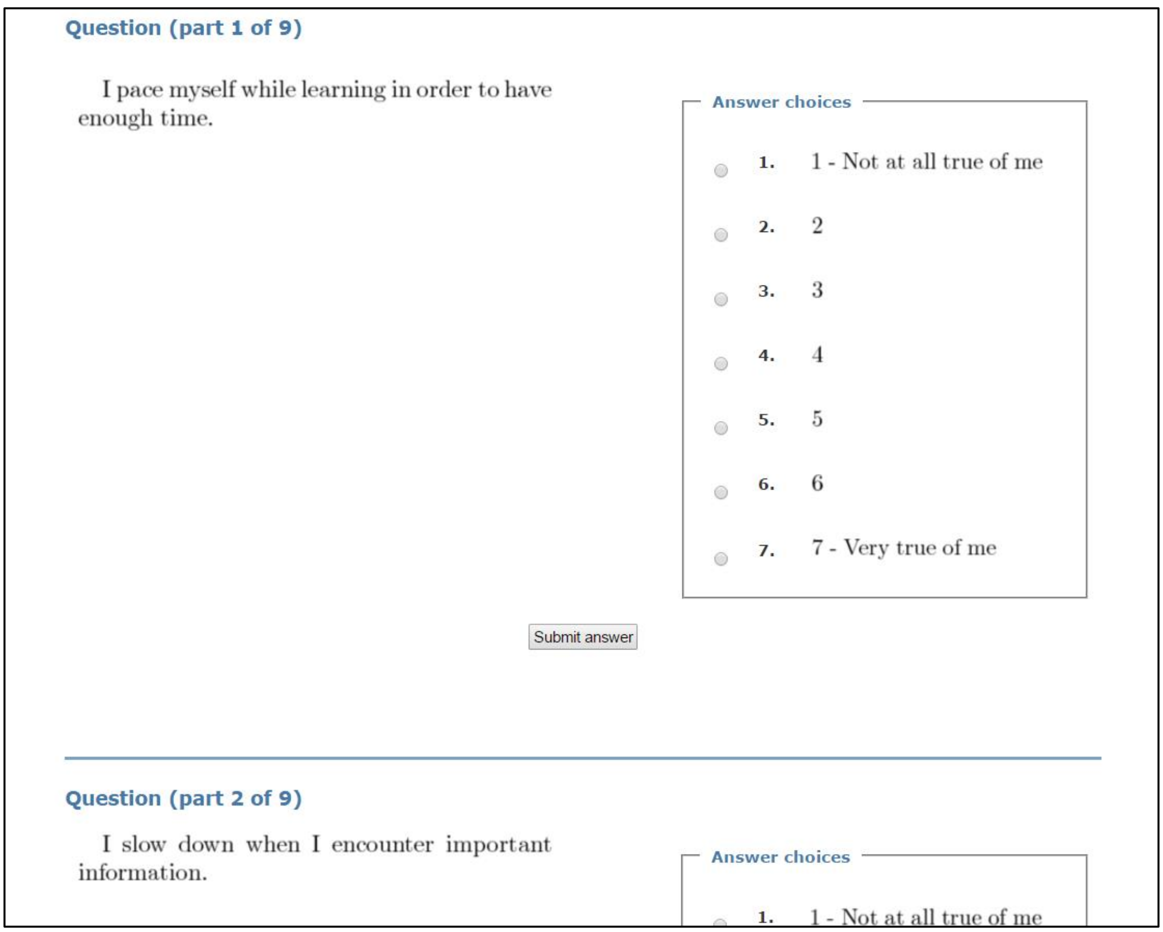

Figure C.1: Sample screenshot from Questionnaire learning module.

Slide #1: Introduction

Questionnaire

Please answer the following survey of academic behaviors and beliefs. Your responses will help us evaluate the effectiveness of this course. Completing this questionnaire may also give you a deeper understanding of how you like to learn and how you might improve your learning.

Rate each item from 1 - "Not at all true of me", to 7 - "Very true of me".

Be sure to click "Submit" for each item.

