MATHEMATICS ANXIETY AS A MEDIATOR FOR GENDER DIFFERENCES IN 2012 PISA MATHEMATICS SCORES

Jennifer Cox
Indiana University
jennycox@iu.edu

Erik Jacobson
Indiana University
erdajaco@indiana.edu

Although gender differences in mathematics are smaller than they have been in the past, prominent voices still attribute these differences to a variety of fixed individual factors, such as genetic characteristics of men and women. We hold the alternative view that these differences can be ultimately attributed to malleable factors. From this vantage, societies could influence gender differences in mathematics by changing students' experiences in school. In this study, we built on prior work suggesting that mathematics anxiety causes lower mathematics scores. In particular, we found that mathematics anxiety entirely explains the gender differences evident in mathematics scores from the 2012 US Programme for International Student Assessment (PISA). Furthermore, we found that gender moderates the mediating role of mathematics anxiety: math anxiety is more detrimental for male than for female students. Because math anxiety is a malleable individual characteristic, we conclude that gender differences reveal more about gendered societal experiences than they do about innate characteristics of men and women.

Keywords: Gender and Sexuality; Equity and Diversity; Assessment and Evaluation; Affect, Emotion, Beliefs, and Attitudes

Headlines such as "Men in science think they are more intelligent than female counterparts, study reveals" (Richards, 2018) and "Study: 6-year-old girls say they are less 'brilliant' than boys. Why?" (Botkin-Kowacki, 2017) and "Why don't young girls think they are smart enough?" (Cimpian & Leslie, 2017) are not uncommon in the media today. Many researchers have challenged claims that "boys are better at math than girls" (e.g., Ding et al., 2006; Hyde et al., 2008). However, small average score differences between boys and girls on large-scale mathematics tests remain, particularly at the top of the score distribution, leading some to assume that girls are not as talented as boys in mathematics.

In this paper, we use the 2012 Programme for International Student Assessment (PISA) dataset to examine this small but persistent gender gap on mathematics exams. Although gaps analyses have been criticized for deficit thinking and not supporting individual students' mathematical identities (e.g., Gutiérrez, 2008), they often inform researchers and policymakers about necessary adjustments to educational systems. Lubienski (2008) notes, "It is dangerous for the mathematics education community to refrain from gaps analyses and allow others to speak in our place" (p. 352). Two recent cases illustrate this point. Mark Perry (2016), an economics professor at the University of Michigan Flint Campus used boys' and girls' average score differences on the mathematics portion of the SAT to assert that "closing the STEM gender degree and job gaps may be a futile attempt in socially engineering an unnatural and unachievable outcome" (para. 12). Likewise, Eric Rasmusen (2019), a professor in the highly-ranked Kelley School of Business at Indiana University, publicly and repeatedly agreed with an article entitled "Are Women Destroying Academia? Probably." In the article, differences in IQ scores were used to say that "geniuses" were most often men, and women's empathetic and emotional nature is the "enemy" of genius and, therefore, academia (Welton, 2019; see also Brice-Saddler & Paul, 2019). We find these views problematic because they frame female achievement in terms of fixed, innate characteristics.

Over the years, much scholarly work has been dedicated to understanding boys' and girls' mathematics score differences, and has produced clear evidence for a wide variety of contributing

In: Sacristán, A.I., Cortés-Zavala, J.C. & Ruiz-Arias, P.M. (Eds.). (2020). *Mathematics Education Across Cultures: Proceedings of the 42nd Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*, Mexico. Cinvestav / AMIUTEM / PME-NA. https:/doi.org/10.51272/pmena.42.2020

factors. Nearly all of these factors—high-stress and timed environments, decreased curricular alignment, negative depictions in media—are related to high mathematics anxiety, which itself is a malleable factor. If educators can lessen mathematics anxiety in early grades, then more girls might increase their confidence in mathematics and subsequently pursue STEM careers. This can have a global effect, as Smith and colleagues (2015) note, because more women in STEM increases creativity and innovation. As we discuss below, researchers have also documented that mathematics anxiety affects a larger percentage of girls than boys and operates to reduce mathematics performance. Looking across these findings suggests the question that guided our research: *To what extent does mathematics anxiety explain the small but persistent gender gap in mathematics exam performance?*

