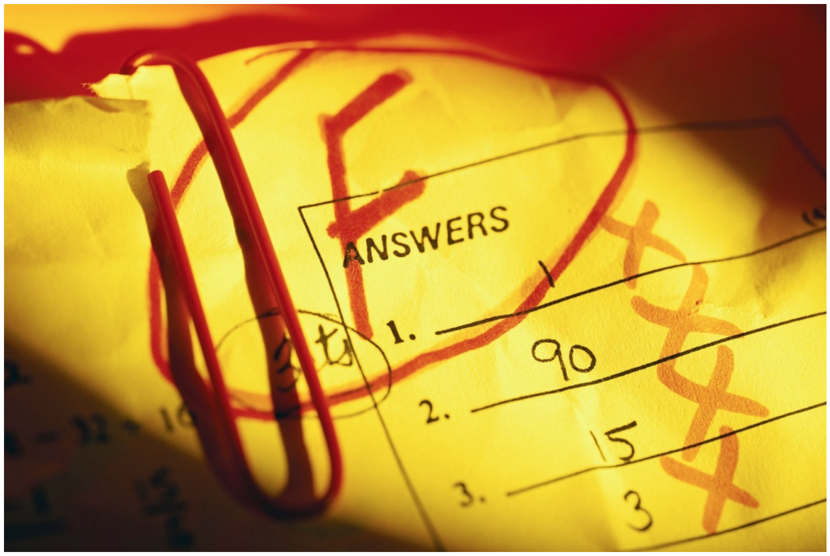
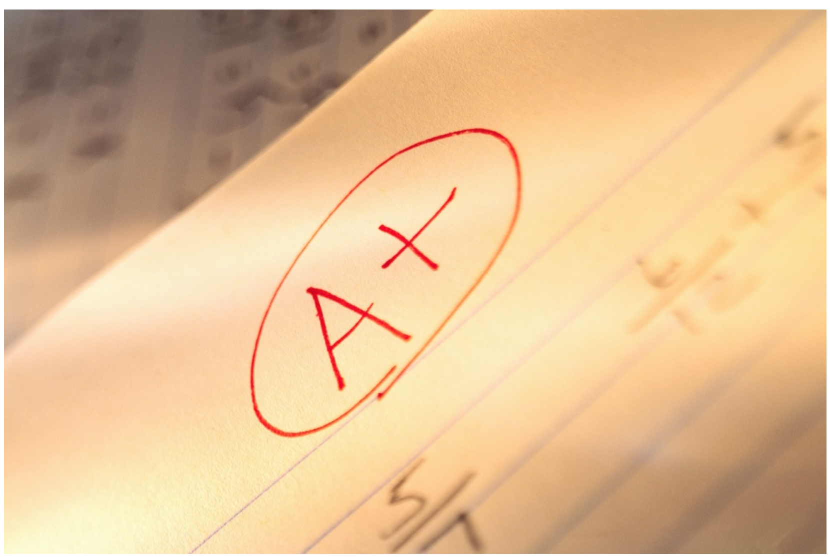


Too Afraid To Learn:

The role of math anxiety in cognition and what you can do about it



A handbook for teachers and administrators

By Cristina Post

Table of Contents

Introduction

Whenever I mention that I am a math teacher, it seems like I get the same reaction: an eye roll, or "Better you than me," or "I always hated math." If I mention that I study math anxiety, people respond with a story of one of their near relatives, friends or themselves. It is rare that I get a positive response to the idea of studying math, and that is not surprising: the most conservative estimate I have seen is that over two thirds of the American public has math anxiety (Burns, 1998). I was part of those two thirds: when I was in 11th grade, my honors trigonometry teacher recommended me for a lower level math class, because I didn't "have a mathematical mind," and that pursuing math would just "stress me out." Determined to stay in the honors level, my only option was to have him as a teacher for yet another year, and he was right: calculus was a stressful class for me, and I did not do very well, constantly worried that I would prove him right and reveal my weakness in math (I know now that this was part of a "fixed mindset" on my part – a concept I'll discuss later).

When I got to university, I took the second semester of calculus and did reasonably well, well enough to prove to myself that my math teacher was wrong about me. However, after that one semester I promptly avoided math for the rest of my education. After all (I thought), I had only succeeded in math because I studied harder in math than any other subject, but I lacked any real talent or skill at math. I even found myself unable to calculate the tip at dinner, remembering my anxiety during sixth grade math rather than remembering what I learned there. When I became a fourth and fifth grade teacher four years after college ended, I was faced with the necessity of teaching math. I revisited basic concepts and found that I could no longer even remember how to do long multiplication; I had to start at the beginning and relearn all of math.

As an adult, however, without feeling the pressure of teachers or parents, I found that math, to my complete surprise, was very easy and made complete logical sense.

As I relearned concepts and gained confidence, I felt my anxiety about teaching math decrease, and as my anxiety decreased, the concepts that I had been avoiding for years (like percents) starting getting easier and easier. With my own anxiety in check, I had more attention free to pay to the students, and for the first time I was able to see the anxiety in the faces in front of me in the classroom. I started playing math games, telling math stories, and sharing every trick and shortcut that I remembered from elementary school that had helped me get through the lesson. Whatever garnered a positive reaction I did more and more often, and my students quickly joined in the game. The math classroom was full of laughter, and I loved teaching math. At my next school, I became a middle school math teacher, and the story was always the same. By the time students were in fifth and sixth grade, many of them were afraid of math. They would meet me after school for help, and while some of the time we worked on math concepts, more and more often we worked on strategies to overcome their fear of math. It isn't possible to teach a whole week of material in one hour after school, so I concluded that their gains in class were due in large part to their newfound confidence. In class, the games and stories did their job as we joked our way through percents and pre-algebra, and within a year, we were all learning math.

This handbook is the result of my study of math anxiety: what is it, what it does, what causes it, what we can do about it, and why we should care. I hope that it will serve as a resource for teachers and administrators to support discussion in professional learning communities within schools.

