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Math Anxiety: A Factor in Math Achievement Not to Be Ignored

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Abstract

The United States is currently not producing enough graduates in science, technology, engineering, and math (STEM) fields to meet the demands of a technology-dependent society. Although there are many efforts in place to improve STEM education in the United States, most notably, President Obama's *Educate to Innovate* campaign, these efforts focus mostly on innovating the teaching of math content and less on the role of affective factors in math achievement. Here we discuss a phenomenon known as math anxiety (i.e., negative feelings of tension and fear that many people experience when engaging in math) and the implications math anxiety carries for math success and STEM engagement. We begin by highlighting the most recent findings from research in psychology, education, and neuroscience on math anxiety. We then discuss the consequences of math anxiety as well as likely causes and promising remediations. We suggest that the initiatives currently underway to improve STEM involvement and achievement would benefit from educating current and future teachers, parents, and even students about math anxiety, its causes, consequences, and possibilities for amelioration.

Keywords

math anxiety, math achievement, STEM involvement, STEM success, policy recommendations

Tweet

To increase students' interest in STEM, we have to address their "fear of math."

Key Points

- The United States is not currently producing enough graduates to work in STEM fields.
- Current initiatives largely ignore the widespread phenomenon of math anxiety.
- Math anxiety negatively impacts interest in and performance in math.
- Research in psychology and education has uncovered techniques that reduce math anxiety and increase math performance.
- Policymakers and curriculum designers are urged to consider math anxiety research when designing and implementing programs aimed at increasing the number of STEM teachers in the United States and the number of students interested in STEM careers.

Introduction

> One of the things that I've been focused on as President is how we create an all-hands-on-deck approach to science, technology, engineering, and math . . . We need to make this a priority to train an army of new teachers in these subject areas, and to make sure that all of us as a country are lifting up these subjects for the respect that they deserve.
>
> —President Barack Obama, Third Annual White House Science Fair, April 2013

The importance of a strong science and technology workforce cannot be over stated. Indeed in their Executive Report, the President's Council of Advisors on Science and Technology state the following:

> The success of the United States in the 21st century—its wealth and welfare—will depend on the ideas and skills of its population. These have always been the Nation's most important assets. As the world becomes increasingly technological, the value of these national assets will be determined in no small measure by the effectiveness of science, technology, engineering, and mathematics (STEM) education in the United States. STEM education will determine whether the United States will remain

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> a leader among nations and whether we will be able to solve immense challenges in such areas as energy, health, environmental protection, and national security. It will help produce the capable and flexible workforce needed to compete in a global marketplace. It will ensure our society continues to make fundamental discoveries and to advance our understanding of ourselves, our planet, and the universe. It will generate the scientists, technologists, engineers, and mathematicians who will create the new ideas, new products, and entirely new industries of the 21st century. It will provide the technical skills and quantitative literacy needed for individuals to earn livable wages and make better decisions for themselves, their families, and their communities. And it will strengthen our democracy by preparing all citizens to make informed choices in an increasingly technological world.

Unfortunately, the United States is currently facing what many have deemed a “STEM crisis”—not producing enough graduates to work in STEM fields. Although many efforts are in place to improve math education in the United States, efforts that focus solely on the role of cognitive factors (e.g., increasing math requirements, developing novel teaching strategies) are overlooking the very important role that the social and emotional factors play in math achievement. Improving the math content that we teach only addresses part of the issue at hand, we also need to address affective factors, such as math anxiety, that are known to affect math learning, math performance, and interest in pursuing STEM majors and careers. In this article, we outline the current state of the field of math anxiety research, unpack the impact that math anxiety has on math achievement, provide the latest insights into what causes math anxiety, and what we can do to reduce math anxiety’s negative impact on math achievement and participation in STEM.

