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Missed Opportunity in Mathematics Anxiety

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ABSTRACT

In our technologically advanced society proficiency in mathematics is paramount to success in the science, technology, engineering, and mathematics (STEM) employment sector. Mathematics anxiety negatively affects an individual's physiological and cognitive functioning, which results in the individual obtaining lower achievement in mathematics. The consequences of low mathematics achievement can have devastating consequences for the individual's career in STEM fields which require high level mathematics. This article will provide a review of the prevalence of mathematics anxiety, its historical development, as well as theories from education, psychology, neuroscience and causal factors purporting to provide a comprehensive understanding of mathematics anxiety. We propose a fourth causal factor, missed opportunity, in which the individual is high functioning academically, but exhibiting mathematics anxiety. He or she is not able to perform well in mathematics due to missing the opportunity to learn the foundational mathematics knowledge necessary in STEM fields.

Keywords: mathematics anxiety, mathematics achievement, STEM, causal factors

INTRODUCTION

Mathematics anxiety causes an adverse reaction to the physiological and cognitive functioning of an individual when mathematics is presented. This anxiety creates a false measurement of the individual's true mathematics ability (Ashcraft, 2002). Underperformance in mathematics due to anxiety, is problematic in our mathematically dependent, technologically advanced society (Beilock & Maloney, 2015; Foley et al. 2017; Suarez-Pellicioni, Nunez-Pena, & Colome, 2016). For example, the science, technology, engineering, and mathematics (STEM) employment sectors are all dependent on a solid foundation of mathematics skills (Foley et al., 2016). The development of these skills can be hindered by the presence of mathematics anxiety causing students to underachieve. The consequences of low mathematics achievement can have stifling effects on students' performance and students' career trajectories in the STEM fields as well as other fields requiring mathematical competence. Given the demand for high levels of mathematics ability in our society, it is important to understand the historical development and factors causing mathematics anxiety; in particular the factors influencing its onset. However, before delving into the history and factors influencing mathematics anxiety, it is important to first define mathematics anxiety and then document the prevalence of mathematics anxiety in society to provide a contextual background for this construct.

DEFINITION OF MATHEMATICS ANXIETY

Mathematics anxiety is a multidimensional construct which raises the complexity of studying this area as many factors can trigger anxiety (Devine, Carey, & Szucs, 2018). Students can feel tension and anxiousness when presented with numbers in a mathematics class or when asked to perform a mathematical calculation.

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When the anxiety is triggered, the individual may experience a cognitive disorder, which is one of the dimensions of mathematics anxiety. The cognitive dimension focuses on the disruption to the working memory caused by mathematics anxiety. When an individual is given a mathematics problem, worry (i.e., the cognitive dimension) associated with mathematics anxiety causes the disruption to the working memory, so that it is less available for use. Thus, the individual's performance in mathematics would decline as the working memory is occupied by worry and unable to perform the calculation at hand (Maloney & Beilock, 2012; Shi & Liu, 2016).

People experiencing mathematics anxiety may also experience an affective disorder which has been documented as a second dimension of mathematics anxiety (Dowker, Sarkar, & Looi, 2016). The affective dimension is the emotional component and resulting physiological symptoms that the individual experiences as the result of mathematics anxiety. The individual may experience symptoms such as: rapid heartbeat, perspiration, shaking, and nausea (Dowker et al., 2016; Liebert & Morris, 1967; Lyons & Beilock, 2012; Park, Rameriz, & Beilock, 2014; Pizzie & Kraemer, 2017). For example, when asked for the total amount of 5 items that cost $19.95, a person who does not have mathematics anxiety and is reasonably competent in mathematics, is likely to recognize that $19.95 is almost $20 and 5 x $20 = $100. In comparison, a person who has mathematics anxiety may not be able to respond at all regardless of whether they have the mathematical knowledge or not.

Further illustrating the complexity of mathematics anxiety is its interwoven relationship between test anxiety. Research has documented a strong correlation between mathematics anxiety and test anxiety (Ashcraft, Kirk, & Hopco, 1998; Hembree, 1990). Subsequently, findings from test anxiety may prove useful to researchers studying mathematics anxiety. Hembree (1990) identified the dimensions of the constructs, thereby necessitating the control of test anxiety when the research endeavoured to only examine mathematics anxiety (O'Leary, Fitzpatrick, & Hallett, 2017).