How to Use This Handbook

This handbook serves as a teachers' reference guide to removing math anxiety from the classroom. Each section is preceded by bullet points that map out key points for quick reference and greater utility. When appropriate, resources for deeper learning are suggested. It may prove useful as part of a professional development program that includes professional learning communities participating in action research, based on a model described by Susan Loucks-Horsley and others (2010). I personally believe that if teachers know about a problem, understand the cause of it, the effects it has on the children, and most importantly, what they can do about it, they will do their best to incorporate the solution into their teaching. However, if there is little administrative or collegial support for change, professional development programs fail to have a lasting impact on practice (Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2010). Central to success is developing a professional learning culture and carrying out action research. While this handbook is not meant to provide a definitive methodology for how to create a professional learning culture or conduct action research, a brief outline of both are provided to help teachers place the handbook in a context that might prove useful in their communities.

Professional Learning Cultures

Three main strategies contribute to building a professional learning culture. The first two are external. For example, administrators can provide resources and time away from students and other responsibilities. If administrative support is not available, building a professional network of teachers outside of schools or districts that creates ongoing relationships between members can serve as a community to support professional learning. In order to be effective, professional networks must contain some way for communication to continue over time, rather than designed around one particular workshop and then abandoned. A third strategy, which this handbook is designed to support, comes from the individual teacher rather than external directives from administration or professional development consultants. I don't mean to imply that teachers should bring the material home from a workshop and start teaching others, rather that they start a community themselves by initiating dialogue around the issue, working with administrators to develop support for the community, and encouraging others to participate in other similar or complementary workshops to build and enrich an ongoing conversation with professional colleagues (Loucks-Horsley et al., 2010).

Action Research

The first step to changing teaching practice is for teachers to determine whether math anxiety is present in their classrooms. While no questionnaire is yet available for children under grade 3, one is currently being developed and tested for validity (Krinzinger, Kaufmann, & Willmes, 2009). A questionnaire is provided that has been found valid for grades 4-8 (Chiu & Henry, 1990; Appendix A). High school and college students can use a shortened version of the Math Anxiety Rating Scale developed by Richardson and Suinn in 1972, which is also provided (sMARS; Alexander & Martray, 1989; Appendix B). Action research requires teachers in the professional learning community to share data from the initial survey, create a plan to counteract the problem, test their ideas in the classroom, document the results, and report results back to the learning community (Laucks-Horsley et al., 2010). Sample methods for counteracting math anxiety are outlined in this handbook. All methods have been researched and published in peer-reviewed journals, but details of implementation may need to vary between school systems and regional cultures. Using data to inform teaching methodology not only empowers the teacher and children to change the culture of the classroom, it also provides valuable information for education research. Professional networks outside of individual schools are a great way to contribute to an ongoing discussion on how to reduce math anxiety and increase math learning in schools.

Resources for developing professional learning communities

Loucks-Horsley, S., Stiles, K., Mundry, S., Love, N., Hewson, P. (2010). *Designing Professional Development for Teachers of Science and Mathematics*. Thousand Oaks, CA: Corwin

Brighton, C. (2009). Embarking on Action Research. *Education Leadership*, *66*(5), 40-44.

Why Math (Anxiety) Matters

The scientific and mathematical literacy of our nation's population has been of growing concern over the past decades. In an increasingly globalized economy, our ability to produce skilled workers in science, technology, engineering, and math (STEM) fields is seen as important to our economic success as a nation. Not only do we need to increase the number of "knowledge workers" whose specialized skills allow them to be innovators and leaders in STEM fields, we also need to improve the STEM competence of workers who are not destined for higher education, as more and more jobs require technical competence (United States Department of Labor, 2007) [DOL]. While only five percent of the workforce works in STEM fields, that five percent is responsible for over fifty percent of the United States' sustained economic growth (Babco, 2004). Within the job growth provided by STEM fields, seventy-eight percent was in computer and math fields (DOL, 2007).

Two major tests compare international student performance in science and math, Trends in International Mathematics and Science Study (TIMMS), and the Programme for International Student Assessment (PISA). TIMMS tests students in fourth and eighth grade, and PISA tests students at age fifteen. In 2007, the United States ranked ninth of the thirty-six participating countries of the fourth grade TIMMS, and sixth of the forty-seven taking the eighth grade TIMMS, an improvement over previous testing times and higher than the international average of 500 (National Center for Education Statistics, 2008) [NCES]. The 2006 PISA, however, shows the United States testing below the international average of 498, ranking twenty-fifth of the thirty industrialized countries who took the test (McKinsey & Company, 2009). The difference is alarming, as the TIMMS focuses on curricular material that would be used in a classroom setting, but the PISA has an emphasis on mathematical literacy, focusing on math that would be applied in real world settings (NCES, 2008).

As will be explained in greater detail later in this handbook, research on math anxiety shows that after math anxiety sets in around fourth grade, standardized tests results are no longer indicative of student achievement (Ashcraft, 2002). If over two-thirds of Americans are math anxious (Burns, 1998), and math anxious people tend to do poorly in math, avoid math classes and avoid careers that contain math (Hembree, 1990), then remediating math anxiety is clearly important for economic success as a country. Luckily, we do have effective strategies for alleviating math anxiety, and even in the absence of any remedial math content, lowering math anxiety corresponds to a gain of twenty percentile points (Ma, 1999), a significant increase by any standard. More important than the test scores, however, is the increased standard of living that might be possible by helping children to pick from a wider array of careers, especially in a high-growth field such as STEM careers.

