Math Anxiety: Causes and Solutions

A Literature Review

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The Pervasiveness of Math Anxiety

Math anxiety is one of the most common academic issues in the United States. In spite of more than half a century of nonstop policy efforts intended to increase national rates of scientific literacy, American 15 year olds placed 28th in math scores in a field of 71 countries in 2015 (DeSilver, 2017 February 15). Although this dismal statistic raises pressing concerns about our international security and future as a global competitor there are more immediate consequences facing learners and teachers.

There is no universally accepted definition of math anxiety. Vahedi and Farrokhi (2011) define it as "negative cognitions, avoidance behaviors, and feeling pressured and inadequate in performance that combined to interfere with solving math related problems in both general life and academic situations" (p. 362). However, Looney, Perry and Steck (2017) cite other researchers who identify a number of somatic and emotional sensations associated with math anxiety:

> Fears of failure (Liew, Lench, Kao, Yeh, & Kwok, 2014; Peixoto & Almeida, 2010; Wach, Spengler, Gottschling, & Spinath, 2015),
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> Doubt/lack of effort (Hemmings & Kay, 2010; Tobias & Weissbrod, 1980),
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> Tension (Woodard, 2004),
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> Avoidance of math related activities (Chiang, & Lin, 2014; Kelly & Tomhave, 1985; Liew et al., 2014).

According to Andrews and Brown (2015) 71% of Americans cannot calculate gas mileage, 58% cannot figure a tip and 78% do not have the skills to compute loan interest. While STEM bachelor's degrees earned in universities and US colleges rose from 398,602 to 589,330 between 2000 and 2012 this was not enough to satisfy demand for skilled scientists and

engineers. To meet this need the United States relies on foreign workers; in 2008, 38% of workers at the PhD level were immigrants.

According to Giest, (2003a, 2003b), evidence for mathematical learning exists in children only a few months old. Sadly, anxiety associated with math begins soon afterwards. Math anxiety can be measured by the second grade, implying that it begins much sooner than that (Wigfield and Meece, 1988; Jameson, 2014; Geist, 2015). Generally, it gets worse as time goes on, and by the time students enter college it is well established. Several researchers report that as much as 85% of entering college freshmen suffer some degree of math anxiety, (Iossi, 2007; Perry, 2004). Majorities of individuals in the United States fear and dislike mathematics, according to survey results (cited in Ramirez et al., 2013).

Clearly, Americans are woefully unprepared to excel at anything requiring basic math. Daily math challenges like monitoring fuel mileage, determining whether discounts or sales are truly economical, and weighing costs of auto loans and unsecured credit offers are situations in which American consumers can easily make poor and very costly decisions.

Anxiety as a Negative Reinforcer of Avoidance Behaviors

Anxiety associated with math or numbers undoubtedly plays a large role in math related issues. Anxiety is a powerful motivator, but one that is poorly understood. In behavioral terms, anxiety is a negative reinforcer – that is, its removal increases the chance that learners will engage in avoidance behaviors in the future. This idea runs contrary to what we usually believe about avoidance behaviors and leads parents and teachers to unwittingly contribute to anxiety associated with mathematics.

For example, when a long-term drug addict ingests a drug they are not seeking a high, nor are they demonstrating a moral weakness or failure. They are highly anxious about impending

painful withdrawal symptoms and use the drug to avoid the anxiety associated with those symptoms.

The same thing is true of learners who are anxious about mathematics. They avoid math courses to escape the painful anxiety they experience when exposed to numbers, not becasue of laziness or lack of ambition. One of the most common avoidance behaviors is procrastination, but the anxious student does not procrastinate because they enjoy procrastinating; they are simply avoiding the pain of numbers.

Another avoidance behavior is rushing through calculations, leading to errors. In this case the learner is not over confidant or uncaring; they are simply trying to make the pain last as briefly as possible. They are far more motivated to return themselves to a pain free state than they are to a math problem.

Unfortunately, teachers and parents treat these behaviors as if they are acts of non-compliance, rebellion or maliciousness, when they are simply sincere efforts of self-preservation. Learners with math anxiety are not avoiding the math, they are avoiding the anxiety that exposure to it generates. Teachers and parents of learners with math anxiety should treat them with the same sensitivity as they do for people suffering from PTSD or General Anxiety Disorder.

Causes and Results of Math Anxiety

This begs the questions then of what causes math anxiety. This is a two-part question. First, what causes the anxiety related to math, and second, how does state anxiety degrade the ability to perform mathematical equations?

Research on math anxiety tends to ignore causative factors and concentrates instead on environmental correlations such as socio economic status, gender discrimination, and the influence of teachers who also suffer from math anxiety.