Math Anxiety

Many people experience a genuine fear of math. Not only do they become nervous when engaging in math tasks, they also avoid math and math-related professions, severely limiting their future career and earning opportunities (Hembree, 1990; Chipman, Krantz, & Silver, 1992). The resulting scarcity of skilled STEM workers has negative consequences at the national level, particularity as our society becomes increasingly dependent upon technology (Chipman et al., 1992). Those individuals who experience fear and apprehension when faced with the prospect of doing math are said to have “math anxiety” (Richardson & Suinn, 1972). While it may not be surprising that many people experience anxiety in high-pressure math testing situations (e.g., the math section of the SAT or the GRE), many people also experience anxiety even when engaging in mundane everyday math tasks like calculating a tip at a restaurant or deciding whether or not they received the proper change at the grocery store (e.g., Maloney & Beilock, 2012). In fact, for some people, their levels of math anxiety are so high that they become nervous even simply reading aloud mathematical equations (Ashcraft & Moore, 2009).

Feelings of math anxiety are widespread. In the United States, an estimated 25% of 4-year college students and up to 80% of community college students suffer from a moderate to high degree of math anxiety (Beilock & Willingham, 2014) and worldwide, increased math anxiety is linked to decreased math achievement (Lee, 2009). This decreased math performance is not limited to academic situations. Math anxiety is also related to poor drug calculations among nurses (McMullan, Jones, & Lea, 2012), reduced teaching self-efficacy among teachers (Swars, Daane, & Giesen, 2006), and impaired financial planning (McKenna & Nickols, 1988), meaning that, even outside of academics, math anxiety can have large and detrimental consequences in people’s daily lives.

How Math Anxiety Impacts Math Achievement

Math anxiety is not simply a proxy for low math ability—meaning that when people have poor math skills they feel anxious about them (Ashcraft & Kirk, 2001; Hembree, 1990). Rather, when math-anxious individuals are faced with a math task, they experience worries—often about performing poorly on the math task—and these worries tie up valuable thinking and reasoning resources needed for the task at hand. Specifically, these worries tie up working memory resources (Ashcraft & Kirk, 2001), our “mental scratchpad” that allows us to “work” with whatever information is held in consciousness (Beilock, 2010). Working memory is a limited capacity system that integrates, computes, stores, and manipulates the information to which a person is attending (Baddeley, 2000; Engle, 2002; Miyake & Shah, 1999). Because higher-math-anxious people are essentially doing two things at once when they do math (i.e., attending to their worries and doing the math), their math performance suffers. In this respect, math anxiety itself actually *causes* people to perform worse in mathematics than their abilities warrant.

Neuroscientific data, in which functional magnetic resonance imaging (fMRI) was used to examine differences in brain activation between higher- and lower-math-anxious children while they performed math questions, provide initial support for the idea that math anxiety disrupts working memory resources important for success on the math task at hand (Young, Wu, & Menon, 2012). When engaging in math, not only do higher-math-anxious students show more activation in brain regions that are associated with processing negative emotions (i.e., the amygdala), they also show less activation in brain regions associated with working memory (i.e., the dorsolateral prefrontal cortex and the posterior parietal lobe) and optimal math performance.

It is important to note that disruption of working memory processes is not the only link between math anxiety and poor math performance. Math anxiety also causes students to avoid math, math classes, and math-related careers (Hembree, 1990), and this avoidance undoubtedly impairs math achievement. After all, it is difficult for someone to hone their math skills if they avoid engaging in mathematical processing. As such, students can enter into a vicious cycle in which their anxiety causes them to perform worse in mathematics, and, as a result, they avoid mathematics and opportunities to improve their skills.

Understanding the mechanisms by which math anxiety causes poor math performance is critical in creating effective interventions aimed at reducing the negative impact of math anxiety on math achievement. It is also important to understand why math anxiety arises in the first place. Although there is not yet an agreed-upon model of what causes math anxiety per se, research within the last 10 years has led to many compelling findings which, taken together, are beginning to unearth a developmental trajectory for the math anxiety–math achievement relation.

The Causes of Math Anxiety

Math anxiety is a multifaceted phenomenon that arises due to a combination of cognitive predispositions, as well as exposure to negative attitudes about mathematics (e.g., Maloney & Beilock, 2012; Wang et al., 2014). Importantly, the foundations for math anxiety are likely laid early in children's learning (most likely even before formal schooling).