EVIDENCE OF MATHEMATICS ANXIETY

The 2012 Programme for International Student Assessment (PISA) reported that 33% of 15-year-old students had mathematics anxiety when asked to perform mathematical tasks according to (OECD, 2013). However, the actual percentage of students who have mathematics anxiety is unknown given that the findings reported by PISA were based on self-reported feelings of mathematics anxiety in comparison to actual measurements of mathematics anxiety. Research by Beilock and Willingham (2014) has shown that 25 to 80% of college students in the United States have self-reported experiencing a moderate to high level of mathematics anxiety. Similar to the findings by PISA, the work by Beilock and Willingham (2014) relied on self-reported indicators of mathematics anxiety. Another self-reported study on mathematics anxiety from the UK was by Chinn (2009) who presented 2984 students in grades 7 to 11 with a questionnaire on mathematics tasks and performance situations that may create mathematics anxiety. He applied stringent criteria for each level of mathematics anxiety and found that only 2 to 6% of secondary students had high mathematics anxiety. These findings may be attributed to the extremely limiting criteria used in Chinn's study given that our review of literature did not reveal other studies with similar findings. Large percentages of students (i.e., 20 to 50%) with mathematics anxiety have also been reported (Ashcraft & Kirk, 2001; Johnson-Wilder, Brindley, & Dent, 2014) however, these studies utilized empirical testing using physiological measurements such as functional magnetic resonance imaging (fMRI) (Lyons & Beilock, 2012; Pizzie & Kraemer, 2017; Young, Wu, & Menon, 2012) and electroencephalography (EEG) (Klados, Pandria, Micheloyannis, Margulies, & Bamidis, 2017). In contrast to these high percentages of students with mathematics anxiety, Ashcraft and Moore (2009) estimated that a smaller percentage (i.e., 17%) of the population actually suffered from mathematics anxiety; however, the work of these researchers is just an estimate and needed corroboration. Given the variability in number of students reported to be suffering from mathematics anxiety, the actual number of students with mathematics is still relatively unknown.

Self-reported research from East Asian countries also reported that students suffer from mathematics anxiety (OECD, 2013). Hence, it appears that mathematics anxiety may be a global problem, despite the over reliance on self-reported measures of mathematics anxiety. However, it is important to question whether it is really possible that these large numbers of students have mathematics anxiety or is it a case of a shortfall in mathematics ability? For instance, if a student is asked to respond to a question in a high stakes assessment (i.e., quiz, test, exam) in which they have not had the opportunity to learn the material being assessed, is it possible that the student was suffering from a missed opportunity to learn which may cause mathematics anxiety (i.e., heart racing, irregular breathing, sweatiness, shaking and feelings of hopelessness) and if left unaddressed, can lead to a more severe case of mathematics anxiety which can become debilitating.

In the studies above, it is not known whether the self-reported measures of mathematics anxiety were early stages of mathematics anxiety characterized by nervousness, worry, and fear or whether students' level of anxiety was debilitating causing increased heart rate, perspiration which stifled their ability to perform mathematics because the processing mechanism of their working memory is not functioning fully. It is likely that students' suffering from mathematics anxiety because of missed opportunity do not have sufficient storage of mathematics knowledge, thus there is nothing to retrieve during bouts of anxiety. In comparison, students who are high performers in mathematics and have relevant information to retrieve are not able to access the information. Despite the confusion related to *measuring* mathematics anxiety versus reporting students' *feelings* of mathematics anxiety and mathematics anxiety attributed to missed opportunity versus mathematics anxiety attributed to debilitating anxiety for those who have mastered mathematics, mathematics anxiety is real and can be measured through physiological and cognitive testing as well as self-reported instruments that measures feelings of anxiety in addition to opportunities to have learned the mathematics. To provide a complete understanding of mathematics anxiety, a historical perspective will provide a backdrop to contextualize its evolution.