- Math anxiety is situational anxiety specific to math
- Math anxiety results in artificially depressed math achievement
- Math anxiety does not correlate with IQ or verbal ability
- Math anxiety occurs with equal frequency in boys and girls
- Math anxiety is distinct from stereotype threat, a condition where girls underperform in math due to low societal expectations
- Stereotype threat is communicated by math anxious teachers as early as Grade 1
- Math anxiety has three ages of onset, around Grade 4, around Grade 9, and freshman year of college
- Once math anxiety exists, standardized tests are no longer a valid measure of math achievement

Math Anxiety Defined

Anxiety can be defined as a state of emotion involving fear and dread, out of proportion to the severity of the threat (Hembree, 1990). People who suffer from anxiety may do so as a function of temperament, where anxiety is a personality trait. Trait anxiety is distinct from state anxiety, a type of anxiety that is transient and only exists in response to a specific situation (Robyak, 1986). Math anxiety is a state anxiety, which means that it does not present in other academic areas and cannot be attributed to personality or temperament. It is often broken down into different components, such as affective math anxiety, which refers to feelings of nervousness, tension, and fear, and cognitive math anxiety, which refers to fears surrounding performance, whether in social situations or on math assessments (Beasley, Long, & Natali, 2001). Math anxiety is strongly negatively correlated with math achievement (Ma, 1999), and so in order to understand math anxiety fully, we need to examine a second state anxiety often comorbid with math anxiety: test anxiety. While anxiety surrounding math tests is clearly related to cognitive math anxiety, text anxiety has been found to be a distinct state anxiety in children older than Grade 6, and the two require separate interventions to alleviate both problems

(Dew, Galassi, & Galassi, 1984). Math anxiety does not correlate significantly with IQ or verbal aptitude (Ma, 1999), though it does correlate moderately with trait anxiety (Ashcraft & Moore, 2009). Students suffering from trait anxiety will exhibit anxiety in situations that are not specific to math, and they should be referred to a school counselor or outside resources for help in alleviating symptoms. Students who only exhibit anxiety in the math classroom do not have trait anxiety and can be treated according to methods outlined later in this handbook.

In order to measure math anxiety and examine its relationship to performance and ability, a number of questionnaires have been developed. The most common is the Mathematics Anxiety Rating Scale (MARS), a measure most appropriate for adult, college- and high school-aged students and consisting of 98 items (Richardson & Suinn, 1972). In 1989, Alexander and Martray developed a shortened MARS (sMARS) that contains 25 items and is more easily administered in the high school classroom (Appendix B). Ashcraft (2002) has since found that, for older students, an abbreviated test is equally valid, and in fact, simply asking, “On a scale of 1 to 10, how math anxious are you?” correlates well with a shortened version of the MARS. However, tests like the MARS are not appropriate for younger children, as being able to reflect on their own anxiety and abstract different types of anxiety is a skill that has not yet developed in elementary-aged children (Fischer & Bidell, 2006). Accordingly, Chiu and Henry developed the Mathematics Anxiety Scale for Children (MASC) in 1990 for grades 4 through 8 (Appendix A). A factor analysis of the test showed that while adults and adolescents differentiate between math anxiety and test anxiety, sixth graders are not yet able to (Beasley, Long, & Natali, 2001). While adults are able to respond differentially to math tests, social performance of math, or math in general, children younger than Grade 6 cannot differentiate and see experience math anxiety as a global construct. The MASC results can therefore be used to target specific interventions for students in grades 7-8, but in grades 4-5, a more general strategy should be used.

Since adults and adolescents can differentiate between different types of math anxiety, but younger children cannot, we need more research investigating the effects of math anxiety on math achievement in the younger grades. Perhaps due to the ease of interviewing and testing college-aged adults, the research is heavily biased towards older age groups. While we find significant relationships between math anxiety and math performance in adults, we may not find it at every grade level. Hembree's meta-analysis of the research up to 1990 did not encompass students younger than Grade 6, as insufficient studies had been carried out in the younger grades. Ma's 1999 meta-analysis, which focused on pre-college students, found insufficient research below Grade 4. I have only found one recent study on Grades 1 to 3 (Krinzinger, Kaufmann & Willmes, 2009). Research on students at every developmental stage is necessary to plan and time effective interventions, and also to help inform teacher-training strategies.

Math Anxiety versus Stereotype Threat

Neither the MASC nor the MARS found any significant difference in the prevalence of math anxiety in boys versus girls (Chiu & Henry, 1990; Ma, 1999). However, it is common to hear in schools that math anxiety affects girls disproportionately. This is due to the added burden of under-performance due to stereotype threat (Steele, 1997). Cultural stereotypes that girls are less able to do math often results in negative parent or teacher attitudes towards female students' math abilities. These attitudes can foster gender differences in emotional reactions to math, where girls report significantly less enjoyment and pride in their math experience, even when achievement levels are the same. Common feelings reported include anxiety, hopelessness, and shame (Frenzel, Pekrun, & Goetz, 2007), leading to the perception that girls suffer from math anxiety more than boys do. Math anxiety occurs when the student fears he does not have the capacity to meet high expectations, and stereotype threat is the result of low expectations (Beilock, Rydell, & McConnell, 2007).

Under stereotype threat a negative vision of one's own abilities is activated outside of conscious attention and regardless of actual skill. In other words, when girls with high ability in math are tested under conditions of stereotype threat, such as being told the test was designed to reveal gender differences, they under-perform in comparison with male counterparts of equal ability. The same holds true in comparison with female counterparts of equal ability who take the same test without being told the test reveals gender differences (Steele, 1997). Research shows that highly math-anxious female teachers communicate the gender stereotype that girls aren't good at math as early as Grade 1 (Beilock, Gunderson, Ramirez, & Levine, 2010). In this instance, the relationship between math anxiety and stereotype threat is clear, and any attempt to remediate math anxiety must address stereotype threat as well.

Age of Onset

The onset of performance-affecting math anxiety centers around Grade 4 (Hembree, 1990; Newstead, 1998; Ma, 1999) and peaks by Grade 9 or 10 (Hembree, 1990). A study by Jackson & Leffingwell (1999) showed that 16% of college students surveyed had their first negative experience with math in Grades 3 or 4, with 26% reporting a second period of onset in Grade 9-11, and 27% during the freshman year of college. Only 7% reported that they had never developed an aversion towards math. While the recent study by Beilock et al. (2010) shows negative effects on math performance in girls as young as Grades 1 and 2, the cause seems to be anxiety in mathematics teachers, which creates gender stereotypes in young girls but does not yet seem to result in the development of math anxiety in the children. The reduction in performance is therefore attributed to young girls imitating their math anxious teachers. Previous research by Krinzinger, Kaufmann, and Willmes (2009) demonstrated that math anxiety on the part of the student is unrelated to performance through Grade 3.

