MITIGATING THE EFFECTS OF MATH ANXIETY ON STUDENT PERFORMANCE

A THESIS

Presented to

The Faculty of the Department of Education

The Colorado College

In Partial Fulfillment of the Requirements for the Degree

Master of Arts in Teaching

By

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July 8, 2016

Abstract

This study had two goals: to examine the relationship between math anxiety and performance on unit assessments and to see if an open writing task before unit assessments would improve high math anxious (HMA) students' performance on the assessment. The study took place at a high school in southeast Colorado Springs. An honors math II class (n=30) and an honors math III class (n=26) served as the treatment group while a different honors math III class (n=21) served as the comparison group. Students were given the Abbreviated version of the Math Anxiety Rating Scale (A-MARS) to determine their math anxiety score. The results showed a negative correlation between math anxiety and performance on the first unit test, which served as the pre-test. Before both of the next two unit tests, the treatment group was given time to write about their feelings related to the upcoming assessment before it took place while the comparison group was just given the assessment. The HMA students in the math II treatment and math III treatment improved their average on both post-tests while the HMA students in the comparison group scored lower averages on both post-tests. The results point towards the possible benefits of the open writing assignment for HMA students and suggest that other ways to mitigate the effects of math anxiety should be explored.

In order to make important changes to instruction to better facilitate student learning, teachers must be able to gain accurate data from assessments to understand what students have learned. However, there are many factors that contribute to a student's performance other than their mastery of the content. These other factors make it hard for teachers to know what their students have actually learned and what they are having trouble demonstrating on the assessment for other reasons. Additionally, how students gain knowledge is another complex issue with many contributing factors. One factor that inhibits students' ability to demonstrate their knowledge on assessments and gain knowledge during instruction time is math anxiety, which is defined as apprehension, tension, or stress associated with completing math activities.

Some students feel math anxiety when they walk into class. Some feel it when they are anticipating completing homework or an assessment. The feelings associated with math anxiety are obstacles that get in the way of student success in math classes. As a math teacher, it is vital that I explore how math anxiety affects my students so I can give them a better math experience and also gain more accurate data from my assessments. If students constantly have negative experiences when completing math work or thinking about math, it will be extremely hard for them to continue to be engaged in math classes. It is even likely that they will avoid taking math classes in the future, which will limit the majors they can choose in college and the professions they will choose when they are out of school. All math teachers should constantly be searching for ways to reach more students in their classes and give more students access to mathematical knowledge. Currently, we are not fully reaching students who have high levels of math anxiety.

This paper explores math anxiety from many different lenses. The knowledge research narrative, *Math Anxiety: Causes, Effects, and Instruction Remedies,* which begins on page 5, reviews research related to different causes of math anxiety. It also focuses on cognitive and physiological effects as well as effects on math performance. Then, it reviews remedies that other researchers have explored. The action research paper, *Using Writing to Reduce the Effects of Math Anxiety on Student Performance,* which begins on page 18, focuses on research I completed during my student teaching placement. The paper focuses more on research related to the effects of math anxiety. Then, I present my research that explored whether or not high math anxiety students receive lower scores on assessments than low math anxiety students and whether or not an open writing activity before assessments will improve high math anxiety students' scores.

Math Anxiety: Causes, Effects, and Instructional Remedies

Mathematics is a subject that is often associated with anxiety. Math anxiety is a separate construct from other forms of anxiety that has emerged, often defined as feeling of tension, apprehension, or fear that interferes with math performance (Ashcraft, 2002). Math anxiety is related to a large pool of problems with math education in the United States, including low math performance and math avoidance. With the amount of jobs in the Science, Technology, Engineering and Math (STEM) field projected to grow by seventeen percent between 2008 and 2018, math avoidance can be detrimental to students' futures by greatly lowering the number of possible jobs they will have access to based on their skill set (Langdon, D., McKittrick, G., Beede, D. Khan, B. & Doms, M., 2011). Most people within the field accept that what is defined as math anxiety has a negative correlation with general math performance. Recent research has focused on the areas of math performance that math anxiety affects, the causes of math anxiety, and instructional strategies and interventions that may alleviate math anxiety. Identifying the areas contributing to math anxiety and finding effective instructional remedies can allow more students in the United States to be comfortable with math. Comfort with math will make students more likely to take math classes in the future and choose a career that requires math skills. The topic of math anxiety is also relevant to K-12 teaching because studies have shown that teachers can pass on their own math anxiety to students (Beilock, Gunderson, Ramirez & Levine 2010). If math anxiety is negatively correlated with student performance, then teachers need to be be aware of causes, effects, and possible instructional remedies for math anxiety.

A review of recent literature related to math anxiety has shown that working memory and poor performance are factors that are both related to math anxiety (Ashcraft & Kirk, 2001; Ma and Xu, 2003; Ramirez, Gunderson, Levine & Beilock, 2013). Another trend that recent research has revealed is brain activity related to negative emotions and pain perceptions in math anxious students (Beilock & Lyons, 2012; Young, Wu & Menon, 2012). Finding possible causes and examining cognitive effects has implications for creating instructional strategies that can reduce math anxiety or even be preventative for younger students. Some research has examined instructional remedies that are meant to reduce math anxiety. Teacher use of humor prior to tests has been shown to relieve tension and improve test performance (Ford, T.E., Ford, B.L. Boxer & Armstrong, 2012). Student use of metacognitive strategies during tests has also improved performance of math-anxious students (Legg & Locker, 2009). Allowing students to write openly about their emotions and feelings related to math before completing a math task has also improved student performance (Ramirez & Beilock, 2011). Finally, creating a low-stakes environment and helping students develop high self-efficacy has eased the effects of math anxiety on student performance (Griggs, Patton, Rimm-Kaufman & Merritt, 2013).

Literature Review

Research on math anxiety began in the 1970s. In order to assess the progress made in understanding math anxiety, Hembree (1990) performed a meta analysis that is often cited in more recent math anxiety research. Some of his main findings, as noted by Ashcraft and Krause (2007), were that math anxiety had a correlation of -.30 with letter grades received in high school courses, -.75 with math enjoyment, -.64 with motivation to take more math, and -.31 with extent of high school math taken. These findings, while significant, are now almost 25 years old; current research looks to delve deeper into the issue of math anxiety and how it affects students. In order to learn more about math anxiety, researchers have focused on the causes of math anxiety, the effects math anxiety has on students--including performance, likelihood of taking more math classes, and general feelings towards math--and possible instructional strategies that may reduce math anxiety.

Causes of Math Anxiety

This paper will ultimately focus on possible instructional strategies to reduce the effects of math anxiety in high school students. However, in order to formulate effective instructional strategies, understanding the origins of math anxiety is also important. Some research has found math anxiety to emerge as early as the elementary school years (Ramirez et al., 2013; Young et al., 2012). Other research has examined the presence of math anxiety in middle school and high school (Ma & Xu 2003). When trying to help students with math anxiety, teachers must understand that the problem may be very deep-rooted, and therefore hard to fix.

Though Hembree's (1990) meta analysis showed that researchers have consistently found a negative correlation between math anxiety and math performance, none of these findings determined the causal ordering of math anxiety and math performance. Ma and Xu (2003) used a longitudinal study to find out more about the relationship between math anxiety and math performance. There are three possible causal orderings: either math anxiety is a cause of math performance, math anxiety is an effect of math performance, or math anxiety and math performance are reciprocally related. Discovering the causal ordering can help researchers get to the root causes of math anxiety. Beginning their study with seventh graders (N=3,116), Ma and Xu (2003) measured levels of math anxiety compared with math performance year-by-year. One of the important findings was the stabilization of math anxiety and math performance over time. Math achievement remained stable throughout the entire study, as the correlative values between seventh and 12th grade ranged from .91 to .98. Math anxiety, on the other hand, stabilized following the seventh grade. More significant were the findings related to the researchers' question of causal ordering. The findings showed that achievement during a certain year had a slight negative correlation with the student's math anxiety in the following year (-.20 between seventh and eighth grade, -.14 between 9th and 10th grade). They also found a minimal correlation between math anxiety and future math performance.

The findings suggest that low math achievement may be an initial cause of math anxiety. Since math achievement was stable in this study, students who perform poorly are likely to continue to perform poorly in future years. Poor performance then leads to more math anxiety. The results also showed that math anxiety in grade eight, for example, is not significantly related to math achievement in grade nine. However, the study did not address the relationship between math anxiety levels in one year and math achievement in that same year. Based on Hembree's (1990) findings, it is possible that math anxiety levels in a particular year can still have a negative correlation with math achievement in that same year. Math achievement and math anxiety levels from the same year being negatively correlated could explain why math achievement was stable throughout the longitudinal study. Students may fall into a vicious cycle of high math anxiety and low math performance. Ma's and Xu's findings suggest that the best way to break the cycle is to either find out why math achievement is negatively correlated with future math anxiety or find out how to help student overcome their math anxiety to improve their achievement.