Perspectives

Mathematics Gender Gaps Analyses

Researchers have found that girls outperform boys on many school measures, from grade point average to number of undergraduate, masters, and doctoral degrees in their postsecondary years (e.g., Carnevale et al., 2018). Although several researchers have found no significant gender differences on mathematics tests like state-mandated end of course assessments, National Assessment of Educational Progress (NAEP), and Pearson's Stanford Achievement Test (e.g., Ding, et al., 2006; Hyde et al., 2008), some suggest that there still might be a slight gap in scores at the higher end of the score distribution, specifically, on more challenging items that may not have been explicitly taught in school (e.g., Downey & Vogt Yuan, 2005, Lubienski & Ganley, 2017). For instance, a 2016 study by Stewart et al. found no overall gender difference for math calculation, geometric concepts, basic math concepts, and addition. The researchers did find a significant difference in solving "real-life complex math problems," which had multiple steps and required the test-taker to respond orally (p. 53). In addition, researchers have found significant score differences on the AP Calculus exam, the mathematics SAT, and the quantitative portion of the Graduate Record Exam (Niederle & Vesterlund, 2010). Cimpian and colleagues (2016) found that score differences on the Early Childhood Longitudinal Study were significant as early as first grade at the higher end of the distribution and widened throughout elementary school. Other researchers, even as early as Aiken's 1972 publication, have found little to no score differences for elementary-aged children—especially on curriculum-aligned tests, but find that a gap in scores expands in the high school years (e.g., Aiken, 1972; Casey et al., 2001, Hyde et al., 2008).

We first discuss factors that have been shown to contribute to boys' and girls' score differences on mathematics tests. A number of researchers note that timed tests can be particularly damaging to math-anxious students (e.g., Walen & Williams, 2002; Whyte & Anthony, 2012). Neiderle and Vesterlund (2010) suggest that, on average, boys are more competitive and confident than girls and use this competitive nature in high-stress test-taking environments. As mentioned, some scholars suggest that girls perform better on school-taught material (Downey & Vogt Yuan, 2005; Lubienski & Ganley, 2017) as well as tasks that involve computations and memorized procedures (Ganley & Vasilyeva, 2014). In other words, if the test is not aligned to curriculum to which they have been exposed, boys tend to score better. Others suggest differences in the ways girls and boys solve problems, with studies showing that, as early as 1st grade, girls tend to use concrete strategies like modeling and counting while boys use more creative problem-solving strategies (Fennema et al., 1998) Lubienski and Ganley (2017) state, "Girls' teacher-pleasing behavior is likely a consequence of gender socialization and […] is likely linked to later differences in mathematical problem-solving approaches, with girls following teacher-given rules more often than boys" (p. 74). In contrast, many researchers suggest that boys tend to have better spatial skills, which could improve scores on problems with measurement, space, and shape (e.g., Halpern et al., 2007; Lubienski & Ganley, 2017). Cimpian and colleagues (2016) found that teachers consistently rated girls' mathematical proficiency lower than boys with similar achievement and behaviors. Some researchers suggest that stereotype threats and negative depictions of girls and math in the media might deter girls from pursuing STEM courses and careers, with the "math is for boys" stereotype influencing students as early as 2nd grade (e.g., Cvencek et al., 2011; Gunderson et al., 2012). Halpern and colleagues (2007) believe sociocultural forces such as parent beliefs and expectations, teacher encouragement, and peer influences contribute to score differences. Van Langden and colleagues (2006) suggest that the more gender equality in a country, the smaller the score differences. They also posit that girls do better in math when they are in "integrated classrooms" instead of "differentiated systems," i.e., separate classes in which students are placed according to ability. In sum, competitive environments, timed tests, decreased curricular alignment, teacher-pleasing behaviors, less gender equity in a country, a "math is for boys" viewpoint—almost all factors mentioned—could be related to mathematics anxiety.

Mathematics Anxiety

Mathematics anxiety has been defined as "a feeling of tension and anxiety that interferes with the manipulation of numbers and the solving of mathematical problems in a wide variety of ordinary and academic situations" (Richardson & Suinn, 1972, p. 551). It differs from general anxiety and test anxiety; math anxiety can be exhibited in people who excel in testing situations in other subjects, and it can occur even during anticipation of interacting with numbers.