However, research on the broader topic of anxiety often includes references to fear. Joseph Ledoux, a long time neuropsychologist and recognized authority on anxiety describes the relationship between fear and anxiety this way:

> Anxiety and fear are closely related. Both are reactions to harmful or potentially harmful situations. Anxiety is usually distinguished from fear by the lack of external stimulus that elicits the reaction. The sight of a snake elicits fear, but the remembrance of some unpleasant experience with a snake or the anticipation that you may encounter a snake are conditions of anxiety. Fear…is related to behavioral acts of escape and avoidance in threatening situations, and when those actions are thwarted, fear becomes anxiety. (LeDoux, 1996, p. 228).

Ledoux goes on to say "…the essence of anxiety is the unpleasant feeling – the apprehension, dread, angst and worry – that one experiences when one perceives a lack of control in situations of uncertainty and risk" (Ledoux, 1996, p.253).

Ledoux's comments bring to mind two related psychological concepts, bullying and learned helplessness. Maier and Seligman (1976) established the construct of learned helplessness in an experiment in which they locked a dog in a cage with an electric grid upon which to stand. Repeated shocks were applied to grid, but there was no way for the dog to escape. Very quickly, the dog accepted the inevitability of the shocks and made no attempt to move off the electric grid, even when there was no barrier to movement. The dog learned it was helpless.

Math anxiety can be considered a form of learned helplessness. There is no way for them to escape the pain of mathematics, so they stoically accept it and endure the unpleasant social and emotional pain until it finally ends. Hackworth (1985) poignantly describes the experience of dogs and learners subjected to the psychological torture of anticipating episodes of unremitting pain with no avenue of escape.

Definitions of both bullying and learned helplessness are met if math learners consistently experience announcements of failure from teachers and parents or social rejection from peers. Both the learner and the dog in the Maier/Seligman experiment share very similar experiences – in both cases they cannot escape and are forced to endure aversive experiences. Both the dog and the learner resign themselves to enduring the suffering until it ends, and have no belief in their ability to change the course of their lives. They both live with Ledoux's "apprehension, dread, angst and worry" of anxiety. This is a good time to recall the findings by Iossi, (2007), and Perry, (2004) that about 85% of entering freshmen report math anxiety.

Gary Namie, of the Workplace Bullying Institute, defines bullying behavior as "…acts of commission or omission manifested as: verbal abuse; behaviors – physical or nonverbal – that are threatening, intimidating or humiliating; exploitation of a vulnerability – physical, social or psychological; or some combination of one or more categories" (Namie, 2011, p.13). Learners with math anxiety always seem to have a vast collection of incidents related to math that are "threatening, intimidating or humiliating" fitting Namie's definition of bullying.

Social Pain and Math Anxiety

Interestingly, non-academic books aimed at helping learners overcome math anxiety are filled with painful anecdotes clearly linking math anxiety with social trauma, such as

embarrassment, humiliation, shame and disgrace (Kogelman and Warren, 1979; Ruedy and Nirenberg, 1990; Arem, 2003; Tobias, 1993; Hackworth, 1992).

The social trauma leading to math anxiety is not just emotional discomfort; our brain processes the pain of social trauma the same way it processes physical pain. Matthew Lieberman is a leading authority on social neuroscience, the study of how the brain processes social interactions. Lieberman contends that the brain processes social pain very much like physical pain. In a fascinating series of fMRI experiments Lieberman finds that the same brain structure involved in processing physical pain, the dACC, also process the pain of social rejection. Incredibly, he found that over the counter pain remedies, (that is, Tylenol), diminishes the sensation of social pain, measured by both subjective reports from participants and the objective measures of activity in the dACC (Lieberman, 2013).

Research indicates that one of the most common sources of math anxiety are teachers themselves. In one sense, math anxiety is contagious – parents and teachers who suffer from math anxiety easily pass it onto their children and students.

For example, Maloney, Ramirez, Gunderson, Levine and Beilock, (2015), found that children of parents suffering from math anxiety also tended to suffer from math anxiety – but only if parents helped the children with their homework. The more the parents helped, the more severe their children's math anxiety became.

Ruff and Boes, (2014) report that more than half of people reporting math anxiety recall it beginning with a hostile or insulting teacher in elementary school. Clearly, insults and hostility are counterproductive in the classroom, however, if half of the people reporting math anxiety also report it beginning with verbal abuse by a teacher it is a common experience.

Positive behaviors of teachers are an important factor in preventing math anxiety. Researchers call this “Instructional Immediacy” and define it behaviorally as “primarily nonverbal, include smiling, eye contact, decreased proximity, use of paralinguistics, open/relaxed posture, and body truncation toward the student.” (Kelly, Rice, Wyatt, Ducking and Denton 2015, p.172). In other words, “instructional immediacy” is simply normal politeness. The troubling aspect of this avenue of research is that behaviors other than those defined as “instructional immediacy” are occurring at all.