MATHEMATICS ANXIETY HISTORICAL DEVELOPMENT

Mathematics anxiety has been studied since the mid-1950's when it was first described as *number anxiety* (Dreger & Aiken, 1957). Later, the affective and cognitive dimensions of mathematics anxiety construct were identified in 1967 (Wigfield & Meece, 1988). Despite this early interest in mathematics anxiety, there was not much movement in studying mathematics anxiety given that in the 1950's through to the late 1960's society was dependent at the time on an economy based on the labour market drawing on physical labour (i.e., factories). It was not until the 1970's that a scale was developed to measure mathematics anxiety, which spurred further research in this area (Richardson & Suinn, 1972). Tobias (1978), a leader in mathematics anxiety, defined mathematics anxiety as, "the panic, helplessness, paralysis and mental disorganization that arises among some people when they are required to solve a mathematical problem" (p.65; Tobias & Weissbrod, 1980). Tobias continued to play a leading role in mathematics anxiety research in the 1990s (Tobias, 1993). Her research focused on understanding why female college students, who stopped pursuing mathematics courses, held strong beliefs in a gendered false assumption that females are not capable of completing higher level mathematics (Tobias, 1991). The seminal work of Ashcraft and Faust (1994) led mathematics anxiety studies in a new direction with their research findings demonstrating differential mathematical processing due to mathematics anxiety. Starting in the 2000's, which parallels advancements in technology, research focused on how fear of mathematics can negatively affect an individual's academic performance, cognition, stress levels, and career opportunities (Ashcraft, 2002; Lyons & Beilock, 2011; Ma & Xu, 2004). These early researchers have contributed to the theoretical lens from which mathematics anxiety is studied.

THEORIES OF MATHEMATICS ANXIETY

Theories of mathematics anxiety have advanced from education, psychology, and neuroscience to provide a comprehensive understanding of mathematics anxiety (Buckley et al., 2016). As research advances in this field additional theories are utilized. Recently, processing efficiency theory and attentional control theory (Passolunghi, Caviola, Agnostini, Perin, & Mammarella, 2016) have been used in the field of mathematics anxiety research. The processing efficiency theory (PET) posits the relationship between anxiety and performance by putting forth the notion that anxiety has two functions: it increases worry which in turn reduces attentional resources and it decreases attentional control over the performance (Eysenck & Calvo, 1992). For example, if a student is required to simplify $(-2)^3$, the student may not focus or attend to the negative aspect of the number and respond to the question as $(2)^3$. Attentional control theory (ACT) which is an extension of PET, focuses on the negative effects that anxiety has on the individual's processing efficiency by means of the individual's attention control (Eysenck, Derakshan, Santos, & Calvo, 2007). As well, a new interpretation framework highlighting the significance of the appraisal process in the development of mathematics anxiety is at the forefront of research in the next decade (Rameriz, Shaw, & Maloney, 2018).

The interpretation framework suggests that if students can positively reappraise their negative responses associated with mathematics anxiety, then they may be able to view mathematics as a challenge and not something to be avoided. Rameriz et al. (2018) purported that, "it can be effective to encourage individuals to reappraise their math anxious reaction or embrace the view that disfluent learning can be useful" (p.156). For instance, if a teacher is able to get the student to interpret his or her anxious feeling upon entering a mathematics class as a feeling of excitement instead of anxiety then learning is more likely to take place. For instance, writing about their feelings about mathematics may help reduce the level of anxiety by diffusing the anxiety through expressive writing (Park, Rameriz, & Beilock, 2014). Additionally, having students recognize the importance of hard-work and struggle to learn mathematics will also benefit their learning process.

Despite the recent advances, three of the most widely used theories to describe mathematics anxiety are: deficit theory (Tobias, 1986), debilitating anxiety model, and social cognitive theory (Dowker et al., 2016; Rameriz et al., 2018). The deficit theory claimed that a poor performance in mathematics leads to mathematics anxiety (Tobias, 1986). Some of the possible causes of the poor performance in the deficit theory were the result of mathematical learning disabilities in early childhood such as dyscalculia (Passolunghi, 2011), self-regulation deficits when learning mathematics such as attention deficit hyperactivity disorder (ADHD) (Jain & Dawson, 2009; Lee et al., 2014), and decrease in mathematics performance from one year to the next due to the students remembering their prior poor mathematics performance, particularly in male students (Ma & Xu, 2004). In contrast, female students attended to poor performance only in critical transition periods, such as entering junior high school or high school (Ma & Xu, 2004). In summary, if the cause of mathematics anxiety is related to the deficit theory and a student does not receive mathematics intervention, then the learning decreases exponentially in subsequent years in comparison to the students' age appropriate peers.