Dowker (2019) describes two dimensions of mathematics anxiety: cognitive and affective. The cognitive dimension closely relates to test anxiety and involves performance anxiety, worry, and "fear of failure." The affective dimension is often labeled as "emotionality" and refers to fear, nervousness, tension, and their related physiological reactions. Most importantly, the affective dimension occurs in the presence of numerical situations, with or without a test. Mathematics anxiety is not just correlated to performance deficits, but many researchers have suggested that mathematic anxiety has a causal relationship with performance deficits (e.g., Hembree, 1990; Ma, 1999). Ma (1999) describes two theoretical models that typically guide mathematics anxiety research: an interference model and a deficits model. In the interference model, mathematics anxiety disturbs the recall of prior knowledge and experiences, often causing lower scores; some scholars refer to this as the "debilitating anxiety model" (Carey et al., 2016). In the deficits model, researchers believe repeated poor performances produce increased levels of mathematics anxiety. In this model, lower scores are often attributed to poor test-taking skills and study habits. Several researchers have posited a bidirectional relationship between these two models, creating a vicious cycle of high mathematics anxiety and low mathematics scores (e.g., Carey et al., 2016; Dowker, 2019).

Working memory and the brain. Math anxiety has been shown to deprive people of their working memory, leading to lower scores, supporting Ma's interference model (e.g., Beilock & Willingham, 2014; Dowker, 2019). One might think that students with larger amounts of working memory could memorize every fact and formula and thus have lower levels of mathematics anxiety, but a counterintuitive result has been found. Children with high levels of working memory have a more pronounced negative relationship between math anxiety and math achievement (e.g., Beilock & Willingham, 2014; Dowker, 2019; Lubienski & Ganley, 2017; Lyons & Beilock, 2012; Maloney & Beilock, 2012). Dowker (2019) posits that those with higher levels of mathematics anxiety have more preoccupying thoughts and mental rumination, depleting crucial working memory resources. Consistent with Dowker's findings, Maloney and Beilock (2012) say, "Math anxious individuals tend to worry about the situation and its consequences. These worries compromise cognitive resources, such as working memory, a short-term system involved in the regulation and control of information relevant to the task at hand" (p. 404). In other words, students might be quite talented at memorizing formulas and procedures for use in normal classroom activities or homework, but the effects of mathematics anxiety might break down these rote procedures during stressful situations. Although other students might be able to solve the problem in a creative or novel way, students who have relied on rote memorization could further deplete their cognitive resources.

Neurologically, children with math anxiety show more activity in their right amygdala when performing mathematical tasks, and this area of the brain is known for processing negative emotions and fear (e.g., Beilock & Willingham, 2014; Chang & Beilock, 2016). When the right amygdala was active, there was a decrease in activity in the areas of the brain responsible for mathematical reasoning (Chang & Beilock, 2016). Psychologists at the University of Chicago refer to this as "working memory disruption," hypothesizing that students with higher working memory resources often use algorithms and problem-solving strategies with multiple steps, which are more susceptible to disruption during situations that induce anxiety (Ramirez et al., 2013). Further, Lyons and Beilock (2012) showed that the anticipation of doing math triggered the dorso-posterior insula in the brain, which is the area of the brain associated with bodily threat but also visceral pain; therefore, mathematics anxiety can be neurologically associated with physical pain.

Teacher, peer, and parent influences. Several researchers have noted how others might influence a student's level of mathematics anxiety. As early as 1959, Banks suggests that repeated failure, parents' and peers' unhealthy attitudes towards mathematics, and teacher insecurities can all contribute to students' negative associations with mathematics. Beilock et al. (2010) agree that mathematically anxious teachers at the elementary level impact students' mathematics achievement, especially when girls mimic the anxieties of their female teachers. Unfortunately, this can be a cyclical problem as the majority of elementary teachers are female, and a disproportionate number of preservice teachers have mathematics anxiety or worry that they will be unable to teach mathematics effectively. Brown and colleagues (2011) found this number to be 60% of preservice teachers, while Jackson and Leffingwell (1999) found that only 7% of preservice teachers in their study had only positive mathematics experiences in their K-16 schooling. Whyte and Anthony (2012) suggest that parents who suffer from math anxiety can transfer this to their children, and parents who give math a low status or, contrastingly, apply extra pressure to their children may contribute to mathematics anxiety as well.

