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Reflections on mathematics ability, anxiety, and interventions

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ABSTRACT

Competency in mathematics is needed to respond to the vast employment opportunities available in the STEM sectors. These employment opportunities all require basic foundational mathematics skills, yet there is a shortfall of mathematics abilities due, in-part, to mathematics anxiety. Mathematics anxiety can surface as fear and avoidance of mathematics and has been linked to low mathematics performance and ability (Ashcraft, 2002; Luttenberger et al., 2018). This thought paper (Snell, n.d.), paper begins with a synthesis of research on mathematics anxiety including the known causal factors: cognitive/affective, social, and genetic as well as the recently proposed causal factor, missed opportunity (Brewster & Miller, 2020). Missed opportunity refers to cases where an individual who is capable academically to comprehend mathematics but has missed the opportunity to learn basic foundational skills in mathematics. Missing the opportunity to learn foundational concepts in mathematics places great stress, which can result in feelings of anxiety. Next, a synthesis of interventions for mathematics anxiety such as mindfulness exercises (Brunyé et al., 2013) and expressive writing (Brewster & Miller, 2022; Park et al., 2014) are discussed, which led to the realization that interventions are more complex than previously reported given that other factors can affect interventions such as duration of writing, quality of instruction, or additional stressors causing anxiety, including test anxiety. Knowing the causal factors influencing an individual's mathematics anxiety may prove beneficial to designing more focused and influential interventions.

Keywords: mathematics anxiety, expressive writing, STEM

INTRODUCTION

Throughout the 21st century, mathematics has been and will continue to play a vital role in the lives and workplace of all citizens. Some may argue that the development of user-friendly interfaces for cell phones and tablets has replaced the need for an understanding of basic level mathematics, but this is not the case given that people still require an understanding of quantity among other basic mathematics skills. For example, many people have difficulty identifying whether 0.025 is larger or smaller than 0.25 (Van de Walle et al., 2018). This might seem like an insignificant problem but numeracy errors of 10 or 100-fold by misplacing a decimal can have dire consequences. In the case of medicine, Lesar (1998) acknowledged that calculation errors in prescribing medications is a well-known problem in the field of medicine. More pointedly, he indicated that the errors were the result of incorrect decimal point placements and mathematical calculations. Another case highlighting the severity of poor mathematics skills is drawn from a Norwegian study that involved reviewing a data base of medical incidents where they found 100 numeracy related errors in a one-year span (Mulac et al., 2021). These are only two examples of basic numeracy errors and their consequences in medicine but many, and possibly most, other occupations require some level of basic numeracy and are also likely to experience problems due to errors in numeracy.

The science, technology, engineering, and mathematics (STEM) occupations all require more than basic skills in mathematics. Johnson (2010), a NASA scientist, exemplified the significance of mathematics in these careers with "we will always have STEM with us. Some things will drop out of the public eye and will go away, but there will always be science, engineering, and technology. And there will always be mathematics". Johnson (2010) underscored the significance of mathematics similar to the work of Brewster and Miller (2022) who also recognized the role of mathematics in the STEM fields. Thus, it is reasonable to conclude that mathematics plays a significant role in society and individuals' careers, and therefore the shortfall in mathematics ability reported by Stokke's (2015) and others (Jarvis et al., 2015; Wu, 2009), is a paramount issue that affects the well-being of today's society and will greatly impact the extent to which these disciplines will advance. Even more alarming is the recent release of the national assessment education progress (NAEP) measuring mathematics ability of nine-year-olds, which indicated an even greater decline in mathematics ability as a result of the pandemic (Mervosh, 2022).

We have underscored the significance of mathematics in society while at the same time recognized the challenges individuals have experienced in doing foundational mathematics, which, for many, has been attributed to mathematics anxiety (Ashcraft &

Kirk, 2001; Beilock & Willingham, 2014; Johnson-Wilder et al., 2014; OECD, 2013). As noted by Kusmaryono et al. (2022), mathematics anxiety affects student achievement whereby an increase in mathematics anxiety correlates to a decrease in mathematics achievement. A decrease in student achievement can subsequently present barriers to learning more advanced mathematics and entering the STEM careers. It is important to also note that low levels of mathematics anxiety do not habitually correlate to a decrease in achievement (Altakhayneh, 2020).