In the United States, children as young as first grade report varying levels of math anxiety, which is linked to decreased math achievement (Ramirez, Gunderson, Levine, & Beilock, 2013; Maloney, Ramirez, Gunderson, Levine, & Beilock, 2015; Young et al., 2012). Math anxiety appears to increase across development until it peaks at about ninth or tenth grade and then plateaus thereafter (Hembree, 1990), persisting into older adulthood (Donelle, Hoffman-Goetz, & Arocha, 2007).

Cognitive Predisposition to Math Anxiety

In a series of studies with adults, Maloney and colleagues have shown that higher-math-anxious individuals may not represent or process numbers in the same way as their lower-math-anxious counterparts. For example, Maloney, Risko, Ansari, and Fugelsang (2010) presented higher- and lower-math-anxious undergraduates with a display containing from one to nine squares, with participants being asked to identify the number of squares on the screen. While participants were instructed to be as fast and accurate as possible, they were under no specific time pressure. When asked to enumerate the number of squares, higher- and lower-math-anxious individuals performed equally well when one to four squares were presented, but when there were five or more squares on the screen, the higher-math-anxious adults were slower and less accurate at counting the squares, making errors on as many as 15% of the trials when nine squares were presented. One important difference between enumerating objects within the one to four range (called subitizing) and the 5+ range (called counting) is that we do not have to count small numbers of objects—rather when we look at a set of three squares, we simply "know" that there are three (Trick & Pylyshyn, 1993). However, when there are five or more squares, we usually have to count each object to know how many there are. Higher-math-anxious adults have difficulties counting simple objects. Counting is believed to be a foundational skill upon which higher level math is based (e.g., Geary, 1993; Gelman & Gallistel, 1978), meaning that individuals who do not master counting also experience difficulty with more complex mathematics (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004).

As it happens, higher-math-anxious individuals not only have difficulties counting, they also perform worse than their less anxious counterparts when they simply have to compare the magnitude or size of two numbers. Numerical magnitudes are thought to be represented mentally on an internal mental number line (somewhat like a ruler). This mental number line is believed to drive our "number sense," the ability to efficiently process magnitude (Dehaene, 2011). Each number is thought to hold a specific place on the number line and share representational features with the numbers close to it. In other words, "2," "3," and "7" have distinct representations on the number line but "2" and "3" are more similar to each other than "2" is to "7," for example.

The most commonly used task for assessing the precision of one's mental number line is the numerical comparison task. In this task, participants may see one number (e.g., 4) and be asked whether that number is smaller than or larger than a standard (e.g., 5), or participants may see two simultaneously presented numbers (e.g., 3 and 7) and be asked to say which is the larger number. Although there are different variants of the task, they all yield a similar pattern of results. This pattern is known as the numerical distance effect, which refers to the fact that people are faster and more accurate at indicating which of two numbers is larger when the numerical distance separating the two numbers is relatively large (e.g., 2 vs. 7), compared with when it is relatively small (e.g., 8 vs. 7; Dehaene, Dupoux, & Mehler, 1990; Moyer & Landauer, 1967). Recall that if we think of the mental number line as being akin to a ruler in our minds, then the closer two numbers are on that ruler (e.g., 2 and 3) the harder they are to tell apart.

Importantly, there are individual differences in people's ability to compare numbers, and these individual differences are thought to index the precision of one's mental number line (e.g., Holloway & Ansari, 2008). Specifically, when people have a relatively small numerical distance effect (i.e., they are comparably quick when it comes to comparing both far and close number pairs), this is thought to reflect a very precise mental number line. Conversely, if people have a large numerical distance effect (i.e., they struggle with comparing close numbers relative to far numbers), this is thought to reflect a non-precise mental number line (Holloway & Ansari, 2009).

Just like counting, number comparison is a core numerical skill, and one's ability to compare two numbers serves as a building block for more complex math. People with a larger numerical distance effect (i.e., those with less precise representation of number) tend to have poorer fluency in mathematics (Holloway & Ansari, 2009; Mundy & Gilmore, 2009), and accuracy and speed of number comparison predict future math achievement.

Maloney, Ansari, and Fugelsang (2011) looked at numerical comparison ability in lower- and higher-math-anxious adults. Higher-math-anxious individuals exhibited a larger numerical distance effect than their lower-math-anxious peers, both when comparing one number to a standard and when comparing two simultaneously presented numbers, suggesting that higher-math-anxious adults have less precise representations of numbers (i.e., a "fuzzier" number line) than their lower-math-anxious peers.