Interventions to Decrease Math Anxiety

Some researchers have suggested that there is an optimal amount of mathematics anxiety that will positively affect performance. The graph is a curvilinear relationship, an inverted U-shaped curve. Cognitive reactions to mathematics anxiety might include "blanking out" or self-doubt, while an affective reaction might include the fear of looking stupid. Physical reactions for both dimensions might include perspiring, an increased heart rate, or nausea (Frieberg, 2005). In a 2010 study, researchers informed one group of participants that anxiety could help to improve performance but said nothing to the control group (Jamieson et al., 2010). When students took a practice Graduate Record Examination (GRE), the control group had more salivary alpha amylase (sAA)—an indicator of stress—than the test group. In addition, the group that was told anxiety improves performance had higher scores both on the practice test and on the actual GRE, taken 1-3 months later.

Jamieson et al. had a simple approach for lessening the impact of mathematics anxiety on high-stakes standardized tests like the GRE, but others have posited interventions to help with mathematics anxiety in everyday situations. In recent years, Ganley et al. (2019), have proposed the use of the Math Anxiety Scale for Teachers (MAST) to reduce the harmful effects of teachers' mathematics anxiety on students' learning. They note that teachers with high levels of mathematics anxiety avoid the subject, spending less time on mathematics lessons, especially in whole class discussions. Whyte and Anthony (2012) suggest promoting a positive classroom culture with effective teaching practices, such as having students share creative approaches to problem solving. They also suggest utilizing math fiction books, journal writing, and math autobiographies in the classroom. Researchers who noted the negative impact of timed tests (e.g., Walen & Williams, 2002; Whyte & Anthony, 2012) suggested providing ample time for assessments. Recently, Schaeffer et al. (2018) used an app to help mathematically anxious parents creatively interact with their children while discussing mathematics. After using the app for even a short period of time, parents reported feeling less anxious about math, and these results were maintained even two years after the study. This was an important finding, as parents' negative associations with math are often reflected in their children. Maloney and Beilock (2012), also note the importance of journal writing, saying that writing about emotions for 10-15 minutes before a test can boost the scores of students with mathematics anxiety. Lastly, students develop a negative relationship with mathematics when they are told there is only one right way to do a problem. When less emphasis is put on memorization and more weight is placed on creative problem-solving, students are less dependent on their working memory when working on mathematics problems.

Methods

Data for the present study come from the public release version of the 2012 US PISA data set. These data were selected because they are nationally representative, include trustworthy instruments measuring the focal constructs of our investigation (i.e., mathematics anxiety and of student achievement) as well as important covariates. More recent PISA data has not included the variables of interest. Participants were 4978 students aged 15 to 16 years old. The sample was 50.7% male, 52% White, 13.1% Black, 24.0% Hispanic, 4.6% Asian, 4.3% identified as multiracial, and 2.1% identified as other (n = 67, missing).

We used the PISA mathematics score as the dependent variable in our analysis. Because not all students answer the same questions when taking the PISA assessment, five plausible values are reported for each student instead of a single score. The differences between the plausible values for a specific student capture the uncertainty about the student's estimated math score. We completed the analyses described below with each of the five math scores, then used accepted methods to pool results (Rubin, 1987).

The first independent variable was a math anxiety instrument based on 5 rating items (e.g., "I often worry that it will be difficult for me in mathematics classes," "I get very tense when I have to do mathematics homework," "I get very nervous when doing mathematics problems," "I feel helpless when solving a mathematics problem," and "I worry that I will get poor grades in mathematics"). The composite score for the five-item math anxiety questionnaire was available within the PISA dataset. According to the technical report (OECD, 2014), the variable was transformed to an international metric with a mean of 0 and a standard deviation of 1 for all OECD countries that participated in the PISA 2012 (OECD, 2014). The internal validity of this multi-item construct was evaluated with Cronbach alpha = 0.88 and deemed to have good internal consistency. The sample mean was -0.104 and ranged between -2.370 and 2.550. By design, not all students answered each section of the survey. Thus, there were 1720 students with missing scores on the math anxiety measure. We used full information maximum likelihood estimator which is robust to missing data and this technique allowed us to include all students in the analysis. Self-reported gender was the second independent variable, and a summary of this variable is provided above. Finally, we used the PISA standardized index of economic, social and cultural status (ESCS) which summarizes occupational status, parent education, family wealth, home educational resources, and an index of possessions relative to each country context. The sample mean was 0.188 and ranged between -3.80 and 3.12 (n = 63, missing).