Another leading theory of mathematics anxiety was conceptualized as the debilitating anxiety model which is based on the premise that mathematics anxiety will reduce performance in mathematics (Carey et al., 2015). For example, if a teacher calls on a student to respond to a mathematics question as part of the class lesson, a student with mathematics anxiety may experience adverse physiological symptoms (i.e., rapid heart rate, cognitive confusion, perspiration). Lyons and Beilock (2012) used functional magnetic resonance imaging f(MRI) to investigate the physiological changes that occurred in mathematically anxious students. Their findings showed that the student's frontoparietal network became activated when anticipating a mathematics task. The frontoparietal part of the brain is where working memory occurs. Thus, the work of Lyons and Beilock (2012) provided evidence that mathematics anxiety affects the cognitive functioning of students and thereby hinders their ability to learn mathematics. However, it would have been worthwhile if Lyons and Beilock (2012) had measured mathematics anxiety from a range of students with low anxiety experience stress and worry in comparison to students who have more debilitating mathematics anxiety showing the negative physiological symptoms. It is possible that students with low anxiety may not show an activated frontoparietal network. This would demonstrate different levels of mathematics anxiety; some of which could be addressed with appropriate intervention while other cases with more debilitating symptoms may need more in-depth psychological support.

The challenge to determine whether mathematics anxiety causes a decline in mathematical performance or whether a lack of mathematics ability or acuity causes the mathematics anxiety has created considerable discourse in research. A review of causal directions between mathematics anxiety and mathematics performance by Carey et al. (2015) compared the deficit theory with the debilitating anxiety model. The deficit theory supported mathematics anxiety as a development that occurs because of the student's deficit in his or her mathematics ability or learning, while the debilitating anxiety model is based on the premise that mathematics anxiety in the individual will reduce mathematics performance. According to Carey et al. (2015), research utilizing debilitating anxiety model manipulates the level of anxiety in the individual to observe the individual's change in mathematical performance. Although the notion has been used for some time, it is recently that the term debilitating anxiety model has been used to describe this decline in performance caused by mathematics anxiety. Carey et al. (2015) mentioned that this research is supported in longitudinal studies (Ma & Zu, 2004) and studies with children with learning disabilities.

The summation of their review proposed a third possible theory to explain mathematics anxiety, which is the reciprocal theory (Carey et al., 2015). The reciprocal theory offers a bidirectional relationship between mathematics anxiety and mathematics performance which would occur in a cyclical fashion. If an individual experiences anxiety when thinking about or performing mathematics, then this can result in poor mathematics performance. Conversely, if the individual's mathematics performance is poor, then this can cause the individual to suffer from mathematics anxiety, so that it becomes difficult determining which comes first the mathematics anxiety or the poor mathematics performance (Carey et al., 2015)?

Another prominent theory used to convey an understanding of mathematics anxiety and to further explain the type of connection between mathematics anxiety, mathematics performance, and achievement is social cognitive theory (Bandura, 1986). This theory purports that mathematics anxiety affects the individual's cognitive abilities, as well as his or her physiological changes that can affect them as mathematics anxiety takes hold (Ashcraft, 2002; Lyons & Beilock, 2011). Using cognitive theory in their research, Maloney and Beilock (2012) wanted to investigate and determine the connection between mathematics anxiety in the student and the resulting poor mathematics performance. Although, previous research supported the idea that mathematics anxiety was caused by the individual being less skilled, possibly due to a missed opportunity to learn the mathematics, and perhaps less practiced and prepared in the area of math (Rameriz et al., 2018), Maloney and Beilock (2012) purported that perhaps the link between mathematics anxiety and performance in mathematics could be caused by working memory being less available for use because it was occupied by worry when the individual was given a mathematics problem.