Ashcraft & Faust (1996) hoped to find out if part of the reason for the negative correlative relationship between math anxiety and math performance could be due to lower mastery of mathematical skills. The researchers began by comparing the levels of math anxiety in 80 undergraduate students to their performance on a standard math achievement test. The correlation between math anxiety and performance was almost in line with Hembree's (1990) findings, but they needed to perform a more in-depth analysis of the test performance to begin to answer their research question. They found that math anxiety did not have an effect on students' performance with questions of basic elementary school whole number arithmetic. The separation between performance of high math anxious and low math anxious students occurred at the more difficult parts of the test. When participants had to answer a two-digit addition problem that used the carry operation, high math anxious students averaged fewer than one correct answer in every five questions.

The findings may suggest that if students know the material, their math anxiety may not affect their performance as much. In Howard's & Whitaker's (2011) qualitative study about students' negative and positive feelings toward math, one student said math class created fear because he did not want to walk into a class where he would immediately feel stupid. "Feeling stupid" can relate not only to content mastery, but also to classroom environment. Giving students a variety of tools to help them understand the content may help reduce anxiety. Creating an environment where they do not "feel stupid" when they do not understand a concept could also reduce their negative feelings towards math.

The fact that math anxiety had little to no effect on simple arithmetic problems and a noticeable effect on more complex problems could also be due to the amount of working memory required to complete more complex problems. If math anxiety affects use of working memory, problems that require more use of working memory may be more difficult for individuals with high levels of math anxiety to complete.

Cognitive Effects of Math Anxiety

Another way to explore the relationship between math anxiety and math performance is to identify the effects that math anxiety has on the brain. If math anxiety is grounded in cognitive effects, then teachers may be able to better understand why students with higher levels of math anxiety struggle in math classes. Multiple studies have shown that math anxiety inhibits working memory, which could make high performance harder when memory recall is needed (Ashcraft & Kirk, 2001; Ramirez et al., 2013). Utilizing functional magnetic resonance imaging (fMRI), research has also found that students with math anxiety have more activity in areas of the brain that process negative emotions (Young et al. 2012). Similarly, use of fMRI has also shown that students with math anxiety may experience pain when anticipating completing a math task (Beilock & Lyons, 2012). Understanding the cognitive effects of math anxiety could help formulate instructional strategies that would be beneficial for students with math anxiety.

Math anxiety and memory. Since students often need to be able to recall information to be successful in math, a natural relationship to examine is the relationship between memory and math anxiety. Ashcraft & Kirk (2001) researched the effects of math anxiety on working memory through three experiments. Their first experiment tested the effects of math anxiety on working memory capacity. They tested participants' ability to remember words from a string of sentences and answers to a string of simple addition problems. They also collected data about the participants' grades in high school math, number of high school math courses taken, and rated math anxiety. Their findings confirmed previous results (Hembree, 1990) that highly math anxious (HMA) individuals receive lower grades in math class and tend to take less math classes. The Shortened Math Anxiety Rating Scale (sMARS), used to classify HMA students, score had a correlation of -.28 and -.29 in those respective areas. Additionally, the sMARS scores had a correlation of -.36 with the ability to remember words and -.44 with the ability to remember numbers. Therefore, individuals with high levels of math anxiety could be more likely to have a smaller working memory capacity, which can affect the difficulty of a variety of school activities.

To explore the effects of math anxiety on working memory, Ashcraft & Kirk (2001) performed an experiment to see if math anxiety disrupts working memory. The treatment group was required to look at either a two-letter string or a six-letter string, then perform an addition problem, then recall the two-letter string or six-letter string. The results showed the HMA individuals had a higher percentage of errors during the recall phase following the addition problem. The gap was also wider when the addition problem was two-column and required a carry operation. It is possible, then, that math anxiety does disrupt working memory, and does so to a greater extent when problems are more difficult.

Ramirez et al. (2013) also examined the relationship between math anxiety and working memory. Similar to Ashcraft & Kirk (2001), they measured students' working memory capacity and math anxiety. However, Ramirez et al. went a step further and examined how math anxiety affected students with high and low capacities for working memory. Another difference in their study compared to previously mentioned research is that the participants were first and second graders (n=162). The researchers found that students with high working memory were more affected by math anxiety than students with low working memory. A possible explanation is students with high working memory depend more on their ability to use that working memory during problem solving while low working memory students may use heuristics, "tricks," or short cuts to problem solve. Since math anxiety can hinder access to working memory, the students that depend more on their working memory will be more affected by math anxiety.

Math anxiety and emotion. Beyond looking at working memory, some researchers have used fMRI scans to identify which parts of the brain are active while math anxious individuals are performing math tasks. Young et al. (2012) measured participants'(n=46)--ranging from ages 7 to 9--brain activity while completing simple and complex arithmetic problems. Complex problems involved two numbers ranging from two to nine. Simple problems always involved the number one with another number between two and nine. Prior to the fMRI scan, students were assessed for IQ, general anxiety, working memory capacity and math anxiety. They found that students who fell into the category of highly math anxious (HMA) experienced hyperactivity in the amygdala, which is a region of the brain that processes negative emotions and fearful stimuli (as cited by Young et al., 2012). HMA students also showed lower levels of activity in areas of the brain associated with math and numerical reasoning. Additionally, hyperactivity in the amygdala was unique to HMA students. That is, IQ, general anxiety and working memory capacity did not affect amygdala activity in students who were not in the HMA category. Therefore, the activity in the amygdala seen in HMA individuals during the math tasks from the study was likely due to their math anxiety and not some other factor.

Math anxiety and pain perception. Other researcher has found that math anxiety does not just cause negative emotions, but can also cause painful experiences. Beilock & Lyons (2012) were interested in extending research on math anxiety and brain activity by looking specifically at brain activity during the anticipation phase of completing a math task. On a computer test, participants were told whether each question was going to be a math task or a spelling task before actually seeing the problem. The researchers used fMRI to measure brain activity during the anticipatory feelings set off by the cue. The results showed increased brain activity in HMA individuals in three regions associated with pain perception: the left and right bilateral dorsal posterior insula (INSp) and the mid-cingulate cortex (MCC). There was a positive correlation between left INSp activity and math anxiety following the math task cue, with a partial r value of .737. Similarly, activity in the right INSp correlated with math anxiety following the math task cue with a partial r value of .845. Finally, the partial r value for the MCC was .814. The results suggest that the anticipation of completing a math task can create discomfort, or even pain, in HMA individuals. Pain perception could explain results that have shown HMA individuals tend to avoid taking math classes when possible. Students who feel pain when anticipating math could view math classes as threatening situations that should be avoided. In order to break the cycle of math avoidance, teachers need to be aware of the pain HMA individuals feel during the anticipatory period and find ways to make math a more pleasant experience for these individuals.

Reducing Math Anxiety

Instructional strategies for reducing math anxiety have emerged since researchers have been able to identify math anxiety causes and cognitive effects of math anxiety. Instructional strategies meant to reduce negative feelings, such as teacher use of humor prior to tests, have emerged and shown positive results (Ford et al., 2012). Student use of metacognitive strategies has proven to reduce the effects of math anxiety on math performance (Legg & Locker, 2009). The strain other strategies, such as memorization, could be greater than when students use different metacognitive strategies. Writing openly about feelings and emotions related to a math task prior to starting the task have also shown to improve performance (Ramirez & Beilock, 2011). Openly addressing feelings during anticipation of completing a math task may relieve some of the physical and mental discomfort that some math-anxious students have been shown to experience. Finally, one approach to structuring a classroom, the responsive classroom approach (RC), focuses on giving students metacognitive strategies, giving students time to address their emotions, and promotes positive mindsets when completing math activities.

Ford et al. (2012) researched the effects of providing humorous stimuli to participants (n=84) before a math test on test scores. Based on research that humor reduced state-dependent anxiety and findings that math anxiety is negatively correlated with math performance, the group hypothesized that the students receiving the treatment of humorous stimuli prior to taking the test would outperform the control group. For the 20 question math test, the treatment group scored an average of almost one point lower on the eight-question state anxiety questionnaire following the test. They also answered, on average, three more questions correct than the control groups. Therefore, humorous stimuli might reduce state anxiety, or anxiety that arises due to a certain environment. Humor prior to a test may help anxious individuals to perform better in usually stressful test situations.

Beyond pre-test treatment strategies, research has found that there are certain strategies that students can acquire that help reduce math anxiety. Legg & Locker (2009) assessed whether metacognitive strategies moderate the effects of math anxiety on performance, reaction time, and confidence when completing a math task. The researchers began by measuring the participants' levels of math anxiety. Students were then asked to perform a series of modular arithmetic problems. They were also asked to rate their confidence in each answer before moving on to the next question. Following the completion of all of the problems, they were given the *State Metacognitive Inventory* (SMI). The SMI asked participants a series of questions related to their awareness, their cognitive strategies, their planning and their self-checking while completing the math test. HMA participants who reported more use of metacognitive strategies performed better than other HMA participants and reported higher levels of confidence. Hence, metacognitive strategies could alleviate the negative effects of math anxiety on math performance. Though more research needs to be done on the metacognitive anxiety reductions, these results could have major implications for how math teachers structure their lessons. Providing students with opportunities to develop metacognitive strategies when problem solving could improve their performance if they consistently experience math anxiety.