Meyers and Rocca, (2001), examined college students perceptions of the effect of verbal abuse and argumentativeness by teachers on classroom climate and student motivation. Not surprisingly, verbal abuse was rated by students as negatively associated with motivation. In other words, when teachers verbally abuse their students the students did not feel encouraged to pursue their academic tasks. That is not especially surprising. The notable aspect of this study, and a very sad one as well, is the ease with which the experimenters were able to find students who self-identify as victims of verbal abuse by teachers.

The power of social experiences cannot be understated when considering the sources of math anxiety. Research supports the contention that simply telling a college student they will be socially isolated later in life has a profound effect on their immediate cognitive abilities.

Baumeister, Twenge and Nuss (2002) gave 40 undergraduates a personality test then randomly told some of the participants that they would likely never marry and would live very solitary lives with few close friends. Following this, all the subjects were given a number of cognitive assessments. The subjects who were told their lives would likely be solitary scored significantly lower on all measures of cognitive performance – IQ, number recall, Graduate Record Examination (GRE) Analytical Section and Nonsense Syllables Recall – than the control

groups who did not receive such messages. Post Hoc tests of treatment effect reveals highly robust scores, indicating that not only did a statistically significant treatment effect take place, but also that the effect was unusually strong.

Looney, Perry, and Steck, (2017) did a qualitative examination of 15 student teachers preparing for their first year of elementary school teaching. They examined the degree to which these aspiring teachers experienced math anxiety and their self-efficacy in the area of mathematics, both of which are associated with student math anxiety. They found the results surprising and cite similar work by Chang (2015) who used a much larger sample to examine the transmission of math anxiety from teachers to students.

> Upon examination of initial math attitudes and beliefs reported by participants within the first week of the course, it became clear that many of the pre-service teachers had a high level of anxiety regarding the subject and a low self-efficacy for completing math problems. The fact that these future teachers had many negative things to say about math, yet will be the very individuals teaching the subject of math to elementary level students is alarming. As previous research evidence has demonstrated, (Chang 2015) the negative attitudes toward math, lack of confidence in their own abilities to do well in math, and the non-efficacious beliefs for teaching math to others will likely aid in the perpetuation of negativity toward math in young students (Looney, Perry, and Steck, 2017, p.35)

Chang (2015) selected 58 elementary school teachers and their 1244 students and administered mathematics efficacy instruments to all of them. The incidence of math anxiety among the teachers was so common and intense that it significantly influenced the scores of math anxiety of the students. Interestingly Chang also found that high self-efficacy among students mediated the effect of the teacher's low efficacy. In other words, students who were

more confidant of their abilities than the teachers were of theirs were not as affected as students who already had low math self-efficacy. It would be interesting to know the extent to which the high efficacy students recognized low efficacy in their teachers.

Effect of Anxiety on Working Memory

Working memory is our ability to hold discrete bits of information in our conscious or short-term memory. Most cognitive researchers believe that we can hold no more than four numerical digits at one time in our working memory. This is why telephone companies present nine digit phone numbers as two groups of three digits and one of four digits, and financial institutions break up account numbers into groups of four. By creating "chunks" of data points, we combine numbers into portions we can keep in our conscious memory (Oakley, 2014).

We use working memory when doing mathematical calculations by holding numbers while we attend to calculations. For example, when multiplying 23 x 2 in our mind we first multiply 2 x 3 and hold the product of 6 in our working memory while we then multiply 2 x 2 for a product of 4, then put the 4 and 6 together for a solution of 46.

Working memory has been described as the "integration, manipulation and temporary storage of information that is relevant to an individual's focus of attention", (Miyake and Shah 1999). Moore, McCauley, Allred, and Ashcraft, (2014), find that individuals reporting high math anxiety have difficulty integrating, manipulating, and temporary storing information when attempting mathematical computations. Math anxiety is both the cause and result of temporary impairment of working memory.

LeDoux (1996) tells us that working memory integrates three general kinds of information. When an induvial encounters a situation – say, opening a math quiz on the computer – working memory holds that visio-spacial image. Simultaneously it seaches long-term

memories of a match for the image. If strong negative emotions are associated with that image the amygdala – the brains fear center – activates. Instantly a number of neurological events occur. Neural circuits to the Executive Functioning area of the brain in the prefrontal cortex are activated and working memory is immediately dedicated to assessing the environment for threats. At the same time, the amygdala sends a signal to the thalamus releasing stress hormones initiating the fight or flight instinct.