In light of social cognitive theory (Bandura, 1986), numerous studies (Ashcraft, 2002; Ashcraft, Kirk, & Hopko, 1998; Suares-Pelliconi, Nunez-Pena & Colome, 2016) have been conducted to determine that mathematics anxiety affects all stages of cognitive mathematical processing, such as pre-processing, processing, and retrieval of knowledge during a mathematics task. Further evidence supporting the negative ramification of cognitive disruption caused by mathematics anxiety on the student's performance was research conducted by Hembree (1990). In Hembree's (1990) study with highly mathematics anxious adolescents, he found that adolescents would avoid mathematics related activities. This seems like a reasonable consequence of poor performance in mathematics and mathematics anxiety as most people tend to avoid tasks, they are not good at (Sokolowski & Ansari, 2017). This supports the notion that mathematically anxious individuals may avoid mathematics, which in turn can have a detrimental impact on their educational opportunities as their ability in mathematics does not progress.

These six theories have been developed to conceptualize factors influencing mathematics anxiety and how mathematics anxiety affects student's mathematics performance. They provide a lens from which the researcher can conceptualize the cause of mathematics anxiety. Further, the complexity of the mathematics anxiety construct adds to the difficulty of identifying a comprehensive theory to contextualize the problem. Hence research exploring mathematics anxiety continues to develop. It is also important to garner an understanding of the causal factors to further strengthen an understanding of mathematics anxiety.

FACTORS INFLUENCING MATHEMATICS ANXIETY

Various factors of mathematics anxiety have been cited contributing to the proliferation of mathematics anxiety in society. These determinants can be categorized into the following domains: cognitive/affective, social, and genetic. We propose the possibility of a fourth domain called, *missed opportunity*, which would account for individuals who are otherwise intelligent and successful, but who still suffer from mathematics anxiety. This new category will be discussed in detail following the presentation of current research on cognitive and affective factors of mathematics anxiety.

Cognitive and Affective Factors

Cognitive and affective factors play a significant role in the development and perpetuation of mathematics anxiety (Suarez-Pelliconi, Nunez-Pena & Colome, 2016). Studies have suggested that there is an interconnection between the cognitive and affective domains in mathematically anxious individuals, referred to as worry, which is an emotional response causing mathematics anxiety (Maloney & Beilock, 2012; Park et al., 2014). Therefore, while a mathematically anxious individual experiences cognitive and physiological symptoms, they also experience the emotional symptoms of worry, thus heightening the anxiety. A study by Devine et al. (2018) later refuted this notion as their findings challenged the belief that mathematics anxiety may not be directly linked to poor mathematics performance as their findings showed that 77% of the highly mathematics anxious group had average or above average mathematics performance. Despite this contradictory result, research participants used in this study had developmental dyscalculia, which may have added the possibility of additional unaccounted for variables in this research which supports our supposition that there may be differentiated levels of mathematics anxiety.

Further, it is difficult to separate the cognitive and affective factors when an individual experiences mathematics anxiety because both typically occur simultaneously. For this paper, they will be considered as one determinant of mathematics anxiety. Several studies (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007; Passolunghi et al., 2016) have been conducted on the physiological effects of mathematics anxiety and stress that reduce the amount of working memory available for learning. Stress is the body's response to pressures resulting from a situation or life event. Various pressures in a student's life can cause stress such as examinations, deadlines, and poor time management for which the student feels unable to cope. When stress is encountered our bodies produce stress hormones (Dowker et al., 2016). These hormones activate a 'fight or flight' response, such as when a student leaves a mathematics exam before they are finished due to overwhelming stress. Jamieson, Peters, Greenwood, and Altose (2016) purported that stress was not always harmful for performance and that reappraising the situation in a positive way may guide the student to see a stressful situation as a challenge and not a threat. For example, if a student was given additional resources and support to help him or her learn material for an upcoming mathematics test, then the student may see the test as a challenge and not a threat. Caution must be taken when considering these results, as these researchers did not measure physiological markers only self-reported appraisals from participants. Stress, although closely linked to anxiety, is the physiological response to a threat in this case mathematics (Devine et al., 2018; Lyons & Beilock, 2012).