Although metacognitive strategies may help reduce anxiety, students who are experiencing negative emotions in anticipation of completing a math task may also need time to openly address those emotions. Ramirez & Beilock (2011) conducted a series of studies to test the effect of writing openly about one's feelings and worries related to an upcoming math test prior to taking the test. They wanted to see if making a situation high-pressure would decrease performance and if the writing treatment would eliminate the "choking effect" that comes with the high pressure situation. In one study, all participants were given the same pre-test. For the post-test, the experimenters increased the pressure by offering monetary rewards for improvement, by changing the scenario so that other people depended on the participants' improvement, and by telling them they were being filmed and evaluated by math teachers. The treatment group was given ten minutes to write about their feelings related to the upcoming task. The experimenters found that the treatment group improved their scores by five percent, while the control group showed a 12 percent accuracy drop. The increase is slight but significant when compared to the fact that the control group showed a noticeable drop in performance during the high-pressure situation. These results suggest that writing openly about feelings associated with anxiety-inducing situations should be explored further as a possible instructional remedy.

Rather than searching for ways to reduce math anxiety, some researchers have also looked for other ways to improve students' performance by manipulating factors that contribute to math performance and may be affected by math anxiety. For example, Griggs et al. (2013) examined the relationship between self-efficacy and math anxiety. Since self-efficacy is a student's belief in their ability to complete a task, any relationship between self-efficacy and math anxiety could help explain the negative correlation between math anxiety and math performance. Students who reported higher levels of math anxiety generally reported lower levels of self-efficacy. Their study tested the effects of implementing a responsive classroom approach on students' self-efficacy, and how the change in self-efficacy related to performance. Twenty different schools enrolled their fifth grade classrooms in the study. The treatment group was exposed to the responsive classroom (RC) approach, which includes equal emphasis on social curriculum and academic curriculum and equal emphasis on the process of student learning and the product of student learning. RC classrooms also depend on a belief that cognitive growth best occurs through social interactions, and it is as important for teacher to know their students and their families as it is to know the content. Students in the treatment group who experienced higher levels of math anxiety were less likely to experience poor self-efficacy than similar students in the control group. Additionally, the negative effect of math anxiety on math self-efficacy was reduced. One possible reason for the reduction is that the stakes in a RC environment are lower. Teachers are trained to make the classroom more comfortable, which encourages students to take risks.

A common theme in all instructional remedies explored is reducing the the threat that students who are math anxious feel when anticipating and completing math tasks. Ford's (2010) humor treatment may be explained by the fact that laughing has been shown to relieve tension felt during threatening situations (as cited in Ford et al.). Metacognitive strategies take difficult, threatening problems and break them down into manageable steps. RC environments are meant to be a safe space where students can feel okay about making mistakes, which reduces the threat felt in high stakes environments. Creating less threatening environments may reverse the cognitive effects that make math anxious students feel negative emotions and pain before and during math activities. Future research should fine tune instructional remedies that have shown positive results and look for other ways to take the threat away from math tasks.

Summary and Future Study

Recent research has advanced understanding of the relationship between math anxiety, math performance, and math avoidance. However, there are still many unanswered questions that can be explored. Ashcraft and Kirk (2001) as well as Ford et al. (2012) used undergraduate participants in a lab setting. Their experiments should be replicated at the high school level because the different environment could change the results. For example, students in a lab setting may feel like they have less to lose. In a high school class, the consequences of low performance in math classes are more substantial. Additionally, high school students and college students are at similar levels of cognitive development, but they are also at different stages of their lives. Replicating procedures from Aschraft and Kirk and Ford et al. should still yield accurate results when used in a high school classroom because of the cognitive similarities of the participants, but the results may vary due to other factors.

Legg's & Locker Jr.'s (2009) findings about how metacognitive strategies can reduce the effect of math anxiety on math performance should used to form a classroom intervention. They found that students with higher levels of math anxiety who reported use of metacognitive strategies following the test performed better than their counterparts who did not use metacognitive strategies. In a classroom intervention, researchers could test how teaching highly anxious math students to use metacognitive strategies that are found on the SMI when math problem solving would affect math performance. Extensive research has shown how math anxiety hinders students' use of their working memory (Ashcraft & Kirk, 2001; Ramirez et al. 2013). When students memorize strategies to solve certain problems, they are strictly depending on their ability to recall these memories when it is time to take the test. Use of metacognitive strategies could create more anchors in the brain and put less stress on working memory, which would help alleviate the effects of math anxiety on their performance.

One limitation associated with the suggestions for future study is that an instructional intervention may not be enough to undo math anxiety that has been shown to begin as early as first grade. The researchers may not have the time or resources to create an instructional intervention that will span long enough to make a difference in levels of math anxiety. However, it is still possible that an instructional intervention could have immediate results.

Using Writing to Reduce the Effects of Math Anxiety on Student Performance

Assessing student mastery is a critical aspect of education, but assessments do not always provide accurate information when student performance is affected by factors other than their level of mastery. Since assessments are used frequently--both by classroom teachers to determine how well students understand the material and by states to hold schools accountable for student performance--it is important that the assessments provide us with accurate data about how our students are learning. In addition to classroom and state tests, students also have to worry about college entrance exams, which could have a direct impact on their future success. Given the amount of testing that students will face throughout their education, gaining information about what affects their performance on tests will help teachers better prepare them for exams and ultimately improve their performance. There are aspects within the students' control that will affect their performance on assessments, such as their effort during class time and their time spent studying. However, teachers also need to consider factors outside of the student's control that may affect their ability to demonstrate knowledge on an assessment.

One factor that has been the focus of research for the last 25 years is math anxiety. Multiple studies have found a relationship between math anxiety and performance on mathematical tasks (Ashcraft & Faust 1996; Ashcraft & Kirk 2001; Ramirez et al. 2013). With a consistently identified relationship between math anxiety and performance, some researchers have begun searching for instructional remedies that will improve the performance of students with high math anxiety. One treatment that has proven to be affective in a previous study is a writing exercise directly before the exam that allows students to write openly about their feelings related to the exam (Ramirez & Beilock, 2011).

The goal of the present study is to replicate Ramirez's results in a different environment. Many of the studies of math anxiety have been performed in a research setting rather than a classroom setting. In order to make progress towards helping students with math anxiety improve their performance, studies need to be performed in a classroom setting where students are constantly assessed on material they learn throughout the year. Additionally, Ramirez structured the study to add pressure to the assessments, but the assessments still did not have a major impact on the participants' future. While students with high math anxiety did see better results, the study did not provide information about how students would perform if the assessment had an effect on their overall grade in a class. Therefore, the first goal of the present study was to see if the students' performance and math anxiety were related as previous studies suggest. The second goal was to see if writing about feelings that were a result of the upcoming exam would be followed by increased performance on exams by students with high math anxiety.

Literature Review

A review of recent literature related to math anxiety has shown that working memory and poor performance are factors that are both related to math anxiety (Ashcraft & Kirk, 2001; Ma and Xu, 2003; Ramirez, Gunderson, Levine & Beilock, 2013). Another trend that recent research has revealed is that areas of the brain related to negative emotions and pain perceptions may be more active in math anxious students (Beilock & Lyons, 2012; Young, Wu & Menon, 2012). Finding possible causes and examining cognitive effects has implications for creating instructional strategies that can reduce the effects of math anxiety or even be preventative for younger students.

Though Hembree's (1990) meta-analysis showed that researchers have consistently found a negative correlation between math anxiety and math performance, none of these findings determined the causal ordering of math anxiety and math performance. Ma and Xu (2003) explored three possible causal orderings: high math anxiety causes low math performance (the interference model), high math anxiety is an effect of low math performance (the deficit model), or math anxiety and math performance are reciprocally related (the reciprocal model). The findings showed that achievement during a certain year had a slight negative correlation with the student's math anxiety in the following year. For example, the standardized parameter estimate was -.20 from 7th grade performance to 8th grade anxiety and -.14 from 9th grade math to 10th grade anxiety. Their data pointed strongest toward the deficit model, which means that low math achievement comes before high math anxiety. They also found that math achievement and math anxiety become stable in the middle school years, meaning students with high anxiety and low achievement will experience similar levels of anxiety and achievement throughout high school. Since math anxiety seems to develop from memories of prior poor math performance, the researchers suggest that teachers need to develop interventions to reduce math anxiety in their students, especially prior to assessment periods.

In order to understand the relationship between math anxiety and math performance, researchers have attempted to identify the effects that math anxiety has on the brain. If math anxiety is grounded in cognitive effects, then teachers may be able to better understand why students with higher levels of math anxiety struggle in math classes. Since students often need to be able to recall information to be successful in math, a natural relationship to examine is the relationship between memory and math anxiety. Ashcraft & Faust (1996) found that math anxiety did not have an effect on students' performance with questions of elementary whole number arithmetic. Rather, the separation between performance of high math anxious and low math anxious students occurred at the more difficult parts of the test. When participants had to answer a two-digit addition problem that used the carry operation, high math anxious students averaged less than one correct answer in every five questions.