Another skill foundational for math is spatial ability, or skill in representing and transforming symbolic, non-linguistic information (Gardner, 1983). Given the abovementioned relations between math anxiety and counting and number comparison, Maloney and colleagues also wondered whether math anxiety is related to spatial ability. Although spatial processing is indeed a positive predictor of math achievement (e.g., Gunderson, Ramirez, Beilock, & Levine, 2012; Uttal et al., 2012), spatial processing is not inherently numerical and certainly does not "feel" like math. Current research suggests that a deficit in spatial ability could easily lead to difficulties with math. For example, Rotzer et al. (2009) argued that poor spatial working memory processes may inhibit the formation of spatial–number representations (i.e., the mental number line) in addition to the storage and retrieval of arithmetic facts which form the basis for complex math. In a similar vein, Assel, Landry, Swank, Smith, and Steelman (2003) argued that children, when first learning to count, often use arrays of objects to represent the cardinal value of the sets to be counted. These spatial representations of the counting task help children to regulate their counting (e.g., keep track of the number of items they have already counted and the items yet to be counted). Thus, difficulties with spatial processing could lead to difficulties with counting, which would lead to further problems down the line (i.e., in more complex mathematics). If higher-math-anxious individuals perform more poorly on spatial tasks, then this finding would lend support to the idea that difficulties in spatial processing may precede the development of math anxiety.

To assess whether a link exists between math anxiety and spatial ability, Maloney, Waechter, Risko, and Fugelsang (2012) asked undergraduates and members of the general population to indicate both their level of math anxiety and how skilled they believed themselves to be at spatial processing. Math anxiety was negatively related to perceived spatial ability. In a follow-up study, Ferguson, Maloney, Fugelsang, and Risko (2015) showed that not only do higher-math-anxious adults believe that they are less skilled at spatial processing, they indeed performed worse than their lower-math-anxious peers on multiple tests of spatial ability.

In sum, higher-math-anxious adults struggle on tasks that assess their counting ability, number representation, and spatial ability, which suggests that math anxiety is related, at least in part, to problems in the basic building blocks of complex math. The logic is as follows: if higher-math-anxious adults also had difficulties with the foundational skills when they were children, and because these building blocks provide the foundations upon which more complex math is built (e.g., if you have trouble counting then you will have trouble adding), then adults with high levels of math anxiety are likely to have started school with difficulties in basic math skills. Maloney and Beilock (2012) proposed that if children begin formal schooling with difficulties in math, then their struggling with math will likely cause them to become anxious about math, avoid further math learning, become more anxious, and so on. A vicious cycle emerges.

Exposure to Negative Attitudes About Mathematics

Although people may be cognitively predisposed to develop math anxiety, there is undoubtedly a social factor as well. Perhaps the most compelling evidence that math anxiety can be transmitted socially comes from new research by Maloney et al. (2015), in which they assessed the impact of parents' math anxiety on their children's math anxiety and math achievement. First- and second-grade children's math anxiety and math achievement were assessed at the beginning and end of one academic year. Parents' math anxiety and frequency of homework help were also assessed. When parents were higher in math anxiety, their children both increased in their own math anxiety and learned less math across the school-year, but, this was only true when the higher-math-anxious parents frequently helped their children with math homework. Importantly, there was little negative effect of parent's math anxiety when the higher-math-anxious parents simply did not help their children with their homework often. Thus, when higher-math-anxious parents frequently help their children with math homework, their help can backfire, leading to increased math anxiety and decreased math learning in their children.

Frequent help with homework may provide opportunities for the higher-math-anxious parents to express to their children their own dislike of and frustration with math and/or confusion about the math itself. These interactions may be demotivating to children, likely reducing the amount of effort children invest in math and the amount of math they learn. And, when children learn less math, they may then become more math anxious.