Another way of tracking the development of math anxiety may be the corresponding drop in math scores on standardized tests. Ashcraft and Moore (2009) state that after the first signs of anxiety appear in fourth and fifth grade, standardized tests are no longer a clear indicator of math ability or achievement. Since we know that math anxiety and test anxiety are related constructs, investigating how math anxiety affects math achievement and performance is vital. As teachers, tracking children's performance on standardized test from year to year may provide insight into whether math anxiety has developed or not.

- Math anxiety decreases math performance by interfering with working memory
- Working memory is a system in the brain that temporarily holds information we are working on, like numbers in a math problem
- A digit span test can serve as a rough estimate of a student's working memory capacity, outlined in Appendix C
- Due to the nature of working memory, math anxious students perform more poorly on problems written out horizontally, such as 324 + 123 = ?

Math Anxiety and Working Memory

We know that math anxiety and math performance are negatively correlated, and since people with high math anxiety do not tend to pursue further learning in math (Ashcraft, 2002), it is difficult for a teacher to know whether poor performance is due to heightened anxiety or to lower levels of math achievement. Despite this ambiguity, controlling for ability makes it clear that there is an interaction between math anxiety and math performance. Research shows that giving college students simple whole number addition problems to solve in untimed, low stress conditions found no difference between low and high anxious learners, but giving the same problems under time pressure showed worsened performance in the high anxious group (Faust, Ashcraft, & Fleck, 1996). This experiment shows that timing tests can reduce math performance without a difference in math ability. To determine when anxiety and competence become interrelated, a second study investigated anxiety effects in a basic math skills test that increased in difficulty with each problem. No anxiety effects were found on performance of whole number arithmetic problems, but fractions, percentages, factoring, and equations with unknowns all showed performance deficits in the high-anxious group (Ashcraft, 2002). Fractions, percentages, factoring, and equations involving unknowns are commonly introduced around the fourth grade, right around the time that math anxiety sets in. This study cannot, however, differentiate between performance deficits due to poor learning and performance deficits due to math anxiety. As a result, further research from cognitive science has focused on the interaction between math anxiety and math achievement to discover the mechanism by which math anxiety interferes with learning.

Ashcraft and Kirk (2001) propose that math anxiety interferes with working memory. Working memory is the system assumed to be necessary to keep information in mind while performing complex tasks, like learning math. This short term system controls the flow of information into long term memory, and consists of four components: the central executive, the visuo-spatial sketchpad (also referred to as the spatial working memory), the phonological loop (also referred to as the verbal working memory), and an episodic buffer, which may combine visual and auditory input with smell and taste (Baddeley, 2010). Math anxiety likely interferes with the phonological loop, as students use up their limited working memory space with verbal worries about their math performance (Ashcraft, 2002). The phonological loop stores speech-like memory traces for about two seconds (Baddeley, 2010), and its capacity can be measured by determining the number of digits that can be held in the verbal working memory (Gathercole, Pickering, Ambridge, & Wearing, 2004), a measurement often referred to as digit span. The digit span test alone is not a reliable diagnostic for working memory in general, but it can serve as an easy estimate of the capacity of the phonological loop by itself. To more accurately determine the capacity of all of the components of working memory, Pickering and Gathercole (2001) have created a Working Memory Test Battery for Children. Working memory capacity can predict performance in a variety of cognitive tasks (Baddeley, 2010; Gathercole et al., 2004), such as school performance, IQ tests, and aptitude tests. In fact, children with a working memory deficit often suffer from mathematical learning disabilities (Andersson & Lyxell, 2007).

Working memory has been implicated strongly in mental arithmetic. The central executive is involved in retrieval of arithmetic facts from long-term memory; such well-known math facts do not seem to require use of the phonological loop. Nonretrieval strategies, when numbers must be manipulated to arrive at the answer, all require use of the phonological loop (Imbo & Vandierendonck, 2007). While children under the age of seven tend to rely on the visuo-spatial sketchpad to support recall of visual stimuli, children beyond that age rely on the phonological loop, a tendency that increases as children age (Gathercole et al. 2004). Ashcraft and Kirk (2001) reasoned that an addition problem requiring the student to carry would place a higher demand on working memory. It takes high-anxious students about three times longer to solve a problem involving carrying than a low-anxious student. To test working memory, they asked students who had been previously assessed in verbal tasks to have similar working memory capacity to remember a series of six random letters while performing the computations. On problems that did not require carrying (ergo no load on verbal working memory), both groups had similar error rates. However, when the participants were required to solve a problem involving the carrying process while remembering the letters, error rates in the high-anxious group rose dramatically (Ashcraft & Kirk, 2001). The implication is that anxiety creates a demand on working memory, and as math problems require more and more working memory capacity to solve, the high anxious group encounters more difficulty. Moreover, since children with low working memory capacity are likely to have greater difficulty with math calculations in general, they are at higher risk for math anxiety, and math anxiety will greatly impact their performance in school. It is therefore of great importance that teachers understand working memory and how math anxiety can affect a child's capacity to learn.

A similar study by Beilock (2008) found that when they controlled for individual anxiety level and divided the sample into low and high working memory capacity groups, placing high working memory individuals in high pressure situations reduced their performance to the same as the low working memory group, further supporting the idea that anxiety takes up space in working memory. Beilock also found that since solving math problems that are horizontally oriented on paper recruits verbal working memory, and solving problems that are written vertically relies only on spatial working memory, individuals who are worried about their performance perform more poorly on problems presented in a horizontal format.

Beilock's work was not restricted to math anxiety, but examined the mechanism of stereotype threat as well. While stereotype threat and math anxiety arise from different causes, the mechanism by which they interfere with performance is the same. When women were placed under stereotype threat by hearing a negative stereotype of women in math directly prior to assessment, they exhibited identical decreases in performance (Beilock, 2008; Steele, 1997). The inner worries and self-doubts of math anxious students and women under stereotype threat take up valuable working memory space and create a deficit in math performance regardless of the person's true mastery of or ability in math. The discrepancy between actual competence or achievement in math and performance due to interference from math anxiety or stereotype threat is referred to as *affective drop* (Ashcraft & Moore, 2009).