The fact that math anxiety had little to no effect on simple arithmetic problems and a noticeable effect on more complex problems could be due to the amount of working memory required to complete more complex problems. If math anxiety affects use of working memory, problems that require more working memory may be more difficult for individuals with high levels of math anxiety to complete. For example, Ashcraft & Kirk (2001) researched the effects of math anxiety on working memory through three experiments. Their findings confirmed previous results (Hembree, 1990) that highly math anxious (HMA) individuals receive lower grades in math class and tend to take less math classes. The Shortened Math Anxiety Rating Scale (sMARS), used to classify HMA students, score had r-values of -.28 and -.29 in those respective areas. Additionally, the sMARS scores had r-values of of -.36 with the ability to remember words and -.44 with the ability to remember numbers. Therefore, according to this study, students who rely on memorization to complete assessments will struggle if they experience high levels of math anxiety.

Ramirez et al. (2013) also examined the relationship between math anxiety and working memory. Similar to Ashcraft & Kirk (2001), they measured students' working memory capacity and math anxiety. However, Ramirez et al. went a step further and examined how math anxiety affected students with high and low capacities for working memory. The researchers found that students with high working memory were more affected by math anxiety than students with low working memory. The reason for this result could be that students who typically have a high capacity for working memory will be affected more if that working memory is blocked by anxiety.

Beyond looking at working memory, some researchers have used fMRI scans to identify which parts of the brain are active while math anxious individuals are performing math tasks. Young et al. (2012) found that students who fell into the category of highly math anxious (HMA) experienced hyperactivity in the amygdala, which is a region of the brain that processes negative emotions and fearful stimuli. Hyperactivity in the amygdala was unique to HMA students. That is, IQ, general anxiety and working memory capacity did not affect amygdala activity in students who were not in the HMA category. HMA students also showed lower levels of activity in areas of the brain associated with math and numerical reasoning.

Another researcher has found that math anxiety does not just cause negative emotions, but can also be related to pain perception. Beilock & Lyons (2012) were interested in extending research on math anxiety and brain activity by looking specifically at brain activity during the anticipation phase of completing a math task. The results showed increased brain activity in HMA individuals in three regions associated with pain perception: the left and right bilateral dorsal posterior insula (INSp) and the mid-cingulate cortex (MCC). They found a partial correlation between activity in the left INSp ($r=0.737$), the right INSp ($r=0.845$), and the MCC ($r=0.814$) and math anxiety following the math task cue. The correlations suggest that the anticipation of completing a math task can create discomfort, or even pain, in HMA individuals. Pain perception could explain results that have shown HMA individuals tend to avoid taking math classes when possible. Students who feel pain when anticipating math could view math classes as threatening situations that should be avoided. In order to break the cycle of math avoidance, teachers need to be aware of the pain HMA individuals might feel during the anticipatory period and find ways to move students past the periods of discomfort.

Ramirez & Beilock (2011) explored one possible way to reduce cognitive and physical effects when they conducted a series of studies to test the effect of writing openly about one's feelings and worries related to an upcoming math test prior to taking the test. They wanted to see if making a situation high-pressure would decrease performance and if the writing treatment would eliminate the "choking effect" that comes with the high-pressure situation. In one study, all participants were given the same pre-test. For the post-test, the experimenters increased the pressure by offering monetary rewards for improvement, by changing the scenario so that other people depended on the participants' improvement, and by telling them they were being filmed and evaluated by math teachers. The treatment group was given ten minutes to write about their feelings related to the upcoming task. The experimenters found that the treatment group improved their scores by five percent, while the control group showed a 12 percent accuracy drop. The increase is slight but significant when compared to the fact that the control group showed a noticeable drop in performance during the high-pressure situation. These results suggest that writing openly about feelings associated with anxiety-inducing situations should be explored further as a possible instructional remedy.

Research up to this point has established a relationship between math anxiety and math performance and has laid groundwork for determining why math anxiety might hurt performance and how to mitigate any negative effects. The present study hopes to test a treatment that could help math anxious students improve their scores on exams.

Methods

Participants

Two classes (n=56) participated in the treatment: one honors integrated math III class and one honors integrated math II class. One class (n=21) of honors integrated math III students made up the comparison group. Students' ages ranged from 15 to 17. The integrated math II class is a sophomore level class that consisted of sophomores as well as some freshmen who were a year ahead in content. The integrated math III class is a junior level class that consisted of juniors as well as sophomores who were a year ahead in content. All students in honors classes had to have been recommended by a teacher at some point during their time in high school, meaning they either work hard or they have shown they have the math skills needed to go beyond regular expectations. This does not mean that every participant is proficient at math, however. Some students are in honors classes because they want the challenge, but they do not necessarily excel in math.

Instruments

Participants were given the Abbreviated Version of the Math Anxiety Rating Scale (A-MARS) in order to determine their perceived levels of math anxiety (see Appendix). The A-MARS has .90 test-retest reliability with the longer Math Anxiety Rating Scale. Questions asked students how much anxiety they felt when performing certain tasks, such as watching a teacher explain a problem on the board, walking into math class, and thinking about an exam one hour before the exam. During the course of the study, participants were given three unit exams, which were meant to test their mastery of the knowledge taught in that particular unit. The first unit exam of the semester served as the pre-test, while both of the next two unit exams were used as post-tests. For the treatment, the writing prompt was displayed using a projector screen. The prompt was "write openly and honestly about any feelings you have related to today's test. For example, you may say 'I am feeling prepared/stressed/nervous for this exam because…' or 'I am not worried about this exam.' You will have four minutes to write, please try to use the entire time provided for writing." Students responded on a separate sheet of paper.

Procedure

Students were given their first unit exam of the semester, which served as the pre-test. They then took the A-MARS survey. The surveys were scored on a scale of 1 to 5. If they answered "not at all" they received a score of 1 for that question. If they answered "very much" they received a 5 for that question. The sum of scores for each question determined their average score on the 25-question survey. The average math anxiety score of all participants was used as the cut-off point to create two groups. Any student receiving a score higher than the average was placed in the high math anxiety (HMA) group. Any student scoring less than the average was placed in the low math anxiety (LMA) group. To address the first goal of the study, participants were split into their class groups (math III treatment, math III comparison, and math II treatment) to analyze the relationship within each class between math anxiety and pre-test scores. Within each class, each participant's math anxiety scores were graphed so pre-test scores were a function of math anxiety scores on a bivariate plot. Best fit lines and R^2 values were calculated to analyze the relationship within each class between math anxiety and pre-test scores. After graphing the results from the pre-test, the average score was calculated for the six subgroups: HMA math III treatment, LMA math III treatment, HMA math II treatment, LMA math II treatment, HMA math III comparison, and LMA math III comparison.

Before taking the next unit exam (post-test #1), students in the treatment group were given four minutes to write openly about their feelings related to the exam. They were given sentence starters such as "I am feeling stressed about this test because…" or "I am feeling ready for this test because…" They were encouraged to write for the entire time and to be as honest and open as possible. Students in the control group were given the test without the treatment exercise before hand.

Average scores were again calculated for the six subgroups to compare with each group's pre-test average. The graphing process was then repeated to see which groups still showed a correlative relationship between math anxiety and performance following the treatment. The process was repeated for the third unit exam (post-test #2) of the semester in order to replicate the treatment. Both post-test scores were then compared to pre-test scores to see which of the sub-groups improved on both tests, improved only on one test, or failed to improve on both tests.

Results

Comparing math anxiety scores with scores on the pre-test showed a negative correlation ($r = -.35$) in the math III treatment group. The math III comparison group saw a similar negative correlation ($r = -.36$). The math II group saw a stronger correlation ($r = -.48$). Once the math anxiety-student performance was established, data analysis shifted to the six subgroups. The HMA math III treatment group scored a 69.7 percent average on their pre-test while the HMA math III comparison group scored a 64.6 percent average. Both the LMA treatment and LMA comparison groups scored 76.2 percent on average. The integrated math II treatment HMA group scored a 63.6 percent average on their pre-test while the math II treatment LMA group scored a 77.6 percent average.

Table 1 shows averages on the pre-test compared to the averages of the two post-tests for the six subgroups. Following the treatment, the math III treatment HMA group scored an average of 70.4 on the first post-test and 80.4 on the second post-test, an increase of .6 percent and 10.6 percent respectively from the pre-test. Their HMA peers in the comparison group scored 60 percent and 61.1 percent averages on the two post tests respectively, which reflect a decrease of 4.6 percent and 3.5 percent when compared to their pre-test. The math III LMA treatment group scored 79.2 percent and 87.5 percent on the two post-tests and the LMA comparison group scored 79.6 and 67.7 percent.

The Math II treatment HMA group scored 77.7 percent and 68.3 percent on the two post-tests, which reflected an increase of 14.1 percent and 4.7 percent from their pre-test. Their LMA counterparts scored an average of 75.8 percent and 83.9 percent.

The math III HMA comparison group was the only group who did not improve on either of the post-tests. The math II LMA treatment group and the math III LMA comparison group only improved on one of the two post-tests. Every other group, the math III HMA treatment group, the math III LMA treatment group, and the math II HMA treatment group, scored better average percentages on both post-tests compared to the pre-test.

Examining the HMA math III treatment group and the HMA math III comparison group is important considering they have similar levels of anxiety and also took the same tests. The gap in improvement between the HMA treatment and the HMA comparison group is 6.2 percent on the first post-test and 14.1 percent on the second post-test. Additionally, only 21 percent of the HMA treatment group failed to improve on either of the post-tests, compared to 35.7 percent of the HMA control group. Performing a unequal variance t-test on the two data sets showed that the difference in averages between the two groups was significant on both post-tests ($p<.05$ and $p<.01$ respectively).