Parents are not the only academic role models. When early elementary school teachers are higher in math anxiety, this can negatively affect students. Beilock, Gunderson, Ramirez, and Levine (2010) assessed the math anxiety of first- and second-grade teachers and the math achievement and attitudes of their students at the beginning and end of the school year. When female elementary school teachers (note that more than 90% of early elementary school teachers in the United States are female; National Education Association, 2001) are higher in math anxiety, their female students not only learn less math across the school-year but they also come to endorse negative stereotypes about girls and math, believing that boys are better than girls at math. Although Beilock et al. (2010) did not report on whether teacher's anxiety affected the anxiety levels of the students, negative attitudes about math (e.g., endorsing gender stereotypes) are related to math anxiety (Hembree, 1990).

Given the findings that higher-math-anxious adults perform worse than their lower-math-anxious peers on tasks assessing the foundational skills upon which more complex math is built (e.g., counting, number representation, spatial processing), and the negative relation between the math anxiety of role models (i.e., parents and teachers) on children's own math anxiety and math attitudes, Maloney and Beilock (2012) proposed that children who start formal schooling having difficulty with the basic building blocks of math may be especially predisposed to pick up on negative social cues and stereotypes from their adult role models that highlight math in negative terms. The difficulties with mathematics, coupled with exposure to negative social cues about math, likely lead to math anxiety.

Math anxiety is related to a host of negative outcomes, including poor math performance, poor math attitudes, and avoidance of math and STEM careers. However, because of our thorough understanding of the mechanisms by which math anxiety affects math performance, and our emerging understanding of the antecedents of math anxiety, many promising new empirically grounded interventions have arisen that serve to either reduce math anxiety or to sever the link between math anxiety and math achievement.

What Can We Do to Reduce Math Anxiety and Sever the Link Between Math Anxiety and Math Achievement?

Because at least part of the negative math anxiety–math performance relation is thought to be caused by worries that disrupt thinking and reasoning resources available for the math task at hand, it follows that reducing the worries (or the negative consequence of these worries) might lead to an instantaneous boost in high-math-anxious individuals' math performance. This is exactly what Park, Ramirez, and Beilock (2014) showed when they employed an expressive writing technique aimed at reducing the number of intrusive thoughts that are experienced while one is anxious (Klein & Boals, 2001). Specifically, adults completed tests of math ability before and after an expressive writing exercise in which they wrote openly for 5 to 10 min about their feelings regarding the upcoming math test. Importantly, the expressive writing led to an increase in the math performance of the most math-anxious individuals. Although we do not want to suggest that a simple writing exercise can undo damage caused by years of avoiding math, it can certainly help highly anxious individuals perform at a level closer to their actual abilities.

One reason that expressive writing may be effective is because it provides individuals with the opportunity to reappraise a potentially negative situation—for example, a math test (Ramirez & Beilock, 2011). When we view an anxiety-inducing situation as a threat, we tend to underperform relative to our abilities. Conversely, if we view that same situation as a challenge, then we tend to perform better (Jamieson, Mendes, & Nock, 2013; Maloney, Sattizahn, & Beilock, 2014). Expressive writing may help anxious individuals to reappraise their view of the upcoming math task—seeing it as an energizing challenge rather than as a demotivating threat. Consistent with this claim, Ramirez and Beilock (2011), who employed the expressive writing technique with test-anxious students, found that students whose writing showed more evidence of reappraising the upcoming test as a challenge showed the greatest benefit of writing.

Further support for the benefit of reappraisal in combatting the negative effects of math anxiety comes from work by Lyons and Beilock (2012) who used brain imaging (specifically fMRI) to investigate neural underpinnings of math anxiety. Lower- and higher-math-anxious participants performed a mental arithmetic task and a difficulty matched word-verification task while in the brain scanner. Overall, lower-math-anxious participants outperformed the higher-math-anxious participants on the math task, but both groups performed equally well on the word task. Importantly, however, not all of the higher-math-anxious participants performed poorly on the math task. And, looking specifically at neural activation when people were just anticipating an upcoming math task sheds light on how some high-math-anxious individuals were able to break the all-too-common math anxiety–math performance link.