- 72% of negative math experiences are attributable to teachers and teaching strategies
- Teacher modeling of math anxiety can cause math anxiety
- Grades 4-8 can be evaluated for math anxiety using the MASC provided in Appendix A
- Grades 9-12 can be evaluated for math anxiety using the sMARS provided in Appendix B
- Group therapy is not effective, nor were curricular interventions
- One-on-one interventions are effective
- Systematic desensitization combined with cognitive restructuring is the most effective technique
- Social-psychological interventions show great promise for scalable change, such as values affirmation interventions and fostering a growth mindset in the classroom
- Building in daily opportunities for incremental improvement can decrease anxiety
- New curricula designed to improve learning can actually increase anxiety levels
- Until math anxiety is remediated, a traditional expository style of classroom minimizes anxiety
- Once math anxiety is remediated, new curricula can be gradually introduced
- Math anxiety reduction is associated with an achievement gain of over 20 percentile points

Strategies for eliminating math anxiety from our classrooms

As teachers, we have an incredible responsibility to nurture and educate the next generation. Unfortunately, studies show that 72% of the negative math experiences that arise in early-middle primary school are attributable to the teacher, rather than math content, family attitudes, or peers (Uusimaki & Nason, 2004). Negative experiences are defined broadly, from a cold teacher presence in the classroom, negative statements about students' math ability, an emphasis on memorization of procedures as a means to learning math, or math teacher modeling of math anxious behaviors (Brady & Bowd, 2005).

Teacher Math Anxiety

While the focus of this section will be on the reduction and prevention of math anxiety in students, our role as a model of student behavior is so crucial that any discussion of math anxiety in students must begin with us. One of the most common ways for math anxiety to develop in the classroom is by teacher modeling of math anxious behaviors (Gresham, 2007; Tobias, 1998; Vinson, 2001). Anxiety is a background emotion, which we exhibit unconsciously through body posture and movements, minimal changes in amount and speed of eye movements, and the degree of contraction of facial muscles (Damasio, 1999). These minimal changes are what children pick up on and react to, creating a learning environment where math is depicted as a subject to be avoided at all costs. Indeed, elementary school teachers who score higher on measures of math anxiety spend less time preparing for math lessons and less time teaching math, modeling this math avoidance (Brady & Bowd, 2005). Math-anxious teachers also tend to focus on teaching skills, rather than concepts (Norwood, 1994), an important part of teaching for understanding. High school teachers, who often have a stronger math background than their elementary school colleagues, do not exhibit these same behaviors (Brady & Bowd, 2005). A survey of college students found that the major exhibiting the highest level of math anxiety was elementary school education (Hembree, 1990), and studies show that over 90% of elementary school teachers score as highly math anxious (Gresham, 2008; Jackson & Leffingwell, 1999). Teachers tend to teach as they were taught (Furner & Berman, 2003; Norwood, 1994). If we, as elementary school teachers, developed math anxiety over the course of our education, we are likely to teach math in the same way we were taught, perpetuating the cycle.

While full-blown math anxiety does not seem to develop in elementary school students until about Grade 4 (Brady & Bowd, 2005; Krinzinger, Kaufmann, & Willmes, 2009; Ma, 1999; Newstead, 1998), elementary school children learn by imitation, perpetuating long held stereotypes in our society that girls are not as good at math as boys are. Research at the University of Chicago found that teachers modeling math anxious behaviors showed negative effects on math performance in girls as young as Grades 1 and 2 (Beilock, Gunderson, Ramirez, & Levine, 2010). Math anxiety in female teachers can potentially foster in their young female students the well-known gender stereotype that 'girls are bad at math.' While math anxiety is found at equal levels in both boys and girls (Ma, 1999), girls are under the added pressure of stereotype threat discussed earlier. Stereotype threat has the same negative impact on performance that math anxiety has, and the fact that over 90% of elementary school teachers are female (Beilock et al., 2010) increases the risk that girls could underperform due to factors unrelated to their actual ability level.

While the traditional measure of math anxiety for adults is the Math Anxiety Rating Scale (MARS), a 98-item questionnaire developed in 1972 by Richardson and Suinn, the results are roughly equivalent to asking the question, "On a scale of 1 to 10, how math anxious am I" (Ashcraft, 2002)? Teachers who are at all math anxious should work to remedy their anxiety before teaching children. All of the same strategies to reduce student anxiety, discussed below, work on teachers as well. Another method would be to find a program with a sympathetic teacher who either understands math anxiety or does not elicit an anxiety reaction, and relearn math. Research shows that teachers' math anxiety levels are significantly reduced by taking methods courses that emphasize the use of manipulatives to achieve understanding (Gresham, 2007). Manipulatives are objects that students and teachers can physically handle in order to help them see actual examples of mathematical principles at work, and they are readily available online or in teacher supply stores.

Reduction of Already Established Math Anxiety

Chances are, as a teacher, you will inherit a class where math anxiety has already taken hold. It's important to note that no matter how talented a teacher you are, no best practices in teaching will help improve math performance without the first step of reducing math anxiety (Furner & Duffy, 2002). Teachers are often able to identify which students are math anxious in their classrooms, but to ensure that no child slips through the cracks, an assessment should be given to all children. Since math anxiety appears to be unrelated to performance up to Grade 3, with onset starting around Grade 4 and peaking around Grade 9, special attention should be paid to Grade 4 through Grade 8. A reliable assessment for this age group (valid for grades 4-8) has been developed by Chiu and Henry (1990), called the Mathematics Anxiety Scale for Children (MASC; Appendix A). Once children are in high school, rating scales that have been developed for college students and adults may be more appropriate, such as the shortened MARS (sMARS; Appendix B), which correlates strongly (0.97) with the original MARS. Since we know that Grade 9 is the second onset period for math anxiety, giving the sMARS at the start of high school is highly recommended.