Hence the purpose of this paper was to review and synthesize literature focusing on the causal factors influencing mathematics anxiety as well as focus on the interventions to address mathematics anxiety (Brewster, 2022; Brewster & Miller, 2022; Hines, 2011; Park et al., 2014). All publications in English that focused on mathematics anxiety spanning all grade levels (i.e., kindergarten to grade 12 and post-secondary education) were included in the search. OneSearch, Google Scholar, and the Thesis and Dissertation databases were searched for articles that focused on describing and identifying causal factors of mathematics anxiety and the impact of interventions on reducing mathematics anxiety. This analysis highlighted the complexity of mathematics anxiety as well as the impact interventions can have on reducing mathematics anxiety. Given this complexity and the need to advance interventions for mathematics anxiety, we prepared this paper in the form of a thought paper (Snell, n.d.), which allowed us to present a brief but concise summary of key literature but to also present our insights and argument on refining interventions for mathematics anxiety.

CAUSAL FACTORS INFLUENCING MATHEMATICS ANXIETY

Mathematics anxiety has been studied since the 1950's (Dreger & Aiken, 1957), however, the impetus to increase the focus of research resources in this area, became more prominent in the 21st century as STEM employment necessitated the requirement for strong mathematics skills. Although research in this field has continued, there has been an absence of understanding of the factors that contribute to the deficit in mathematics ability, including mathematics anxiety, as well as interventions to alleviate its negative effects on mathematics learning, and future STEM careers.

Previously documented causal factors included: cognitive/affective (Suárez-Pellicioni et al., 2016), social (Jakobsson et al., 2013; Luttenberger et al., 2018), and genetic factors (Wang et al., 2014). Cognitive/affective factor refers to the interconnection between the working memory, the cognitive dimension and the affective or emotional dimension of an individual's mental state. When an individual experiences anxiety or worry over mathematics resulting in mathematics anxiety, the individual's working memory becomes limited as a result of the mathematics anxiety (Ashcraft, 2002; Ma & Xu, 2004; Maloney & Beilock, 2012). Whereas the social factor describes the societal beliefs, gender stereotypes, and cultural influences that impact the level of mathematics anxiety in our society (Foley et al., 2017; Jakobsson et al., 2013). The genetic factor refers to the individual's genetic make-up, which may elevate their susceptibility to having mathematics anxiety, although much research is still needed to substantiate this factor (Wang et al., 2014).

A causal factor not considered in this early body of research was posited by Brewster and Miller (2020), which focused on anxiety caused by or created when individuals miss the opportunity to learn mathematics. Missing the opportunity to learn mathematics can be attributed to many reasons such as being absent from school or poor-quality instruction where a teacher, for example, relies on teaching students an algorithmic approach such as when you multiply two negatives, the answer is a positive. Instead, a teacher skilled in mathematics pedagogy would introduce the concept of zero pairs to show students how and why multiplying two negative number results in a positive answer (Van de Walle et al., 2018). Another common reason why students miss the opportunity to learn mathematics occurs when teachers omit a lesson or series of lessons due to insufficient instructional time (Warshauer, 2015). In this case, missing the lesson(s) can have detrimental impact on students' learning of mathematics given that early concepts build on later concepts. For example, it is important for students to understand concepts of 10 such as six and four make 10 or two and eight also make 10 (Van de Walle et al., 2018).

This concept of 10s becomes more complex when considering distance between numbers such 27 and 84. In this case, 27, (or just seven) is three short of making another 10. Knowing that seven and three makes 10 would help students see that 27 and three more (taken from the 84) is 30; now it is easier to see that the difference between 27 and 84, or 30 and 81, is 51. Therefore, missing a foundational concept such as fluency in base 10 can have detrimental and long-lasting affect on learning later concepts. Not understanding these foundational concepts can create anxiety when asked to perform a calculation that draws on an earlier but missing piece of information. What remains unknown is what percentage of those with mathematics anxiety is attributed to each of the four causal factors: cognitive/affective, social, genetic, or missed opportunity.

In a more recent case study of women registered in a return-to-work program (Brewster, 2022), all participants indicated that their anxiety was the result of missing the opportunity to learn mathematics. However, the limitations of Brewster's (2022) study included the small number of participants and second, participants, having scored moderate to high on the mathematics anxiety scale, were not asked to indicate, which of the four causal factors lead to their anxiety. Instead, they were asked if their anxiety was specially attributed to missed opportunity to learn mathematics. Subsequently, the line of questioning used in Brewster's (2022) study may be viewed as leading. We still believe that missed opportunity to learn mathematics is a causal factor of mathematics anxiety but recommend further research to determine the extent to which missed opportunity is a causal factor of mathematics anxiety. It is also important to analyze participants' narratives as they describe in detail what lessons in mathematics were missed, why they were missed, and the level of anxiety the missed lessons has caused.