In Lyons and Beilock's (2012) experiment, before each set of problems, participants saw a cue (a colored box) that indicated whether the next set of trials was going to be a math set or a word set. When anticipating the math problems, a subset of the higher-math-anxious individuals showed increased activation of a frontoparietal network including the inferior frontal junction (IFJ), the inferior parietal lobule (IPL), and the left inferior frontal gyrus (IFGa). Importantly, this network is known to be involved in the control and reappraisal of negative emotions (e.g., anxiety and worry; Ochsner et al., 2004). Among higher-math-anxious individuals, the activation of these regions during the math cue actually predicted the activation of two subcortical regions while performing the math task (right caudate nucleus and the left hippocampus). These subcortical regions are important for coordinating task demands and motivational factors during skill execution. And, the more that higher-math-anxious individuals activated these subcortical regions during the task, the better they performed on the task. These findings tentatively suggest that higher-math-anxious participants who were more likely to reappraise the upcoming math task as a challenge rather than as a threat were better able to control their anxiety during the task and manage the demands of math performance. The end result was that these high-math-anxious individuals performed up to their potential. Reappraisal can easily be taught to students (Jamieson, Mendes, Blackstock, & Schmader, 2010), suggesting that it is a promising pathway by which to combat the negative consequences of math anxiety.

While reappraisal targets the cognitive consequences of math anxiety, other techniques are being investigated that aim to reduce some of the physiological arousal that results from math anxiety (for more on physiological arousal and math anxiety, see Maloney et al., 2014). For example, breathing techniques have been shown to have excellent prospects for reducing the negative consequences of anxiety. Higher-math-anxious participants who were given a focused breathing exercise prior to completing a math task showed a greater increase in math performance when compared with higher-math-anxious individuals who received either an unstructured breathing exercise or an exercise meant to exacerbate their worries (Brunyé et al., 2013).

Although the methods discussed above may prove beneficial in reducing the negative impact of math anxiety on math performance, they are unlikely to prevent the development of math anxiety in the first place. Fortunately, there are simple and low-cost strategies that can be taught to parents and educators that may help prevent children from ever becoming anxious about math. For example, if poor numerical and spatial abilities are a precurser to math anxiety (Maloney & Beilock, 2012), then interventions aimed at bolstering the numerical and spatial skills of children may serve to inoculate them against developing math anxiety. Fortunately, very simple at-home or in-the-classroom interventions may help to improve number and spatial skills. For example, simply having parents and teachers engage in more number-talk and spatial-talk (e.g., counting objects in the house, using words like “curvy” and “angle” when talking about puzzles) with their young children/students may help these children to develop strong foundational number and spatial competencies (Gunderson & Levine, 2011; Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010). Encouraging children to play more frequently with puzzles and blocks may also help to improve their spatial skills (Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005).

Because higher-math-anxious parents can transmit their anxiety to their young children when they frequently help with math homework (Maloney et al., 2015), scaffolding parents homework help with tools such as math worksheets and apps may allow higher-math-anxious parents to provide better math input at home. Preliminary evidence from an intervention using an iPad application in which parents work through math questions with their children on a regular basis has shown that, with proper scaffolding, parents’ math anxiety has less of a negative effect on their children’s math outcomes than what it has otherwise (Berkowitz et al., under review).

In terms of combatting teachers’ math anxiety, research shows that when teaching pre-service teachers, the manner in which the math content is framed can have a marked effect on the math anxiety of the pre-service teachers at the conclusion of the course. Courses geared at teaching how children learn mathematical concepts (i.e., framing the material as “This is how children learn X”) leads to a decrease in pre-service teachers’ math anxiety over the course of the semester, whereas courses geared at teaching the same concepts (i.e., framing the material as “X is what you need to learn”) does not lead to improvements in pre-service teachers’ math anxiety (Tooke & Lindstrom, 1998). This subtle difference in framing could have widespread consequences, given the negative impact of teachers’ math anxiety on their student’s math outcomes (Beilock et al., 2010).