The National Council of Teachers of Mathematics (NCTM, 2000) suggests the following strategies for reducing math anxiety: anxiety management, desensitization, counseling, support groups, bibliotherapy, and classroom discussions. They also encourage teachers to build student confidence by encouraging students to take more math. While any attempt to remediate math anxiety is laudable, research shows that some methods are more effective than others. The best way to remediate anxiety is on an individual level, as discussed below, but some social-psychological interventions show scalable promise as well and will be addressed individually (Yeager & Walton, 2011).

Intervening at the individual level

Pedagogical classroom interventions consisting of innovative curricula, like discovery math, were not effective at reducing math anxiety, nor was group counseling effective. Furner &

Duffy (2002) suggest that teachers act as counselors to individual students to help them overcome math anxiety. In cases where the teacher does not feel comfortable acting as a "counselor", referring a student to the school counselor or to an outside provider may prove to be a better choice. Effective interventions were one-on-one, and the most effective strategy was systematic desensitization, especially when combined with cognitive restructuring (Hembree, 1990), a cognitive behavioral therapy technique aimed at helping students rephrase negative internal dialogues or pessimistic post-exam appraisals (Ma, 1999). Cognitive restructuring, or coping self-talk, can teaching children to reappraise negative or anxiety-provoking thoughts as positive and may help children control their anxiety levels (Kendall, Aschenbrand, & Hudson, 2003). A study involving college students taking the GRE showed that students can interpret the arousal they feel prior to a test as either challenge or threat. While teachers need to take care when generalizing the results to younger students, the study shows that telling students that the anxiety they feel prior to an exam can help them to focus and do well results in higher scores on the math section of the test (Jamieson, Mendes, Blackstock, & Schmader, 2010). The results do not imply that anxiety is a helpful emotion, but rather that helping students to think about their emotions in healthy ways can be helpful in converting the anxiety into a challenge response rather than a threat response. This type of cognitive restructuring is most effective with older children, because they are able to reflect on their thoughts. Kingery and others (2006) provide a framework for understanding how to adapt traditional cognitive restructuring methods for use with younger children.

The concurrent use of systematic desensitization is especially important due to the fact that high levels of anxiety are resistant to verbal reassurance, since emotions are as real as they are perceived to be. Even when negative beliefs are objectively false, they still create the same emotions as true beliefs (Harris, 1989). In systematic desensitization, children are gradually exposed to incrementally difficult math, working with an adult who supports them emotionally as well as academically in order to overcome their fear of math. Not only does systematic desensitization help reduce fear of math, the exposure to the extra content may help improve achievement. Improving achievement also decreased anxiety levels (Hembree, 1990), and even when individual desensitization is not possible, building small incremental goals into daily classes can show students their own improvement and create a positive feedback loop.

Since math anxiety is usually correlated with lower achievement levels, the temptation is to view content as the problem in all cases. However, even with no math content remediation, anxiety reduction alone can return student scores into the normal range (Hembree, 1990). For example, treatments that alleviate math anxiety to the point where they report only low levels of math anxiety are associated with the improvement of a typical student's performance from the 50^{th} to the 71^{st} percentile (Ma, 1999).

Intervening at the classroom level

In classrooms where math anxiety has already formed, a traditional style of classroom can help make students feel more secure. In a traditional classroom the teacher is at the front of the classroom transmitting information to relatively passive learners. This method is not ideal for engendering a high level of math understanding, but it lessens discomfort for students who suffer from lack of confidence, as a strong positive teacher presence, an emphasis on cognitively simple rules, and a clear class structure can help students feel safe (Newstead, 1998). Students suffering from math anxiety learn best in a structured, expository type of classroom (Norwood, 1994). There have been many studies that look to innovative curricula to improve the quality of elementary math class experiences, but while they do often improve the opportunity for true understanding of math, they do not have the desired effect of improving math attitudes and scores, due to the heightened levels of anxiety surrounding the new curriculum (Newstead, 1998).

The above finding does not mean that a structured, expository classroom is the best learning environment for math. Since many of the innovative curricula are preferred for teaching for understanding, one should not rely on traditional methodology just because a high level of math anxiety already exists. Indeed, a traditional math class taught by an unsympathetic teacher can create high levels of math anxiety (Brady & Bowd, 2005). Teachers must take care to assess the anxiety level of students and match teaching style appropriately, while simultaneously integrating math anxiety reduction strategies. As anxiety levels decrease, more effective instructional strategies can be gradually introduced, after a trusting relationship has developed between students and teachers. "Live modeling plus participation" works to reduce phobias because the learner creates a new reality (Frijda, 1988; p.352). In the case of math anxiety, teachers modeling new ways of learning and encouraging students to participate can help students overcome their fear of math in a way that verbal reassurance cannot.

While Yeager & Walton (2011) caution that social-psychological interventions administered in the classroom by the regular teacher often do not yield positive effects, the same interventions in standardized conditions show promise for overcoming negative academic performance due to anxiety and/or stereotype threat. The most promising of these is a growth mindset intervention as proposed by Lisa Blackwell in 2007. By teaching students about "growth mindset," the idea that intelligence is malleable and can be changed by hard work, students earned significantly higher grades in math, even in classrooms that did not endorse innovative curricula. In contrast, students who possess a "fixed mindset," the idea that intelligence is largely innate and cannot be changed, are less likely to take academic risks and display higher levels of anxiety. By shifting students from a fixed mindset to a growth mindset, Blackwell's intervention therefore could also decrease math anxiety levels (though this was not specifically measured in the study).

As discussed earlier, any attempt to remediate math anxiety must address stereotype threat as well. At the classroom level, values affirmation interventions prove promising not only for girls in math and science, but also for other groups under stereotype threat, such as African American students (Miyake et al, 2006; Cohen, Garcia, Apfel, & Master, 2006). Values affirmation interventions ask student to write brief reflections on values that are important to them or define them, such as family or friends, or a specific skill. No content remediation or innovative curriculum is provided. The intervention significantly improves the grades of groups under stereotype threat, even breaking negative trends and beginning students on an upward academic trajectory (Cohen et al, 2006). Self-affirmations take very little time and reduce stress by increasing self-worth, protecting students from ideas that are held about them by others.