Slide #2

1. I pace myself while learning in order to have enough time. (MAI, Regulation of cognition, Planning)
2. I slow down when I encounter important information. (MAI, Regulation of cognition, Information Management Strategies)
3. I ask myself periodically if I am meeting my goals. (MAI, Regulation of cognition, Monitoring)
4. I ask others for help when I don't understand something. (MAI, Regulation of cognition, Debugging Strategies)
5. I know how well I did once I finish a test. (MAI, Regulation of cognition, Evaluation)
6. I consciously focus my attention on important information. (MAI, Regulation of cognition, Information Management Strategies)
7. I think about what I really need to learn before I begin a task. (MAI, Regulation of cognition, Planning)
8. I focus on the meaning and significance of new information. (MAI, Regulation of cognition, Information Management Strategies)

9. I consider several alternatives to a problem before I answer. (MAI, Regulation of cognition, Monitoring)

Slide #3

10. I change strategies when I fail to understand. (MAI, Regulation of cognition, Debugging Strategies)
11. I ask myself if there was an easier way to do things after I finish a task. (MAI, Regulation of cognition, Evaluation)
12. I create my own examples to make information more meaningful. (MAI, Regulation of cognition, Information Management Strategies)
13. I set specific goals before I begin a task. (MAI, Regulation of cognition, Planning)
14. I draw pictures or diagrams to help me understand while learning. (MAI, Regulation of cognition, Information Management Strategies)
15. I ask myself if I have considered all options when solving a problem. (MAI, Regulation of cognition, Monitoring)
16. I reevaluate my assumptions when I get confused. (MAI, Regulation of cognition, Debugging Strategies)
17. I summarize what I've learned after I finish. (MAI, Regulation of cognition, Evaluation)
18. I ask myself if what I'm reading is related to what I already know. (MAI, Regulation of cognition, Information Management Strategies)

Slide #4

19. I ask myself questions about the material before I begin. (MAI, Regulation of cognition, Planning)

20. I try to translate new information into my own words. (MAI, Regulation of cognition, Information Management Strategies)
21. I periodically review to help me understand important relationships. (MAI, Regulation of cognition, Monitoring)
22. I stop and go back over new information that is not clear. (MAI, Regulation of cognition, Debugging Strategies)
23. I ask myself how well I accomplished my goals once I'm finished. (MAI, Regulation of cognition, Evaluation)
24. I focus on the overall meaning rather than specifics. (MAI, Regulation of cognition, Information Management Strategies)
25. I think of several ways to solve a problem and choose the best one. (MAI, Regulation of cognition, Planning)
26. I use the organizational structure of the text to help me learn. (MAI, Regulation of cognition, Information Management Strategies)
27. I find myself analyzing the usefulness of strategies while I study. (MAI, Regulation of cognition, Monitoring)

Slide #5

28. I stop and reread when I get confused. (MAI, Regulation of cognition, Debugging Strategies)
29. I ask myself if I have considered all options after I solve a problem. (MAI, Regulation of cognition, Evaluation)
30. I ask myself questions about how well I am doing while I am learning something new. (MAI, Regulation of cognition, Monitoring)

31. I read instructions carefully before I begin a task. (MAI, Regulation of cognition, Planning)
32. I try to break studying down into smaller steps. (MAI, Regulation of cognition, Information Management Strategies)
33. I find myself pausing regularly to check my comprehension. (MAI, Regulation of cognition, Monitoring)
34. I ask myself if I learned as much as I could have once I finish a task. (MAI, Regulation of cognition, Evaluation)
35. I organize my time to best accomplish my goals. (MAI, Regulation of cognition, Planning)

Slide #6

36. I think I will be able to use what I learn in this course in other courses. (MSLQ, Value, Task Value)
37. If I study in appropriate ways, then I will be able to learn the material in this course. (MSLQ, Expectancy, Control of Learning Beliefs)
38. I believe I will receive an excellent grade in this class. (MSLQ, Expectancy, Self-Efficacy for Learning and Performance)
39. It is important for me to learn the course material in this class. (MSLQ, Value, Task)
40. It is my own fault if I don’t learn the material in this course. (MSLQ, Expectancy, Control of Learning Beliefs)
41. I’m certain I can understand the most difficult material presented in the readings for this course. (MSLQ, Expectancy, Self-Efficacy for Learning and Performance)
42. I think the material in this class is useful for me to learn. (MSLQ, Value, Task)

43. I expect to do well in this class. (MSLQ, Expectancy, Self-Efficacy for Learning and Performance)
44. If I try hard enough, then I will understand the course material. (MSLQ, Expectancy, Control of Learning Beliefs)