In returning the discussion to additional studies in this area, mathematics anxiety was reported to be a sustained reaction to stress, where the student is unable to function in mathematics as he or she would normally be able to do (Dowker et al., 2016; Lyons & Beilock, 2012). Mathematics anxiety has been studied in relation to mathematics performance and overall academic achievement while investigating the deleterious effects on cognition and affect (Park et al., 2014; Maloney & Beilock, 2012).

Cognition and affect as they relate to mathematics anxiety were also examined by Shi and Liu (2016) using the Revised Mathematics Anxiety Rating Scale (RMARS) (Plake & Parker, 1982). They studied 61 highly mathematics anxious (HMA) undergraduates and 61 low mathematics anxious (LMA) undergraduates. Initially these students were given math-related or valence neutral contexts (i.e., the sun rises in the east) while processing simple sentences (drawing on students' verbal working memory). The results showed that the working memory capacity was disrupted when HMA students were presented with a mathematics related condition their performance decreased; this did not occur in the LMA group which confirms our belief that there are differentiated levels of mathematics anxiety. Shi and Liu (2016) also found that the HMA student was not associated with a deficit in working memory when measured using neutral information (i.e., the sky is blue).

As mathematics anxiety can have very real consequences for the cognitive processing dimension of the brain or working memory so can attitudes towards mathematics. Generally thought of as affective elements, attitudes are composed of cognitive, affective, and behavior components (Wigfield & Meece, 1988). Studies have shown that attitudes toward mathematics can decline with age beginning in childhood (Ma & Kishor, 1988; Wigfield & Meece, 1988). For example, around age 12 students develop the attitude that hard work will not be sufficient to earn a good grade (Van de Walle, 1998). These negative attitudes toward the subject of mathematics and its performance can become so severe that they culminate in severe anxiety for the individual (Hembree, 1990). The attitude dimension of the cognitive/affective factors further supports the concept that a *missed opportunity* in this instance can have devastating consequences for the cognitive and affective domains in terms of the individual's ability to learn and perform mathematics. However, there is one treatment strategy utilizing cognitive interference that has been proven to be successful to enable students to reappraise a negative attitude towards mathematics which is expressive writing (Maloney & Beilock, 2016). The individual's anxiety would be lessened by having students express their negative thoughts in writing before a mathematics assessment. Based on past research, this would free up the necessary working memory for performing mathematics (Park et al., 2014; Rameriz & Beilock, 2011).

Social Factors

The social factors of mathematics anxiety, such as societal beliefs, cultural influences, and gender issues, are no less relevant than the determinants of cognition and affect when dealing with mathematics anxiety. Societal beliefs that women and girls are not as good at math as men and boys are pervasive in our culture (Beyer & Bowden, 1997; Jakobsson et al., 2013). These messages proliferate the female's narrative and self-beliefs, thereby perpetuating the notion that they are not as capable at mathematics as males. Studies have shown that females rate their ability to perform mathematics lower than males (Devine et al., 2012; Hembree, 1990; Wigfield & Meece, 1988), which may lead to higher rates of mathematics anxiety among females. Subsequently, female teachers' negative self-belief about their mathematics ability may subliminally, pass this message onto students and possibly create situations leading to missed opportunity for their students to learn mathematics because they may fear the subject (Stuart, 2000). This social effect can have long term and devastating consequences for female students, as females immersed in this cultural paradigm of negative messaging may not even consider embarking on a course of study to prepare for a career in STEM; however many female teachers will consider a career in teaching primary and junior level students (Maloney, Rameriz, Gunderson, Levine, & Beilock, 2015).

Cultural influences can affect the level of mathematics anxiety in our society. Using data from the Pisa 2012 database, Foley et al. (2017) purported that, "cross-national differences in student math anxiety may reflect differences rooted in culture rather than in the level of student math performance" (p.55). For example, Lee (2009) using the 2003 PISA results from 41 countries found that students in Asian countries, despite having low mathematics self-concept and low mathematics self-efficacy, had high mathematics anxiety but were able to perform well in mathematics. Support for the high value placed on academic achievement in Asian cultures, may be responsible for this finding (Ho et al., 2002). Thus, demonstrating the complexity of the cultural effect on mathematics anxiety and performance, and further substantiating the social dimension of mathematics anxiety.