One crucial component of all socio-psychological interventions is that students are unaware of the intent of the intervention (Yeager & Walton, 2011). In both of the interventions discussed, the assignment was given as part of an unrelated class, avoiding any association of stigma from "needing an intervention." The psychological burden of social stigma may be one reason why others have found that classroom interventions tend to be ineffective, as discussed earlier. Rather than attributing positive outcomes to the intervention, growth mindset and values affirmation interventions allow students to take credit for their own improvement, further reducing anxiety and increasing a growth mindset.

Resources for counteracting math anxiety

Tobias, S. (1993). Overcoming Math Anxiety. New York: Norton & Company.

Zazlavsky, C. (1999). Fear of Math: How to Get Over It and Get On with Your Life. New Brunswick: Rutgers University Press.

- Model a positive attitude towards math
- Emphasize that everyone makes mistakes, which are just opportunities for learning
- Use varying types of assessment, and do not assess too often
- Use methods that are fun and engage positive emotion, like storytelling and games
- Provide clear goals and feedback
- Offer choices between tasks whenever appropriate
- Scaffold challenge carefully to improve student confidence
- When using social interaction to teach, ensure that it is cooperative, not competitive

Prevention of Math Anxiety Formation

If you are as lucky as to begin with a class full of mathophiles, preventing math anxiety from forming is much easier than remediating it. The first step in prevention is to like math. Teachers who model a positive attitude towards math are much less likely to have classrooms where math anxiety develops (Beilock et al., 2010). As mentioned earlier, since teachers tend to teach as they have been taught, taking classes in innovative methodology and best practices prior to entering the classroom is crucial to the prevention of math anxiety in students. NCTM (2000) suggests the following for prevention of math anxiety in the classroom:

- Remove the importance of ego from classroom practice
- Make mathematics relevant
- Allow for different social approaches to learning mathematics
- Emphasize the importance of original, quality thinking rather than rote manipulation of formulas
- Characterize mathematics as a human endeavor
- Let student share some input into their own evaluations
- Design positive experiences in mathematics classes
- Accommodate for different learning styles
- Emphasize that everyone makes mistakes in mathematics

NCTM also recommends incorporating NCTM standards and state standards for best practices into regular instruction. When assessing students, use different methods of assessment:

observations, questioning, interviews, performance tasks, students self-assessments, work samples, portfolios, writing samples, paper-and-pencil tests, and standardized tests (Furner & Berman, 2003). Moreover, do not overuse assessment. Research suggests that a lower frequency of evaluation combined with more differentiated tasks increases students' self-perceptions of ability (Dweck, 2002).

Emotion in the Classroom

Research by Immordino-Yang and Damasio (2007) shows that emotion plays a critical role in helping students apply the knowledge they learn in school to inform real-world decision making in social contexts throughout their lives. Therefore, educators have a moral imperative to create a positive learning environment. The focus of this handbook has been the understanding and the elimination of math anxiety, a negative emotion. If the key to optimal math learning is the absence of negative emotion, the implication is that positive emotion must be present. It isn't possible to truly divorce learning from any emotions whatsoever (Immordino-Yang & Damasio, 2007), and shared positive emotions can reduce anxiety and create feelings of contentment and collaboration, while shared negative emotions trigger survival mechanisms, flooding the body with adrenaline, so that all prior learning stops (Butterfield, Martin, & Prairie, 2003).

Keeping a positive affective climate in the classroom may avoid affective drop, the discrepancy between math ability and math performance discussed earlier. While little attention has been given to emotions other than anxiety in math research, it is clear that affect plays an important role in math learning. Children are more highly motivated to learn and achieve in math if the activity is affectively rewarding, rather than anxiety inducing (Frenzel, Pekrun, & Goetz, 2007). Teaching math through nontraditional methods such as storytelling (Zazkis & Liljedahl, 2009), playing games, or involving some other social component to math learning

(Prescott, 2001) can help create a positive learning atmosphere in the classroom. Doing so can help change the amount of dopamine, a chemical in the brain associated with reward and pleasure, which can affect storage of new material in long term memory (Frenzel, Pekrun, & Goetz, 2007). It may also help to talk about math anxiety in the classroom. Part of preventing math anxiety is raising awareness of it and creating a safe environment for students to voice their feelings. Furner and Duffy (2002) recommend that math teachers discuss feelings, attitudes, and appreciation for math with students.

Teachers are the best resources for ideas for generating positive emotion in their students, and they can serve as the best researchers, as well. Methodology for creating positive emotions in math class would be a perfect candidate for an action research project. Using the tools given in the appendices combined with math achievement tests can give measureable outcome goals to begin to accrue data surrounding specific methods for decreasing math anxiety and increasing math achievement. In one action research study, sixth-grade teacher Tisa Lach researched using games in math class to effectively improve math understanding and performance. While she did not look specifically at emotional reactions of her students, she does describe effects that go beyond achievement to include increased social competency and motivation (Lach & Sakshaug, 2005). Such studies may prove useful jumping off points for future research in math learning.

Resources for using storytelling in math classrooms

Schiro, M. (2004). Oral Storytelling & Teaching Mathematics. Thousand Oaks, CA: Sage Publications.

Zazkis, R. & Liljedahl, P. (2009). Teaching Mathematics as Storytelling. Rotterdam: Sense Publishers.

"Flowing" Classrooms

Mihalyi Czikszenkmihalyi (1991) describes the experience of individuals who are engaged in an optimal learning experience where concentration is so complete that there is no space left for worries or irrelevant thoughts as being in a state of *flow*. He describes five characteristics of families that raise children who are more able to achieve flow: clarity, centering, choice, commitment, and challenge. The recommendations can be adapted to create a classroom experience that promotes optimal learning and flow. First, clarity: the students know what the teachers expect of them, as goals and feedback are clear and unambiguous. Second, centering: the students perceive that teachers are interested in what and how they are doing in the present rather than preoccupied with future goals, such as standardized tests. Third, choice: students can be provided with a variety of ways to exercise choice, from task type to social partners to math folder color, and clear consequences if they exercise choice unproductively. Fourth, commitment: create an atmosphere of trust to enable the student to set aside her defenses and become unselfconsciously involved in the task at hand. Fifth, challenge: the teacher evinces a dedication to providing increasingly complex opportunities for learning.