A mediation effect is said to occur when a mediating variable helps explain or account for the relationship between an independent and dependent variable. For example, in this study we wanted to know if the relationship between gender and mathematics score is mediated by math anxiety. A moderation effect occurs when a moderating variable influences the effect of the dependent variable on the independent variable. For example, gender is said to moderate the relationship between math anxiety and math scores if the relationship between these variables differed by gender. Moderated mediation describes a theoretical model that includes a variable that moderates the mediating effect of another variable on the outcome. In this study, we wanted to know whether the extent to which math anxiety accounts for the relationship between gender and math scores differs by gender—a moderated mediation model.

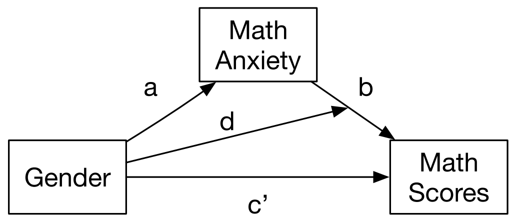

Figure 1: Conceptual model for moderated mediation.

As shown in Figure 1, the total effect of gender on math scores is the sum of the direct effect, c', and the indirect (or mediated) effect, a x b. The coefficient d describes how gender moderates the mediating effect of math anxiety on the relationship between gender and math scores. Following Shevlin et al. (2015) we operationalized moderated mediation by testing the path diagram in Figure 2 which includes an interaction term between gender and math anxiety. In this figure, the moderated mediation is investigated by examining coefficient d, which quantifies the gender difference in the math anxiety, math score relationship. We used lavaan, an R package, to estimate two structural equation models for (1) mediation and (2) moderated mediation for each of the five plausible values for the outcome variable. We used another R package (mice) to combine the results across the five models we estimated. We compared these models with a regression model that used gender and other covariates to predict math scores.

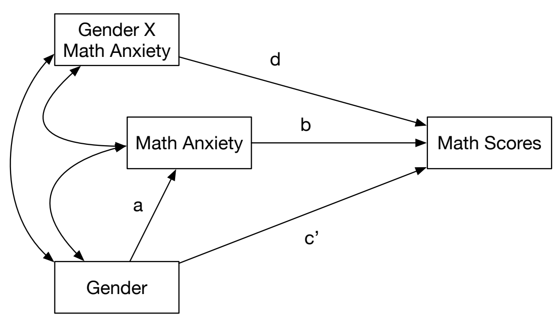

Figure 2: Path diagram used for analyzing moderated mediation.

Results

In the baseline regression model (see Table 1), we found a small (0.093), statistically significant (p < .001) relationship between gender and math scores in our sample after controlling for race and ESCS. The goal of our subsequent analysis was to understand how much of this relationship could be explained by mathematics anxiety. The second model shows that once anxiety is included as a mediating variable, the relationship between gender and math scores is no longer statistically significant (0.020, p = 0.42). Thus, in this sample, anxiety completely mediates the relationship between gender and math scores. The total effect is still the same (0.093, p < .001), but most of this effect is indirect via math anxiety (0.074, $p < .001$). The size of this effect can be quantified as the percent mediation: the indirect effect explains 80% of the total effect.

In the final model, the relationship between gender and math scores is not statistically significant (0.009, $p = 0.71$). In this model we can compare the indirect effects by gender. For males, the indirect effect is 0.085 ($p < .001$) and for females the indirect effect is 0.064 ($p < .001$). Moreover, the difference is statistically significant (.021, $p < .01$). We concluded that gender does influence the extent to which math anxiety explains the relationship between gender and math scores, and in particular, we found a stronger indirect relationship between these variables for male students.

Table 1: Regression and path coefficients for the baseline regression model and for the mediation and moderated mediation models.