In addition to societal beliefs and cultural influences, gender plays a role in the social determinant is mathematics anxiety. Research has examined differences between gender and anxiety, specifically looking at trait anxiety. Trait anxiety refers to a stable personality tendency to attend to fears and worries (anxiety) in various situations (i.e., these people are everyday worriers), as opposed to state anxiety where the individual has a psychological and physiological reaction that is induced by a specific situation (Dowker et al., 2016). Research has shown that females have higher trait anxiety and tend to be more expressive about mathematics anxiety than males, thus greatly influencing their susceptibility to mathematic anxiety (Chapman et al., 2007; Costa et al., 2001). It is important to realize that an individual's anxiety traits can play a significant role in mathematics anxiety in the individual, along with genetic factors which will be discussed next.

Genetics Factors

Having examined some of the possible mathematics anxiety factors of cognition, affect (i.e. moods and emotions), and social now leads to the final domain of factors influencing mathematics anxiety which is genetics. Dowker et al. (2016) purported that it would be highly unlikely that mathematics anxiety would have an identifiable genetic factor. Instead, their findings suggest that mathematics anxiety may be caused by a combination of prior poor experiences in mathematics performance, possibly due to missed opportunity, and a predisposing genetic risk to mathematical problem solving. The complexity of mathematics anxiety and human genetics challenges the possibility of finding a direct link between the two. Evidence of this ramification can be seen in the seminal empirical research of Wang et al. (2014) who conducted a large behavioural genetic study using 514, 12-year-old twins. Their findings revealed that mathematics anxiety correlated significantly with general anxiety and that mathematics anxiety correlated negatively with both problem solving and reading comprehension. Importantly, Wang et al. (2014) found that 40% of the variation in results supported the genetic component with the rest being environmental factors, thus demonstrating the multi-dimensional nature of mathematics anxiety and the difficulty of providing a comprehensive theory for mathematics anxiety. Although Wang et al. (2014) is a key article influencing what is understood about the genetic factor, we posit that almost all students are capable of achieving a minimum of grade 12 level of mathematics, when provided with ample opportunities to learn.

Missed Opportunity Factor

The fourth determinant of mathematics anxiety is what we have described as, *missed opportunity,* which adds to the comprehensive model for mathematics anxiety. *Missed opportunity* would account for individuals who measure highly in other academic domains but display evidence of mathematics anxiety. They can function well in other academic domains but are not able to perform well in mathematics, because they have not had an opportunity to learn the foundational knowledge in mathematics that is required to further learn higher levels of mathematics. This could pertain to a deficit in learning experience as the result of poor mathematics teaching or prolonged or short absences from mathematics classes. For instance, if a student had 3 teachers who had a weak or poor understanding of mathematics then the student could end up with a deficit in mathematics learning. The teacher's lack of competence in mathematics could certainly hinder the teachers' ability to provide necessary instructions to students. Additionally, if a student had the same teacher, who was not confident or competent in mathematics for grades 5, 6, and 7, then the student could end up with a deficit in mathematics learning, because the student has not had the necessary educational circumstances to learn the mathematics that is taught at those grade levels. The student would not have had the opportunity to acquire the foundational learning necessary to advance to deeper more complicated mathematical concepts.

Additional factors which could also be covered under the *missed opportunity* domain could be the quality of instruction or students' absences from mathematics classes which could both affect mathematics learning giving rise to mathematics anxiety in an otherwise capable academic student. Also, the teacher's effect on the student's pre-existing anxiety or trait anxiety, which could translate into higher levels of anxiety activating or heightened response of the amygdala (i.e., frontoparietal area of the brain), which does not allow the working memory to be available for mathematics learning, and the possibility of poor student attention. Studies which have demonstrated support for this teacher's effect have shown that female teachers can transfer their anxiety to their students (Beilock et al. 2010), as well as mathematics anxious parents who help their child with homework (Beilock & Maloney, 2015; Rameriz et al., 2018). Each of these factors demonstrates further support for a *missed opportunity* or deficit in the learning experience. To synthesize the theories and causes of mathematics anxiety, we have proposed a diagram (see **Appendix A**) to show the interplay of factors influencing mathematics anxiety and how it is understood.