In a study on affect in the math classroom, Schweinle, Meyer, and Turner (2006) used methods from flow research to investigate the relationship between positive affect and student motivation in fifth grade math classes. They found that whether or not students believed that they had enough skill to perform the required math tasks was strongly related to positive affect, as was the perception of how important the task was to others. Their data showed that challenge was negatively correlated with students' perception of their ability to succeed, also referred to as efficacy. Flow theory holds that challenge provides an opportunity to learn new skills and enter flow, but in this study, researchers found that was only possible when students perceived the challenge to be well within the reach of their abilities. In-depth investigations of teacher style showed that children were most successful and reported high levels of positive affect when higher levels of challenge were carefully scaffolded, and feedback was “frequent, elaborative, positive, and used to help students develop understanding” (Schweinle, Meyer, & Turner, 2006; p. 288). Moreover, it proved important that social components of the elementary math classroom were cooperative, not competitive, so that students had enough emotional support as well as cognitive support to succeed in math.

While the results of this study are not specific to math anxiety, the authors did find that when classes reported above-average challenge and below-average efficacy, students reported negative affect. In flow theory, this combination is associated with anxiety. This experiment suggests that best practices in teaching that are designed to maximize positive affect may have the extra side effect of reducing anxiety, though further research would be necessary to investigate how math anxiety might potentially interfere with the levels of concentration necessary to achieve flow.

Concluding Remarks

At this time, research in cognitive science has allowed us to begin to come to a strong understanding of math anxiety: what it is, where it comes from, how it affects student learning, and how to remediate it. We also know a lot about best practices in teaching mathematics, and as more and more emphasis is placed on integrating emotion into classroom learning, improvements to math curricula are constant. Of immediate concern is that while the content of many of the current curricula are based on solid research, we also need to research strategies for more effective implementation of the new programs. As we discussed earlier, since students suffering from math anxiety learn best in a structured, expository type of classroom (Norwood, 1994), unfamiliar curricula may inadvertently raise math anxiety levels. We must make sure that implementation is concurrent with efforts to control math anxiety.

Further research is still needed to quantify the effect that harnessing emotion has on math achievement, as a deeper understanding of how a positive emotional climate can help math learning may lead to increasingly effective math curricula. We also need more data surrounding the effect that strategies that promote positive emotion as part of the math curriculum have on the level of student math anxiety. Teachers can contribute to the data pool through action research, as well as by giving voice to their experience in the classroom to provide practical direction for future academic research. If we can find specific ways to teach math that are both more effective for understanding as well as anxiety-reducing, we have the potential to create a generation of children who not only love math but are able to apply it throughout their lives regardless of their ultimate career path.

Appendix A: The MASC (Grades 4-8)

For each item in the list, children should rate the activity according to a 4-point scale in terms of how much anxiety they feel: 4 represents very very nervous, 3 represents very nervous, 2 represents a little bit nervous, and 1 represents not nervous at all. Add the responses together to create a total score for a child's mathematics anxiety level (Chiu & Henry, 1990).

The Mathematics Anxiety Scale for Children:

1. Getting a new math textbook
2. Reading and interpreting graphs or charts
3. Listening to another student explain a math problem
4. Watching a teacher work a mathematics problem on the chalkboard
5. Walking into a math class
6. Looking through the pages in a math book
7. Starting a new chapter in a math book
8. Thinking about math outside of class
9. Picking up a math book to begin working on a homework assignment.
10. Working on a mathematical problem, such as: "If I spend $3.87 at the store, how much change will I get from a $5 bill?"
11. Reading a formula in science
12. Listening to the teacher in a math class.
13. Using the tables in the back of a math book
14. Being told how to interpret mathematics statements
15. Being given a homework assignment of many difficult math problems which is due the next time
16. Thinking about a math test one day before the test
17. Doing a long division problem
18. Taking a quiz in a math class
19. Getting ready to study for a math test
20. Being given a math quiz that you were not told about
21. Waiting to get a math test returned in which you expect to do well
22. Taking an important test in a math class.

Once the MASC has identified math anxious and highly math anxious students, remediation should immediately follow.

Appendix B: The sMARS (Grades 9-12)

The sMARS contains 25 items, each rated on a scale from 1 to 5 for how much anxiety the thought of the item creates in the respondent, where 1 indicates "not at all," 2 indicates "a little," 3 "a fair amount," 4 "much," and 5 "very much." The sum of the item scores provides the total score for level of math anxiety. There are three types of math anxiety examined by the sMARS: math test anxiety (items 1-15), numerical anxiety (items 16-20), and math course anxiety (items 21-25; Alexander & Martray, 1989). Separating the items into the different factors could help teachers to target interventions more appropriately.

1. Studying for a math test
2. Taking the math section of a 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 courses to fulfill requirements
11. Picking up a math textbook to begin a difficult reading assignment
12. Receiving your final math grade
13. Opening a math or statistics 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 a 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 problem 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

It is worth noting that some items may need slight alterations to be applicable to a specific school policy, but that should not alter the general usefulness of the survey.

Appendix C: The Digit Span Test

While digit span is not a reliable tool to assess overall working memory capacity, it can serve as a good estimate of the phonological loop, or verbal working memory, the part of working memory affected by math anxiety. To administer the test, provide a blank piece of paper and a pencil. Ask students to listen for a sequence of numbers, and when the sequence is complete, write down as many as they can remember, in the correct order (Gathercole, Pickering, Ambridge, & Wearing, 2004).

5 8

4 1 5

4 9 6 8

6 1 8 4 3

7 2 4 8 5 6

4 7 3 9 1 2 8

7 2 8 1 9 6 5 3

Sequences are taken from Alamolhodaei (2009).

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