Figures 4, 6, and 7 also show that the post-test scores saw a weakened relationship between math anxiety and student performance. While there was still a downward trend in the math III treatment group, the r-values for the two post-tests were both -.24, suggesting that there was less of a relationship between math anxiety and performance when compared to the pre-test r-value ($r=-.35$). Figures 5 and 8 show the comparison group's relationship remained ($r = .41$) on the first post-test, but was weaker on the second post-test ($r = -.22$).

The math II treatment group's first post-test produced an r-value of .01, which suggests a non-relationship between the two variables on the first post-test. The second post-test returned to the negative correlation with $r = -.31$. Of the five HMA participants in this group, two improved and two failed to improve while one did not have test data available. The two improvements and non-improvements balanced each other out to maintain the negative correlative relationship on the second post-test.

Discussion

Comparing the three exam results with math anxiety scores showed that students with higher math anxiety tended to score lower on tests than students with lower math anxiety. These results are in favor of the hypothesis that high math anxiety inhibits student ability to demonstrate their knowledge on exams. This means that math anxiety will be a contributing factor to inaccurate data about student learning following assessments, which will give teachers an incorrect perception of how they need to proceed following a test. Teachers may look at poor results and decide that some students need to be retaught material. Based on the results of this study, it is possible that students know the material, but their ability to show what they know is inhibited by their math anxiety.

The post-treatment results suggest that the treatment did have a positive effect for the treatment group. Both of the HMA treatment groups improved on both post-tests, while the HMA comparison group was the only group that failed to improve on either of the post-tests. The gap in performance between the HMA treatment and HMA comparison groups, particularly between the two groups who were learning the same material and took the same test, suggests that the treatment accomplished the goal of mitigating the effects of math anxiety on performance. Examining the correlation between math anxiety and test performance on the two post-tests also provides evidence that the treatment might have reduced the effects of math anxiety. Following the pre-test, each group's results showed a negative correlation between math anxiety and test performance. The smaller R^2 from figures 4, 6 and 7 suggest a weakened relationship between the two variables following the treatment. This would mean that the role that math anxiety played in student performance was reduced, which signifies scores were possibly affected by other factors outside the realm of this study.

The LMA math II treatment group and the LMA math III comparison group both failed to improve on one of the post-tests. Since participants in this group have lower math anxiety, their anxiety will not play as much of a role on their performance. Therefore, any change in performance could be due to other factors not measured in this study. However, another important comparison to make is the difference in performance between LMA groups and HMA groups following the treatment. The math II HMA treatment group scored 14 percent lower than their LMA peers, which is consistent with math anxiety and performance being negatively correlated. The HMA group then scored 1.9 percent higher than the LMA group, but this was the only instance in which an HMA group outperformed an LMA group. While all five participants from the HMA group improved on the first post-test, the results were mixed on the second post-test. With two HMA participants improving, two failing to improve, and one with results not available, the data is too inconsistent to make a conclusion. While the first post-test's results seemed promising for closing the gap between HMA and LMA participants in the same class, more research with higher sample sizes will be necessary before any conclusion can be made. Additionally, while both the HMA and LMA treatment math III groups improved on both post-tests, the gap in scores between the two groups did not decrease significantly.

The possible limitation of using actual unit exams rather than a standardized pre-test and post-test is the amount of possible confounding variables. The r-values suggest that there is a negative correlative relationship between math anxiety and student performance, but they also suggest that there are many other factors. An r-value of 1 would mean that math anxiety is the only factor that determines student performance. Therefore, an r-value close to 1 would not be realistic given other possible factors. The many other factors need to be considered when examining the results. For example, the honors math III treatment class is at the beginning of the day while the control honors integrated math III class is at the end of the day. One class could have received better instruction than the other class. Within a particular class, one unit could have been taught more effectively than another unit, which would affect end of unit exam results. Additionally, different levels of mastery likely influenced student results. Since the goal of the treatment is to help students access their knowledge when working on an exam, the treatment will not work if a student does not know the material. Since students need to know the material before math anxiety can be considered as a major factor contributing to poor performance, another factor that needs to be considered is the effort that each student puts forth to learn the material. Effort level prior to the test and mastery need to be controlled in order to know for sure whether or not math anxiety really affects students' results, which is the benefit of using a standardized test that contains knowledge the students should already know.

Finally, the math II treatment group did not have a comparison group that learned the same content and took the same test. Having a comparison group for both content levels would have provided stronger data. However, with a sample size of 77 students, each taking three tests, the results can still inform future instruction while keeping the limitations of the study in mind.

Recommendations

Instructors should recognize that math anxiety and poor performance are related and that they would benefit from looking for ways to reduce the effects of math anxiety on student performance. The writing treatment in this study gave students an outlet to express their emotions and physical reactions before an assessment. Teachers should experiment with the writing treatment or give students other outlets to confront feelings related to an exam. Teachers may also experiment with a variation of the treatment that occurs more frequently throughout the unit rather than directly before the exam.

Teachers can also consider ways to reduce the affects of math anxiety and performance by considering cognitive affects of math anxiety. Results from previous studies discussed in the literature review section suggest that math anxiety inhibits the use of working memory. Therefore, an alternative instructional remedy could involve restructuring tests to reduce the amount of memorization needed to be successful on a test. For example, providing students with a note card will reduce the amount of material they actually have to remember so they can instead use their energy to use the material to solve problems.

While this study focused on assessments, teachers should also think about how math anxiety affects student learning in the weeks leading up to the exam. While much of the A-MARS survey was focused on exams, there were questions that focused on the actual math learning process. For example, one question asks the level anxiety that students feel when a teacher is explaining a problem on the board. This study focused on helping students more accurately show what they have learned. However, it is possible that anxiety does not just inhibit their ability to show what they have learned, but also inhibit their ability to learn. Thus, teachers should try out different class structures that will help their students with math anxiety interact with the material. If many students say that watching a teacher explain a problem on the board makes them feel a high level of math anxiety, teachers should try to avoid direct instruction when possible.

In future action research studies focusing on this topic, researchers can analyze exam results with more depth. For example, they may be able to determine the type of mistake that each student makes on wrong answers on a test. If a student is constantly forgetting the steps needed to solve a problem, teachers can consider the possibility that math anxiety is blocking the student's access to working memory. If a student makes frequent calculation errors, teachers can consider the possibility that math anxiety is affecting the student's basic arithmetic skills. To perform this analysis, teachers can make use of coding different types of mistakes while also having students self-report about what they think caused their wrong answers.

Teachers can also examine other factors that may contribute to lower test scores, such as study habits or time spent studying for the exam to determine if math anxiety is really affecting student performance or if other factors are more prominent. If students studied for an acceptable amount of time in the teacher's eyes, then teachers can start to wonder why the students were still not able to be successful on the exam. Future research should also be conducted over the course of a full semester or a full year. Using the treatment on more exams and collecting data throughout the year should provide a better idea of if the treatment works consistently or not. While there are many obstacles facing students in math classes, math anxiety is one of the most pressing issues, as it inhibits student ability to show teachers what they have learned when they complete assessments. As new effective treatments are discovered, assessments will begin to provide more accurate data about what students are learning.

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Tables

HMA Math III Treatment

Pre-Test	Post Test 1	Post Test 2
69.8%	+.6%	+10.6%

LMA Math III Treatment

Pre-Test	Post Test 1	Post Test 2
76.2%	+3%	+11.3%

LMA Math II Treatment

Pre-Test	Post Test 1	Post Test 2
77.6%	-1.8%	+6.3%

HMA Math III Comparison

Pre-Test	Post Test 1	Post Test 2
64.6%	-5.6%	-3.5%

LMA Math III Comparison

Pre-Test	Post Test 1	Post Test 2
76.2%	+3.4%	-8.5%

HMA Math II Treatment

Pre-Test	Post Test 1	Post Test 2
63.6%	+14.1%	+4.7%

Table 1. Percentage scores on pre-test and overall change on post-test #1 and post-test #2 for each sub-group.