The numbers on the computer screen are a "contextualized threat", that is, a conditioned threat that is an abstraction of past trauma. In the case of math anxiety, a contextualized threat is exposure to numbers or formulas associated with long term memories of social trauma. Interestingly, the brain structure most involved with contextualized fear is not the amygdala but rather the hippocampus. The amygdala is like a filter that screens sensory input while the hippocampus is manages long-term storage (Phillips, and LeDoux, 1992; Akirav, Sandi, and Richter-Levin (2001); Medina, Repa, Mauk, and LeDoux (2002); Mattarella-Micke, Mateo, Kozak, Foster, and Beilock, 2011).

The fact that the hippocampus is so central to the issue of contextualized fear is troubling. It implies that math anxiety is a long-term anxiety disorder that is well established and self-sustaining. Temporary deficits in working memory may only the tip of the iceberg of math anxiety – a sign of more serious damage. Other major mental dysfunctions also involve the hippocampus, such as Post Traumatic Stress Disorder (PTSD), Obsessive Compulsive Disorder, (OCD), and Generalized Anxiety Disorder (GAD) (LeDoux 1996). Math anxiety may be far more sophisticated than an inability to calculate arithmetic problems.

Moore, McCauley, Allred, and Ashcraft (2014) capture the relationship between contextualized threat and the tragedy and frustration of math anxiety in this comment:

> Further, it appears that the emotions encountered … almost undoubtedly include years of experience with failure in the domain and the fear of appearing incompetent if performance is being observed by peers or researchers. (p.330)

Appendix -- Pedagogical Interventions

The richest source of classroom interventions for math anxiety is a literature review by Iossi (2013). Here are highlights of her findings:

Curricular Strategies

Retesting.

The knowledge that a test can be re-taken or that low scoring tests will not be counted towards a grade lowers self-reports of test anxiety.

Self-paced learning.

Students with performance orientation, (competing against others or set criteria), do slightly better in self-paced environments, while those with mastery orientation, (learning for the sake of learning), did not. On a related note, learners with mastery orientation suffer less math anxiety and learners whose teachers have a mastery orientation also suffer lower self-reported levels of math anxiety.

Distance Education.

There is evidence that distance education correlates with lowered math anxiety. This is probably because the prospect of humiliation and social ostracism do not exist when the learner is alone in a safe environment. However, avoidance behaviors, such as procrastination, refusal to participate and rushing through calculations to minimize anxiety, become major issues.

Single sex classes.

There is conflicting evidence that women do better in all female classes possibly because they do not feel intimidated by males presumed competence in math. However, this gender difference seems to be declining with the passage of time. A related issue of sexism in which

males are the victim is the heightened expectations placed on men because of their gender. In any case, single sex classrooms are proving to be increasingly ineffective.

Math anxiety courses.

Many colleges and universities have been offering math anxiety developmental courses for many years and it may be beneficial to study their practices and results. Here is a brief list:

University of Florida	Math Conference Group
Butte College	Math 100: Math Without Fear
American River College	Math 10: Developing Confidence in Math
Chabot College	PSCN 4901 : Dealing With Math Anxiety

Instructional Strategies

Manipulatives.

Three-dimensional models that can be manipulated by hand for demonstration by the instructor or hands on use by students have been found to facilitate learning and decrease anxiety in some individuals. This is probably because concrete objects remove the issue of abstraction allowing students to "see" how calculations affect reality. Global and intuitive learners report lowed anxiety levels when using manipulatives to understand abstract concepts.

Technology.

Generally, the use of computers and calculators does not seem effective in reducing math anxiety. However, there is strong evidence that teaching math and Excel simultaneously returns

good results. This may be because Excel features a number of built in math and statistical functions that eliminate the possibility of minor mistakes causing failure.

Self-regulation.

The most powerful self-regulatory counter anxiety technique is simply developing and maintaining a positive attitude. Journaling, positive self-talk, mission and vision statements all contribute to decreases in math anxiety. Having a viable plan containing pragmatic and proven self-regulation techniques in which the student has confidence seems to be a powerful resource.

Non-Instructional Strategies

Relaxation therapy.

There is little evidence that progressive muscle relation results in reduction in math anxiety, but only when it is not offered in the classroom. Dedicated out of classroom instruction in progressive muscle relaxation, however, seems to return positive results. A brief introduction to progressive muscle relaxation in the classroom, followed by practice with digitized relaxation recordings may be an effective avenue.

Psychological interventions.

There is also evidence that therapeutic techniques such as Cognitive Behavioral approaches, systematic desensitization and expectancy control therapy can be effective in reducing math anxiety, but only when they are given in traditional therapeutic settings, and not when they are given to groups in a classroom setting.

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