INTERVENTIONS TO ADDRESS MATHEMATICS ANXIETY (GENERAL)

Researchers have more recently started exploring interventions for mathematics anxiety. For example, Brunyé et al. (2013) studied the impact of breathing and different levels of attentional focus on reducing anxiety. They found that students with high mathematics anxiety who practiced breathing with high attention focus, were calmer and achieved higher on a timed mathematics test. Brunyé et al. (2013) posited that this mindfulness training freed the working memory part of the brain that was previously occupied by mathematics anxiety. Brooks (2014) also attempted to reduce mathematics anxiety by reframing or repositioning students thinking to a more positive or exciting thought. Similar to the work of Brewster and Miller (2022), Brooks (2014) experimented with three different statements that participants would read prior to completing a challenging mathematics question: please wait a few minutes (neutral), try to remain calm (positive statement), and try to get excited (exciting statement). Brooks (2014) claimed that putting students in an opportunity mindset was more likely to alleviate anxiety than the threat mindset present in mathematically anxious students. Each of these studies aimed to free up the working memory that was consumed by mathematics anxiety but using different interventions.

Interventions That Focus on Expressive Writing

In the late 80's Pennebaker and Beall (1986) first introduced expressive writing as an intervention for a traumatic events mathematics anxiety. While building on this intervention, Pennebaker (1997) went on to utilize expressive writing as a therapeutic strategy. More recently, the work of Ramirez et al. (2018), noted mathematics anxiety researchers have recently published a comprehensive literature review on mathematics anxiety its etiology, interventions, and the introduction of an interpretation account for mathematics anxiety. This innovative framework asks students to reappraise their negative responses toward mathematics to a more positive view, with the hope of positively influencing their mathematics anxiety and performance.

The work of Brewster and Miller (2022) drew upon similar principles in that shifting students' mindset would alleviate anxiety and free up the working memory to focus on the mathematics at hand. Expressive writing gives an individual freedom to write their deepest thoughts and feelings on a particular topic (Pennebaker, 2004). Expressive writing was first used in psychology and Pennebaker and Beall (1986) first introduced it into field of psychology as an intervention for patients who experienced traumatic events. Much later, the work of Brewster (2022) and Brewster and Miller (2022) based their research on the work of Park et al.'s (2014) who studied mathematics anxiety in a strictly experimental nature. Brewster and Miller (2022) expanded on Park et al.'s (2014) work by studying mathematics anxiety in the context of a real mathematics classroom.

Brewster and Miller (2022) experimented with female pre-service teachers given that females tend to report more incidences of mathematics anxiety (Ashcraft & Faust, 1994; Baloglu & Kocak, 2006; Hopko et al., 2003; Luttenberger et al., 2018; Ma & Cartwright, 2003, Wigfield & Meece, 1998), and the impact of mathematically anxious teachers can have a detrimental impact on their students (Beilock et al., 2010; Bekdemir, 2010; Maloney & Beilock, 2012). They measured mathematics anxiety at three intervals: at the beginning of the course, prior to writing the mid-term examination, and prior to writing the final examination using the abbreviated mathematics anxiety rating scale (AMARS), while controlling for mathematics ability (Alexander & Martray, 1989). The 27 participants were randomly selected to one of three groups to write in a journal about:

(a) the things they did yesterday (neutral),

(b) experiences in mathematics (expressive), and

(c) describe your best day ever (positive expressive).

The researchers hypothesized that positive expressive writing was better at alleviating anxiety than the expressive writing intervention given that it was more likely to shift participants' mindset to an opportunity mindset. Their findings did not reveal any statistically significant differences in the measures of mathematics anxiety taken at the pre-, post1-, and post2-test intervals while controlling for self-reported mathematics ability in either of the groups. When reflecting on the outcome of their research, Brewster and Miller (2022), surmised that the duration of the writing may have been a contributing variable that hindered any reduction in mathematics anxiety.

The duration of writing used in Ramirez and Beilock (2011) was 10 minutes and was adopted by Brewster and Miller (2022) in their study with pre-service teachers. Analysis of student journals where they wrote for the 10 minutes at the beginning of each class, showed that many students wrote off topic or doodled on the page, suggesting that 10 minutes was too long, and students subsequently became disengaged with the intervention. In Brewster's (2022) subsequent study, she experimented with just positive expressive writing and reduced the intervention time to seven minutes. In follow-up interviews, Brewster's participants indicated that they wished they had more time to write! This examination of the duration of writing as an intervention for mathematics anxiety has revealed that the characteristics (e.g., age, maturity, level of investment in studies, etc.) of participants experiencing mathematics anxiety may need to be considered when deciding whether to use expressive or positive expressive writing as an intervention to mathematics anxiety. Pre-service teachers in comparison to women in a return-to-work program are likely to have difference life experiences and different levels of investment in their program of study.