(green) average score increased (red) average score decreased

Figures

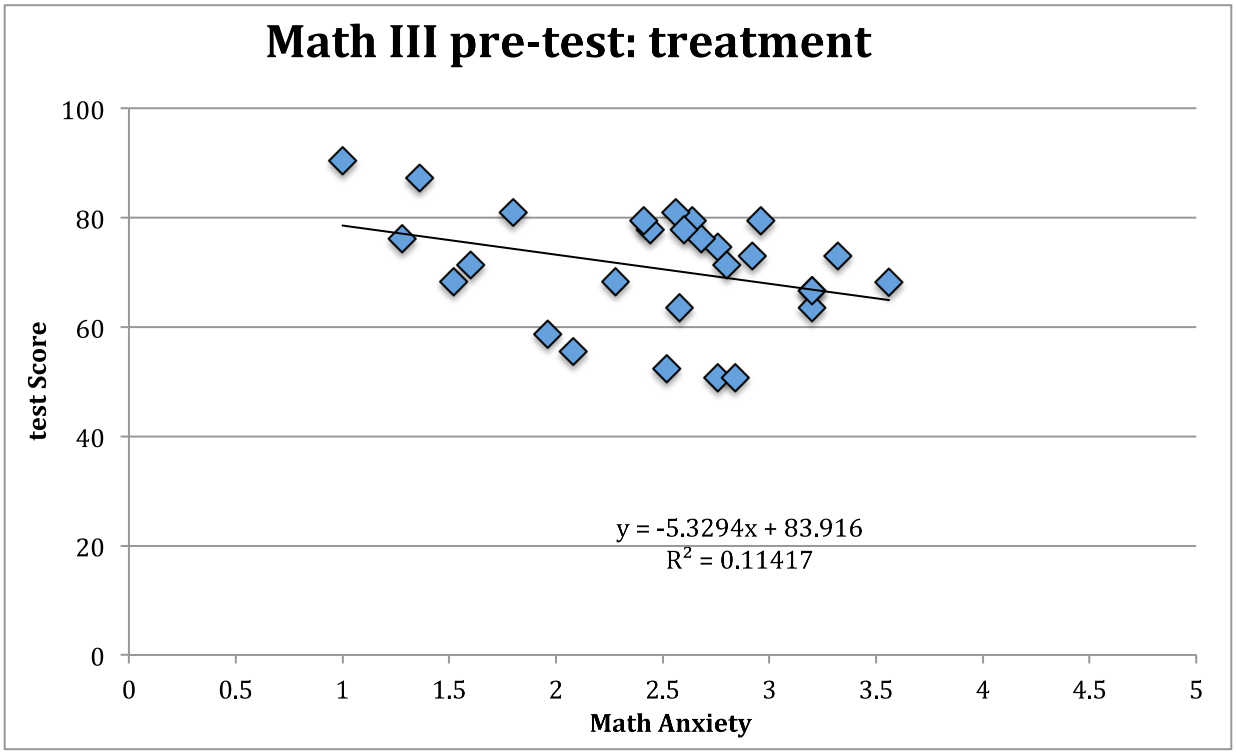

Figure 1. The results of the math III treatment group on the pre-test plotted with math anxiety scores.

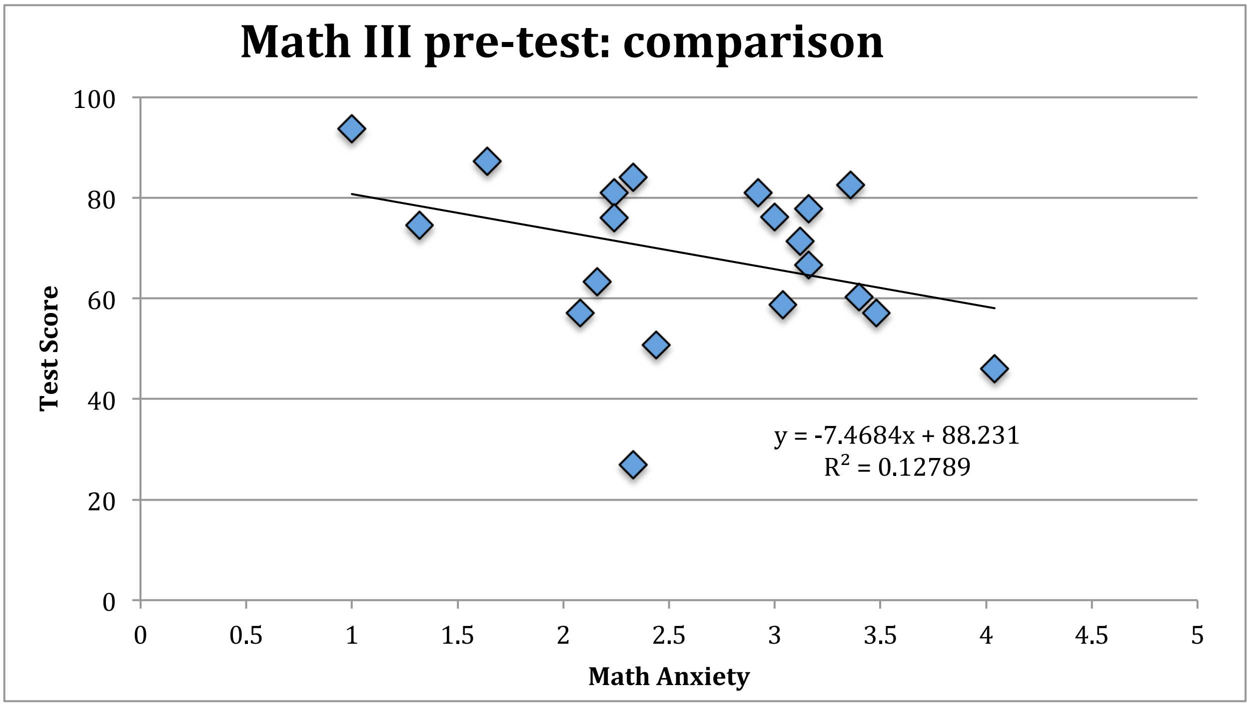

Figure 2. The results of the math III comparison group on the pre-test plotted with math anxiety scores.

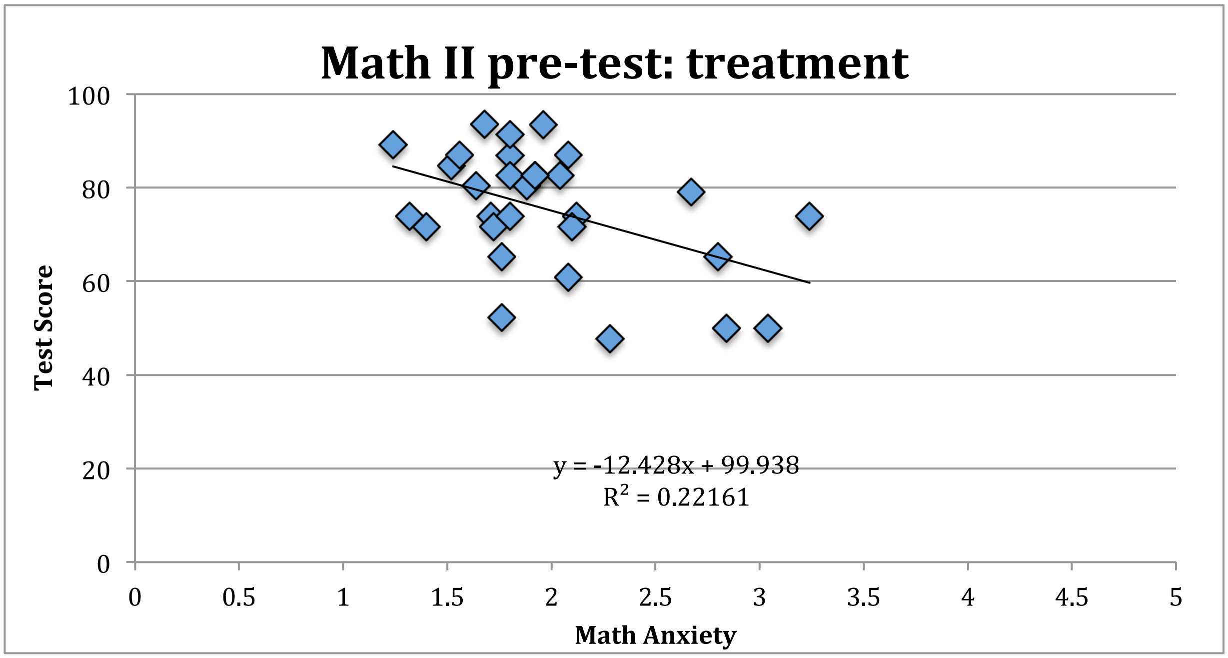

Figure 3. The results of the math II treatment group on the pre-test plotted with math anxiety scores.

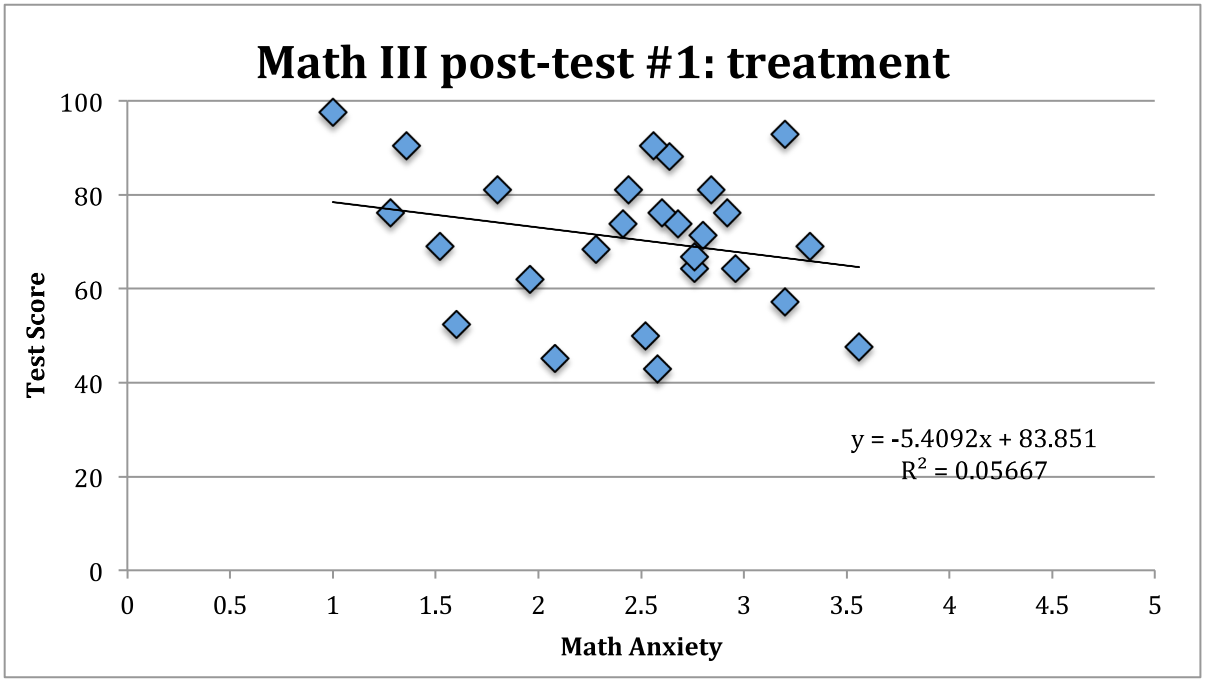

Figure 4. The results of the math III treatment group on the first post-test plotted with math anxiety scores.