	Regression Model	Mediation Model	Moderated Mediation
predicting Math Scores	β (SE)	β (SE)	β (SE)
Male	0.093 (0.025) ***	0.02 (0.024)	0.009 (0.024)
Anxiety		-0.333 (0.013) ***	-0.288 (0.018) ***
Male by Anxiety			-0.096 (0.027) ***
ESCS	0.334 (0.014) ***	0.283 (0.014) ***	0.283 (0.014) ***
Black	-0.833 (0.039) ***	-0.817 (0.038) ***	-0.81 (0.038) ***
Hispanic	-0.273 (0.034) ***	-0.277 (0.032) ***	-0.276 (0.032) ***
Asian	0.47 (0.061) ***	0.427 (0.058) ***	0.425 (0.058) ***
Multicultural	-0.083 (0.063)	-0.12 (0.06) *	-0.131 (0.06) *
Other race	-0.647 (0.09) ***	-0.604 (0.086) ***	-0.596 (0.086) ***
predicting Anxiety			
Male		-0.222 (0.036) ***	-0.222 (0.036) ***
ESCS		-0.151 (0.02) ***	-0.151 (0.02) ***
Black		0.048 (0.057)	0.049 (0.056)
Hispanic		-0.011 (0.048)	-0.011 (0.048)
Asian		-0.13 (0.087)	-0.129 (0.086)
Multicultural		-0.113 (0.091)	-0.113 (0.091)
Other race		0.13 (0.131)	0.13 (0.131)
Direct & Indirect Effects			
Male Indirect			0.085 (0.014) ***
Female Indirect			0.064 (0.011) ***
Difference Male/Female Indirect			0.021 (0.007) **
Indirect Effect		0.074 (0.012) ***	0.064 (0.011) ***
Total Effect		0.093 (0.025) ***	0.073 (0.025) **

Limitations

This study used cross-sectional data, therefore only associations—not causal relationships—can be investigated. Furthermore, mediation relationships depend on theory—not statistics. If the mediation model we presumed for this study is not accurate, then the results of the model are not meaningful (Maxwell & Cole, 2007). Finally, our conceptual model has anxiety causally preceding mathematics scores. Although we have argued in our review of the literature that this assumption is reasonable, not all scholars agree. Moreover, the data we used in this study cannot be used to settle this question because they are cross-sectional and non-experimental.

Discussion and Implications

The goal of this study was to better understand the influence of mathematics anxiety on the small but persistent gender gap in mathematics achievement. We applied moderated mediation to rigorously investigate these relationships, attending to missing data, and controlling for potential confounding variables at the same time. This rigorous method enabled us to accurately evaluate the associations between multiple variables in a large sample data set and draw robust conclusions.

Based on a large sample of 15-year-old students in the US, the results show that math anxiety entirely mediated the association between gender and math scores. In particular, the higher math anxiety of female students entirely explained female students' lower math scores. We also examined a moderated mediation model, in which we allowed the relationship between math anxiety and math scores to vary by gender. The results show that gender does moderate the mediation relationship between math anxiety and math scores. In particular, the anxiety of male students had a stronger negative association with mathematics scores than did the math anxiety of female students. Further, the moderated mediation finding suggests that although there are fewer male than female math-anxious students, the male students who have math anxiety may benefit more than similar female students from interventions because their experience of anxiety is more debilitating. Our results suggest that known interventions that decrease mathematics anxiety might be helpful in narrowing or eliminating the gender gap in mathematics achievement. For example, de-emphasizing rote memorization and encouraging creative problem-solving can lessen mathematics anxiety in early grades. As girls' mathematics anxiety has been linked to their math-anxious teachers in elementary grades, further studies using tools like the Mathematics Anxiety Scale for Teachers (Ganley et al., 2019) would be beneficial. In addition, it will be important to investigate math anxiety's relationship to other factors related to boys' and girls' score differences, such as high-stress environments, decreased curricular alignment, and negative depictions in media.

References

Aiken Jr, L. R. (1972). Research on Attitudes Toward Mathematics. *Arithmetic Teacher*, *19*(3), 229-234.

Banks, J. H. (1959). *Learning and teaching arithmetic*. Allyn and Bacon.