Another outcome of Brewster and Miller's (2022) study that was not addressed in research focusing on other interventions to mathematics was the quality of the instructor teaching mathematics. Brewster and Miller (2022) speculated that their study did not result in any significant findings possibly because students' mathematics anxiety was minimized through quality instruction that drew upon students' strengths and provided reasoning to explain concepts rather than memorizing formulae. For example, students were required to investigate the surface area of a cylinder by unwrapping a cylinder to have one rectangle and two circles; two objects that they were more familiar with (note: students also had previously investigated the area of a rectangle and circle). For these students, their anxiety may have been reduced through quality teaching and therefore, the impact of expressive and

positive expressive writing would not reveal any differences given that this intervention was typically used with students having moderate to high mathematics anxiety (Park et al., 2014).

Brewster and Miller (2022) also noted that the context of the study may be a factor influencing their results. Park et al.'s (2014) study was conducted in an experimental setting, whereas Brewster (2022) and Brewster and Miller (2022) studies were conducted in the context of real classrooms. Research conducted within the context of the phenomenon being studied (i.e., mathematics anxiety in the classroom), is more likely to reflect the true impact and constraints of an intervention (Brewster, 2022; Ramirez et al., 2018). Another important contribution from Brewster's (2022) study was related to the interplay between test anxiety and mathematics anxiety. Each participant in Brewster's (2022) study disclosed in the interviews that expressive writing had helped to reduce their mathematics anxiety, however, participants noted that test anxiety and anxiety related to finding a job or another school program had elevated their general anxiety thus acting as intervening variable prior to the administration of the post-AMARS survey. Subsequently, researchers need to be cognizant when measuring mathematics to account for other anxieties that may also be present.

FUTURE DIRECTIONS

The shortfall in mathematics abilities has primarily been the result of misunderstood foundational concepts in mathematics; not the mathematics taught at the high school or post-secondary level (Chand et al., 2021; Van de Walle et al., 2018). Hence, it is interesting that research on mathematics anxiety has primarily focused on addressing mathematics anxiety at the upper university level (Ramirez et al., 2018). Therefore, Brewster's (2022) study of women in a return-to-work program added to this gap in literature. In the future, it will be beneficial to examine mathematics anxiety in the early grades where foundational concepts are taught and introduce teachers to intervention measures. Brewster and Miller's (2022) study with pre-service teachers had provided their participants with an unanticipated benefit in that while pre-service teachers (training to teach grades kindergarten to 9) were participants in the study, they also learned how writing can be used as an intervention to reduce mathematics anxiety. It would be interesting to survey this group in a couple years to determine the impact of that experience as in whether they used the intervention strategy in their own mathematics classes.

Other considerations for future research should consider participants' engagement and investment in learning mathematics. It is possible that younger students or older students not invested in mathematics may not benefit from a writing intervention and possibly, simple positive statements similar to those in Brook's (2013) study to reframe students' thinking may be appropriate for younger age groups. It is also possible that reappraisal of failure or disappointing achievement can help redirect students' mindset to one that triggers the need for more effort (Boaler, 2018, Dweck, 1975; Ramirez et al., 2018).

Other areas needing further research include determining the optimal duration of writing interventions and whether the writing duration should vary depending on the characteristics of the participants. Further, determining which of the interventions are better for which participants would help instructors select interventions for their students experiencing mathematics anxiety. It is also possible that knowing, which causal factor (i.e., cognitive/affective, social, genetic, or missed opportunity) has influenced a students' mathematics anxiety may provide more insight in determining, which intervention is most appropriate.

Last, it is important to examine the link between mathematics anxiety and test anxiety to determine the extent to which these two forms of anxiety are linked. For example, a student with mathematics anxiety may also exhibit test anxiety. In this case, research is needed to determine the extent to which an intervention for mathematics anxiety will alleviate test anxiety or whether interventions for both forms of anxiety are needed.

We have learned a lot about mathematics anxiety since the advancement of the STEM fields and the role mathematics plays in science, technology, and engineering. Based on discussions presented in this thought paper, the complexity of mathematics anxiety as well as the complexity of interventions for mathematics anxiety is evident and research in this area is likely to continue into the next couple of decades. There is still much to learn about mathematics anxiety, and we have provided a few avenues that would benefit with more research.

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