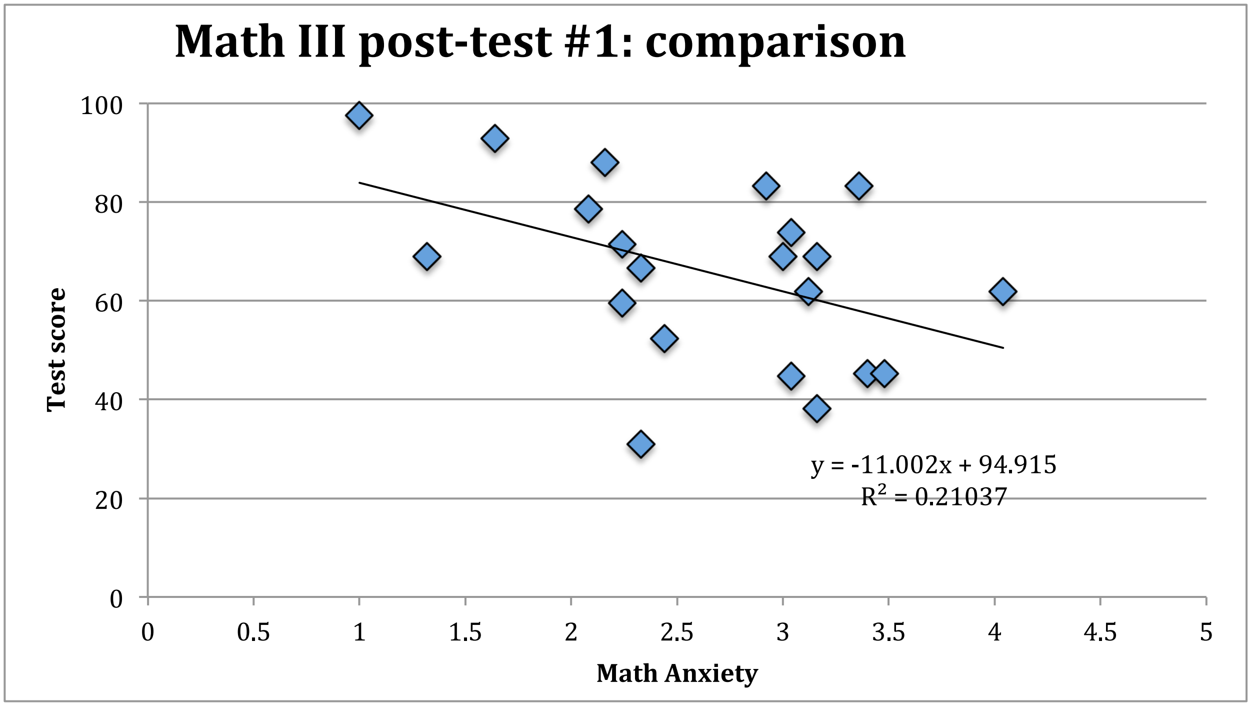

Figure 5. The results of the math III comparison group on the first post-test plotted with math anxiety scores.

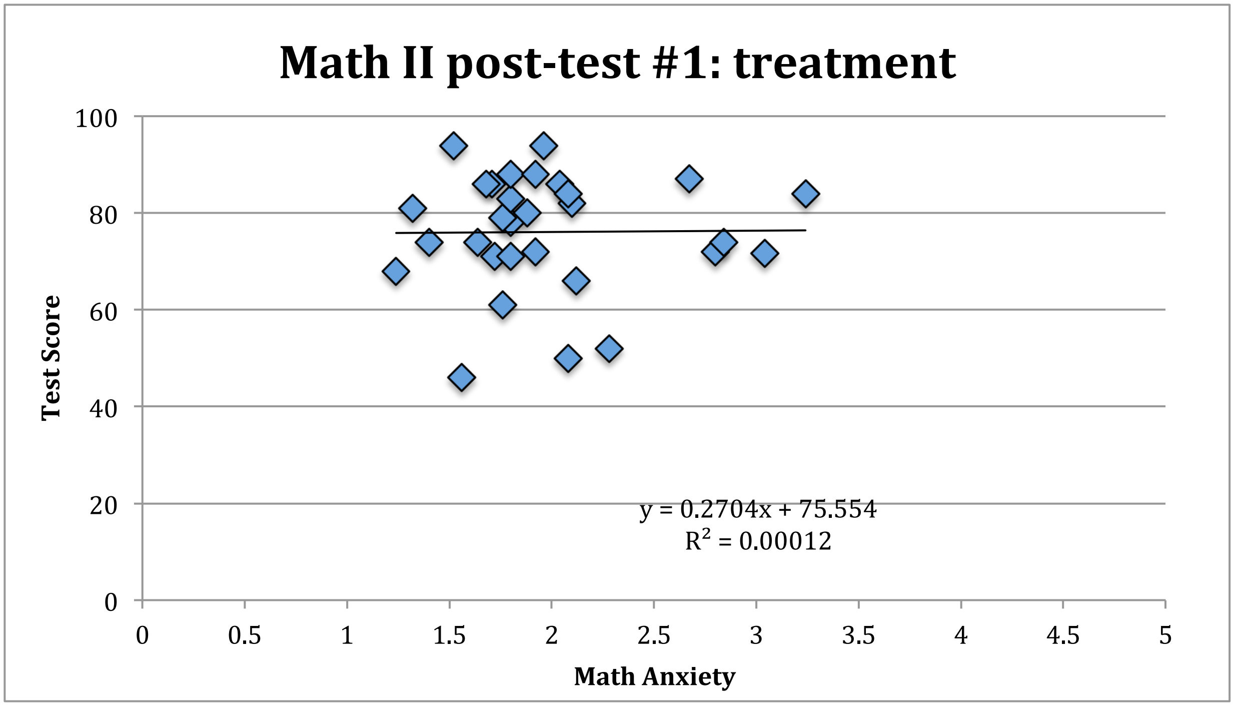

Figure 6. The results of the math II treatment group on the first post-test plotted with math anxiety scores.

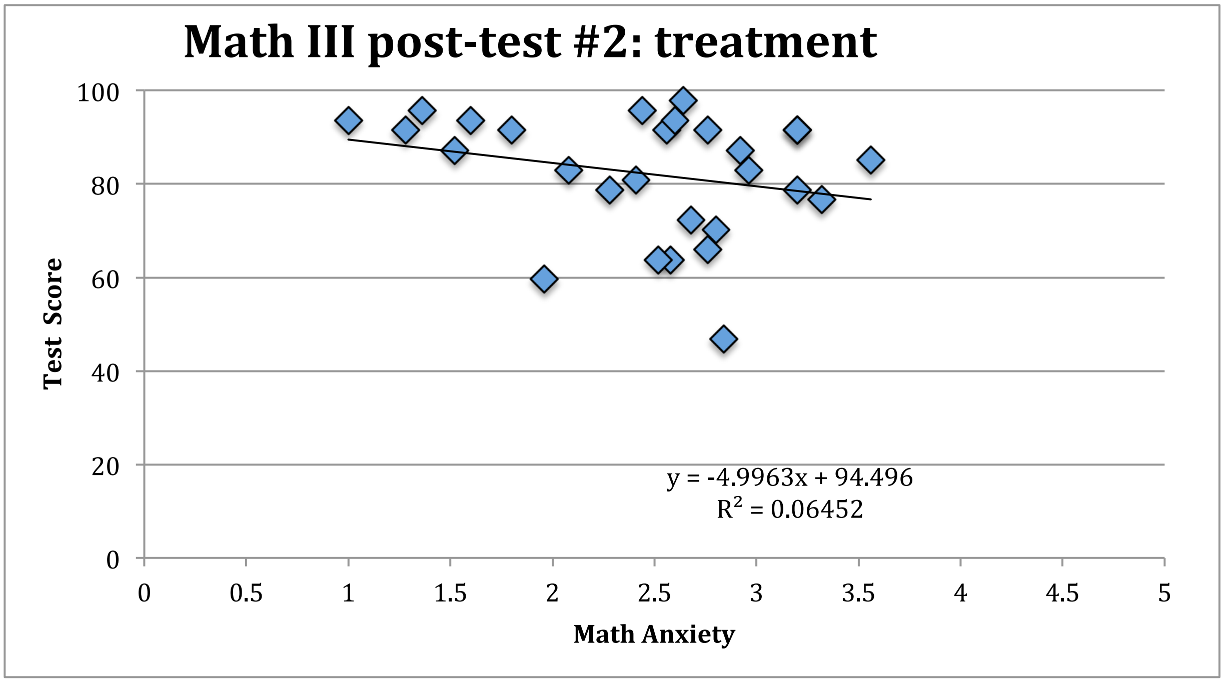

Figure 7. The results of the math III treatment group on the second post-test plotted with math anxiety scores.