Beilock, S. L., Gunderson, E. A., Ramirez, G., & Levine, S. C. (2010). Female teachers' math anxiety affects girls' math achievement. *Proceedings of the National Academy of Sciences*, 107(5), 1860-1863.

Beilock, S. L., & Willingham, D. T. (2014). Math Anxiety: Can Teachers Help Students Reduce It? Ask the Cognitive Scientist. *American educator*, *38*(2), 28-32.

Botkin-Kowacki, E. (2017, January 27). *Study: 6-year old girls say they are less 'brilliant' than boys. Why?* The Christian Science Monitor. https://www.csmonitor.com/Science/2017/0127/Study-6-year-old-girls-say- they-are-less-brilliant-than-boys.-Why

Brice-Saddler, M. & Paul, D. University says a professor's views are racist, sexist and homophobic - but it can't fire him. The Washington Post. Retrieved from http://washingtonpost.com.

Brown, A. B., Westenskow, A., & Moyer-Packenham, P. S. (2011). Elementary Pre-Service Teachers: Can They Experience Mathematics Teaching Anxiety without Having Mathematics Anxiety?. *Issues in the Undergraduate Mathematics Preparation of School Teachers*.

Carey, E., Hill, F., Devine, A., & Szücs, D. (2016). The chicken or the egg? The direction of the relationship between mathematics anxiety and mathematics performance. *Frontiers in psychology*, *6*, 1-6. https://doi.org/10.3389/fpsyg.2015.01987

Casey, M. B., Nuttall, R. L., & Pezaris, E. (2001). Spatial-mechanical reasoning skills versus mathematics self-confidence as mediators of gender differences on mathematics subtests using cross-national gender-based items. *Journal for research in mathematics education*, 28-57. https://doi.org/10.2307/749620

Chang, H., & Beilock, S. L. (2016). The math anxiety-math performance link and its relation to individual and environmental factors: A review of current behavioral and psychophysiological research. *Current Opinion in Behavioral Sciences*, 10, 33-38.

Cimpian, A., & Leslie, S. (2017, January 26). *Why young girls don't think they are smart enough.* The New York Times. https://www.nytimes.com/2017/01/26/well/family/why-young-girls-dont-think-they-are-smart-enough.html

Cimpian, J. R., Lubienski, S. T., Timmer, J. D., Makowski, M. B., & Miller, E. K. (2016). Have gender gaps in math closed? Achievement, teacher perceptions, and learning behaviors across two ECLS-K cohorts. *AERA Open,* 2(4), 1-19, DOI: 10.1177/2332858416673617.

Cvencek, D., Meltzoff, A. N., & Greenwald, A. G. (2011). Math–gender stereotypes in elementary school children. *Child development*, *82*(3), 766-779. https://doi.org/10.1111/j.1467-8624.2010.01529.x

Ding, C. S., Song, K. I. M., & Richardson, L. I. (2006). Do mathematical gender differences continue? A longitudinal study of gender difference and excellence in mathematics performance in the US. *Educational Studies*, *40*(3), 279-295. http://doi.org/10.1080/00131940701301952

Dowker, A. (2019). Mathematics Anxiety and Performance. *Mathematics Anxiety: What Is Known, and What is Still Missing*, Routledge, 62-76.

Downey, D. B., & Vogt Yuan, A. S. (2005). Sex differences in school performance during high school: Puzzling patterns and possible explanations. *The Sociological Quarterly*, *46*(2), 299-321. https://doi.org/10.1111/j.1533-8525.2005.00014.x

Fennema, E., Carpenter, T. P., Jacobs, V. R., Franke, M. L., & Levi, L. W. (1998). A longitudinal study of gender differences in young children's mathematical thinking. *Educational researcher*, *27*(5), 6-11. https://doi.org/10.2307/1176733

Freiberg, M. (2005). Math--that four-letter word! *Academic Exchange Quarterly*, 9(3), 7–12.

Ganley, C. M., Schoen, R. C., LaVenia, M., & Tazaz, A. M. (2019). The Construct Validation of the Math Anxiety Scale for Teachers. Aera Open, 5(1), 2332858419839702.

Ganley, C. M., & Vasilyeva, M. (2014). The role of anxiety and working memory in gender differences in mathematics. *Journal of Educational Psychology,* 106(1), 105-120.