***Slide** #7*

45. I'm confident I can understand the basic concepts taught in this course. (MSLQ, Expectancy, Self-Efficacy for Learning and Performance)
46. I am very interested in the content area of this course. (MSLQ, Value, Task)
47. I'm certain I can master the skills being taught in this class. (MSLQ, Expectancy, Self-Efficacy for Learning and Performance)
48. I like the subject matter of this course. (MSLQ, Value, Task)
49. I'm confident I can do an excellent job on the assignments and tests in this course. (MSLQ, Expectancy, Self-Efficacy for Learning and Performance)
50. Understanding the subject matter of this course is very important to me. (MSLQ, Value, Task)
51. If I don't understand the course material, it is because I didn't try hard enough. (MSLQ, Expectancy, Control of Learning Beliefs)
52. I'm confident I can understand the most complex material presented by the instructor of this course. (MSLQ, Expectancy, Self-Efficacy for Learning and Performance)
53. Considering the difficulty of this course, the teacher, and my skills, I think I will do well in this class. (MSLQ, Expectancy, Self-Efficacy for Learning and Performance)

Slide #8

54. To receive credit for this learning module, you must answer this question "Yes". Did you complete this questionnaire?

APPENDIX D. STUDY CONSENT FORM

Consent for Participation in Research

Title: Calculus concept knowledge and connections to a flipped classroom methodology

Introduction

The purpose of this form is to provide you information that may affect your decision as to whether or not to participate in this research study. The person performing the research will answer any of your questions. Read the information below and ask any questions you might have before deciding whether or not to take part. If you decide to be involved in this study, this form will be used to record your consent.

Purpose of the Study

You have been asked to participate in a research study about the effect of a flipped classroom on students' Calculus concept knowledge, academic attitudes, and learning strategies. The purpose of this study is to determine if students in Calculus sections using a "flipped" methodology have greater learning and/or metacognitive gains than their peers who are enrolled in traditional lecture sections.

What will you to be asked to do?

If you agree to participate in this study, you will be asked to

- Complete a brief questionnaire online.
- Release background data such as age, gender, and ethnicity.
- Release current and future final grade data from any mathematics courses you take at [the university].
- Allow the researcher to use data collected (your questionnaire, your homework assignments, exam grades, [calculus course] final grade, and future mathematics course enrollment data and final grade) in our research analysis.

This study will take approximately 20 minutes of your time outside of regular class duties, and will include approximately 100 study participants.

What are the risks involved in this study?

There are no foreseeable risks to participating in this study aside from loss of confidentiality. Protection against loss of confidentiality is detailed below.

What are the possible benefits of this study?

You will receive no direct benefit from participating in this study; however, results from this study will contribute to a better understanding of how instructors can use homework assignments effectively to help students succeed in the current and subsequent courses.

Do you have to participate?

No, your participation is voluntary. You may decide not to participate at all or, if you start the study, you may withdraw at any time. Withdrawal or refusing to participate will not affect your relationship with [the university] in anyway.

If you would like to participate sign this form and return it now to the investigator, or later using the contact information below. If you wish to receive a copy of this form please use the contact info provided.

Contact info:

[Principal researcher's name]
[Math Department]
[Principal researcher's email address]   [Principal researcher's phone number]

Will there be any compensation?

You will not receive any type of payment for participating in this study.

What are my confidentiality or privacy protections when participating in this research study?

This study is confidential. The confidentiality of your information will be maintained by keeping all data collected for the purpose of analysis only on password-protected devices and online systems. Once online survey data is downloaded to a secure device, it will be erased from the online survey system. All signed consent forms will be kept in a locked desk in the investigator's locked office.

Whom to contact with questions about the study?

Prior, during or after your participation you can contact the researcher [principal researcher's name] at [principal researcher's phone number] or send an email to [principal researcher's email address].

This study has been processed by the [research support office], and the study number is [study number].

Whom to contact with questions concerning your rights as a research participant?

For questions about your rights or any dissatisfaction with any part of this study, you can contact, anonymously if you wish, the [research support office] by phone at [research support office's phone number] or by email at [research support office's email address].

Participation

You must be 18 years or older to participate in the study. If you agree to participate, complete this form and return it to the investigator.

Signature

You have been informed about this study's purpose, procedures, possible benefits and risks, and you have received a copy of this form. You have been given the opportunity to ask questions before you sign, and you have been told that you can ask other questions at any time. You voluntarily agree to participate in this study. By signing this form, you are not waiving any of your legal rights.

Printed Name

Signature Date

As a representative of this study, I have explained the purpose, procedures, benefits, and the risks involved in this research study.

Print Name of Person obtaining consent

Signature of Person obtaining consent Date

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