Relation to Policy

Today, U.S. students are ranked 20th and 27th among their peers throughout the world in science and math, respectively (PISA, 2012). In a large-scale attempt to elevate U.S. students to the top of the pack, President Obama launched the *Educate to Innovate* initiative in 2009, which has provided billions of dollars in additional federal funding for STEM education programs across the country. Although this campaign, by several standards, has been highly effective, we believe that more can be done. Specifically, we believe that particular elements of the initiative can be enhanced by leveraging the research on math anxiety and incorporating a rich discussion of the role of negative affect in creating a barrier to entry into STEM fields. Below we discuss specific components of the Educate to Innovate plan (namely the 100Kin10, which is an initiative aimed at training 100,000 new STEM teachers in 10 years, and the Educate to Innovate’s overarching goal of bolstering interest in STEM fields) and detail how research on math anxiety can be used to enhance the positive effects that this initiative is already having.

Research on Math Anxiety Can Enhance the 100Kin10 Initiative

In response to concerns about a lack of STEM workers, President Obama called for 100,000 new STEM teachers in 10 years, resulting in the creation of 100Kin10 in June 2011. Many U.S. institutions that offer training to pre-service teachers have answered this call by increasing spots for students in the STEM-educator training programs. However, because math anxiety can begin as early as first grade (Ramirez et al., 2013; Maloney et al., 2015), we believe that all teacher education programs in which there is a STEM component (i.e., elementary educator programs as well as STEM-specific educator programs) should include lessons on math anxiety, informing future teachers that success in mathematics requires not only knowledge of mathematical concepts but also the right mind-set. Importantly, because many negative math attitudes develop when children are young, it is important to educate not only the pre-service STEM teachers about math anxiety but also the pre-service early elementary educators, who often serve as children's first formal exposure to science and math concepts. As such, we urge policymakers and curriculum designers to consider formally educating all pre-service teachers in programs in which there is a STEM component, on the evidence-based practices that are known to reduce math anxiety and/or its relation to math achievement. By bringing math anxiety into the forefront of the minds of STEM educators, they will be well-equipped to address (and ideally eliminate) math anxiety in their students when they encounter it.

Creating New Professional Development Courses for Established Teachers

While there is undoubtedly a benefit to educating pre-service teachers about the negative role of math anxiety in STEM education, there are many already established teachers who encounter math anxiety in their students on a daily basis. As such, we recommend creating professional development courses aimed at educating these already established teachers about the research on math anxiety—what it is, how to spot it in students, and what to do to combat its negative effects. We hope that by informing teachers about the evidence-based practices that help to improve math performance in highly anxious students, we can increase the math achievement of the nations' students overall.

Increase Focus on Decreasing Anxiety Not Just Increasing Interest

Many elements of the Educate to Innovate campaign focus on increasing interest in STEM fields. For example, for the last 5 years, President Obama and the White House have hosted the "White House Science Fair." This event features innovative projects, designs, and experiments from elementary and high-school students across the United States, with the 2015 Fair including a specific focus on girls and women who are excelling in STEM. The aim is that the Fair, which is highly publicized, will inspire other young students to become interested in STEM fields. However, events such as these are unlikely to inspire children who have already developed a strong sense of anxiety about math; rather, these events more likely serve to heighten motivation in those students who already enjoy science and math. While we certainly feel that increasing motivation in the already top-performing STEM students is an important piece of the puzzle, it may fall short on inspiring those who already experience a great deal of negative affect regarding mathematics. In addition to events such as the Science Fair, the Educate to Innovate campaign would be well suited to hold similar, high-profile, events that serve to encourage students who are anxious about math and insecure about their math abilities to become interested in and pursue STEM courses and careers.

Conclusion

We believe that the strongest contribution of math anxiety research to public policy is an understanding that success in mathematics requires not only knowledge of mathematical concepts but also the right mind-set. When students are anxious about math, they typically perform at a level that is below that of their actual abilities. Their math anxiety not only causes them to underperform in math but also to avoid math and math-related careers, resulting in fewer professionals trained in STEM disciplines. We urge policymakers to consider affective factors, such as math anxiety, when designing programs aimed at increasing the size of the STEM workforce. By educating the pre-service and already established teachers—who can, in turn, educate their students and their parents—on the negative role of math anxiety in math achievement as well as how to reduce the negative consequences of math anxiety, and by creating programs designed to encourage highly math-anxious students in math, we will make strides toward creating a stronger STEM workforce, and ultimately, a workforce that is better prepared to meet the technological demands of the 21st century.

Authors' Note

Both authors contributed equally.

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