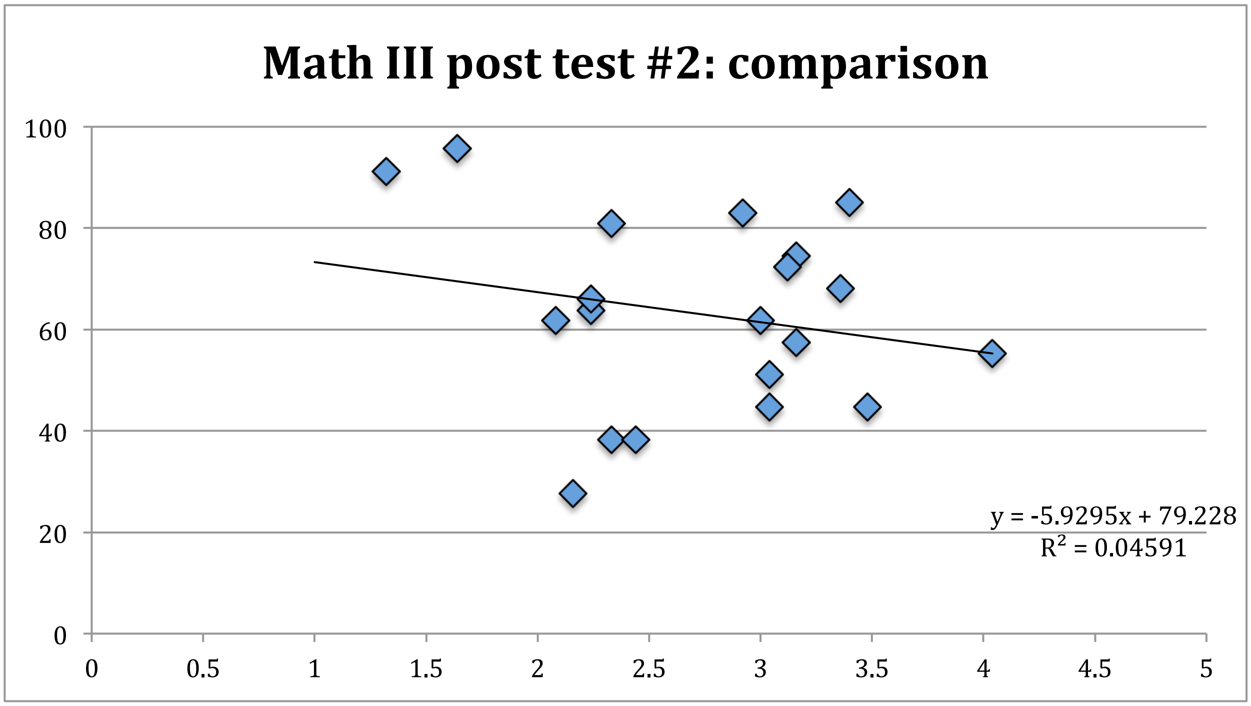

Figure 8. The results of the math III comparison group on the second post-test plotted with math anxiety scores.

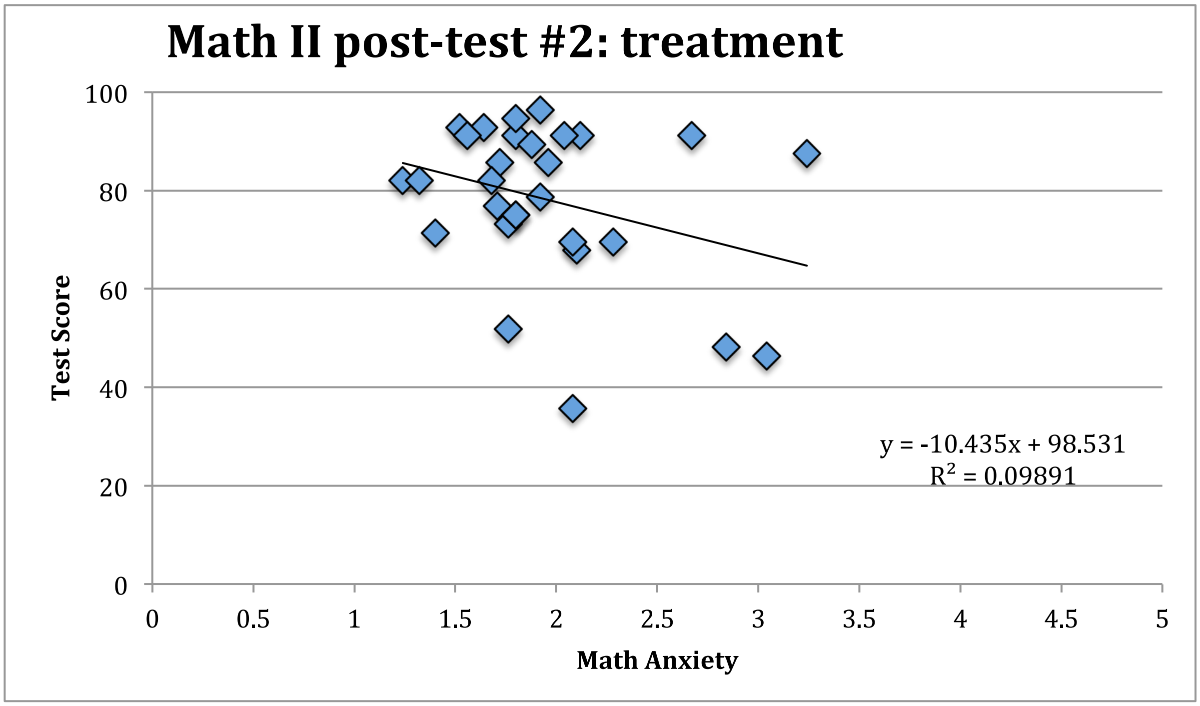

Figure 9. The results of the math II treatment group on the second post-test plotted with math anxiety scores.

Appendix

ABBREVIATED MATHEMATICS ANXIETY RATING SCALE (A-MARS) QUESTIONNAIRE

Please indicate the level of your anxiety in the following situations. Please choose ONE box on each line.

		Not at all	A little	A fair amount	Much	Very much
1.	Studying for a math test.	☐	☐	☐	☐	☐
2.	Taking math section of the college entrance exam.	☐	☐	☐	☐	☐
3.	Taking an exam (quiz) in a math course.	☐	☐	☐	☐	☐
4.	Taking an exam (final) in a math course.	☐	☐	☐	☐	☐
5.	Picking up math textbook to begin working on a homework assignment.	☐	☐	☐	☐	☐
6.	Being given homework assignments of many difficult problems that are due the next class meeting.	☐	☐	☐	☐	☐
7.	Thinking about an upcoming math test 1 week before.	☐	☐	☐	☐	☐
8.	Thinking about an upcoming math test 1 day before.	☐	☐	☐	☐	☐
9.	Thinking about an upcoming math test 1 hour before.	☐	☐	☐	☐	☐
10.	Realizing you have to take a certain number of math classes to fulfill requirements.	☐	☐	☐	☐	☐
11.	Picking up math textbook to begin a difficult reading assignment.	☐	☐	☐	☐	☐
12.	Receiving your final math grade in the mail.	☐	☐	☐	☐	☐
13.	Opening a math or stat book and seeing a page full of problems.	☐	☐	☐	☐	☐
14.	Getting ready to study for a math test.	☐	☐	☐	☐	☐
15.	Being given a "pop" quiz in a math class.	☐	☐	☐	☐	☐
16.	Reading a cash register receipt after your purchase.	☐	☐	☐	☐	☐
17.	Being given a set of numerical problems involving addition to solve on paper.	☐	☐	☐	☐	☐
18.	Being given a set of subtraction problems to solve.	☐	☐	☐	☐	☐
19.	Being given a set of multiplication problems to solve.	☐	☐	☐	☐	☐
20.	Being given a set of division problems to solve.	☐	☐	☐	☐	☐
21.	Buying a math textbook.	☐	☐	☐	☐	☐
22.	Watching a teacher work on an algebraic equation on the blackboard.	☐	☐	☐	☐	☐
23.	Signing up for a math course.	☐	☐	☐	☐	☐
24.	Listening to another student explain a math formula.	☐	☐	☐	☐	☐
25.	Walking into a math class.	☐	☐	☐	☐	☐