In conclusion, the effect of *missed opportunity* in learning mathematics can cause mathematics anxiety because the student feels stress that he or she cannot perform the mathematics. This subsequently causes mathematics anxiety at the lower level of mathematics anxiety. The creation of a model that more fully explains mathematics anxiety, by adding this additional factor, *missed opportunity*, will further improve the understanding of mathematics anxiety for researchers, educators, policymakers, parents, and society as a whole. As society continues to advance in education at an accelerated pace, proper interventions are needed to allow mathematically anxious individuals to thrive and scaffold their learning to develop a complete understanding of mathematics anxiety, so he or she can engage in this exciting frontier.

Disclosure statement

No potential conflict of interest was reported by the authors.

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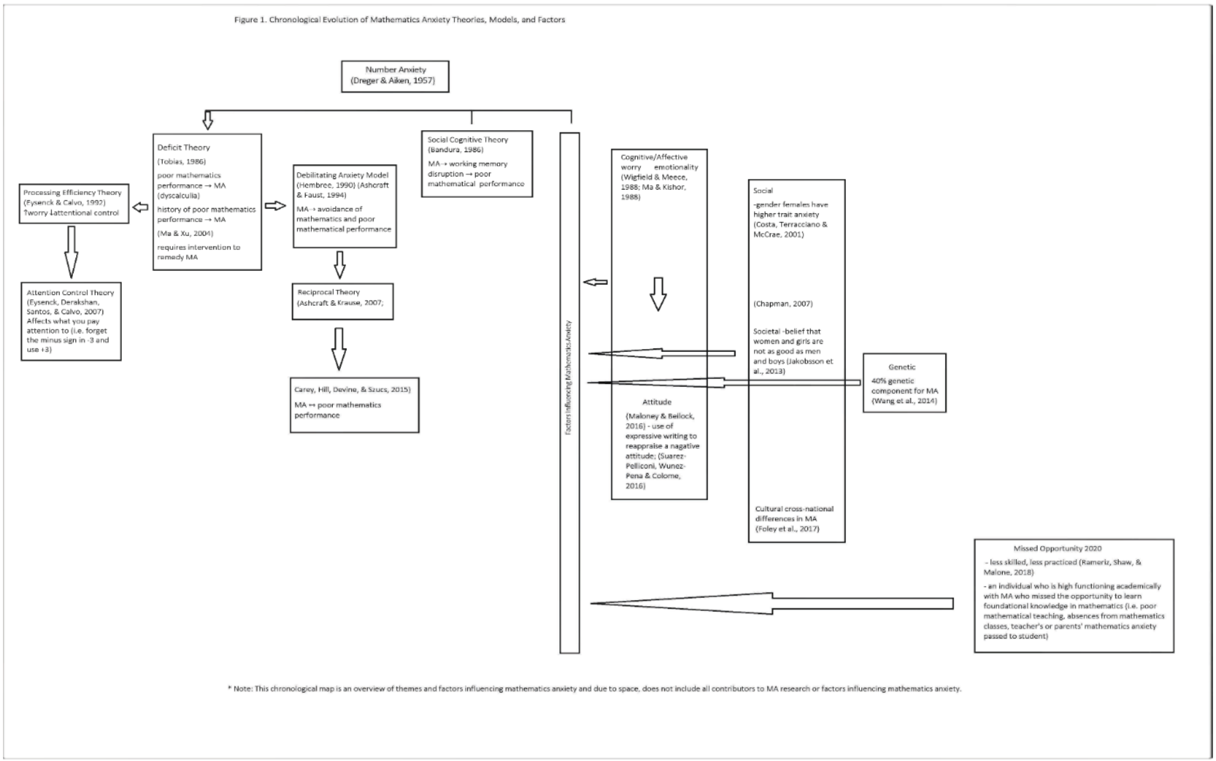
APPENDIX A

Chronological Evolution of Mathematics Anxiety Theories, Models, and Factors



Note. This chronological map is an overview of themes and factors influencing mathematics anxiety and due to space, does not include all contributors to mathematics anxiety research or factors influencing mathematics anxiety.