Gunderson, E. A., Ramirez, G., Levine, S. C., & Beilock, S. L. (2012). The role of parents and teachers in the development of gender-related math attitudes. *Sex roles*, *66*(3-4), 153-166. https://doi.org/10.1007/s11199-011-9996-2

Gutiérrez, R. (2008). A" gap-gazing" fetish in mathematics education? Problematizing research on the achievement gap. *Journal for Research in Mathematics Education*, 357-364.

Hembree, R. (1990). The nature, effects, and relief of mathematics anxiety. *Journal for research in mathematics education*, 33-46.

Hyde, J. S., Lindberg, S. M., Linn, M. C., Ellis, A. B., & Williams, C. C. (2008). Gender similarities characterize math performance. *Science*, *321*(5888), 494-495. https://doi.org/10.1126/science.1160364

Jackson, C. D., & Leffingwell, R. J. (1999). The role of instructors in creating math anxiety in students from kindergarten through college. *The Mathematics Teacher*, *92*(7), 583-586.

Jamieson, J. P., Mendes, W. B., Blackstock, E., & Schmader, T. (2010). Turning the knots in your stomach into bows: Reappraising arousal improves performance on the GRE. *Journal of experimental social psychology*, *46*(1), 208-212. https://doi.org/10.1016/j.jesp.2009.08.015

Lubienski, S. T. (2008). On" gap gazing" in mathematics education: The need for gaps analyses. *Journal for Research in Mathematics Education*, 350-356.

Lubienski, S. T., & Ganley, C. M. (2017). Research on gender and mathematics. *Compendium for research in mathematics education*, 649-666.

Lyons, I. M., & Beilock, S. L. (2012). Mathematics anxiety: separating the math from the anxiety. *Cerebral cortex*, *22*(9), 2102-2110. https://doi.org/10.1093/cercor/bhr289

Ma, X. (1999). A meta-analysis of the relationship between anxiety toward mathematics and achievement in mathematics. *Journal for research in mathematics education*, 520-540. https://doi.org/10.2307/749772

Maloney, E. A., & Beilock, S. L. (2012). Math anxiety: Who has it, why it develops, and how to guard against it. *Trends in cognitive sciences*, 16(8), 404-406.

Maxwell, S. E., & Cole, D. A. (2007). Bias in cross-sectional analyses of longitudinal mediation. Psychological methods, 12(1), 23. https://doi.org/10.1037

Niederle, M., & Vesterlund, L. (2010). Explaining the gender gap in math test scores: The role of competition. *Journal of Economic Perspectives*, *24*(2), 129-44. https://doi.org/10.1257/jep.24.2.129

Organisation for Economic Co-operation and Development (OECD). (2012). *Programme for International Student Assessment (PISA) 2012.* OECD. https://www.oecd.org/pisa/data/pisa2012database-downloadabledata.htm

Organisation for Economic Co-operation and Development (OECD). (2014). PISA 2012 technical report.

Perry, M. (2016, September 27). 2016 SAT test results confirm pattern that's persisted for 50 years—High school boys are better at math than girls. Retrieved from http://www.aei.org/publication/2016-sat-test-results-confirm-pattern-thats-persisted-for-45-years-high-school-boys-are-better-at-math-than-girls/

Ramirez, G., Gunderson, E. A., Levine, S. C., & Beilock, S. L. (2013). Math anxiety, working memory, and math achievement in early elementary school. *Journal of Cognition and Development*, *14*(2), 187-202. https://doi.org/10.1080/15248372.2012.664593

Rasmusen, E. [@erasmuse]. (2019, November 7). Geniuses are overwhelmingly male because they combine outlier IQ with moderately low Agreeableness and Moderately low Conscientiousness" [Tweet]. Retrieved from https://twitter.com/erasmuse/status/1192591814567563266

Richards, A. (2018, April 9). *Men in science think they are more intelligent than female counterparts, study reveals.* Evening Standard. https://www.standard.co.uk/news/world/men-in-science-think-they-are-more-intelligent-than-female-counterparts-study-reveals-a3809496.html

Richardson, F. C., & Suinn, R. M. (1972). The mathematics anxiety rating scale: psychometric data. *Journal of Counseling Psychology*, 19(6), 551-554. https://doi.org/10.1037/h0033456

Rubin, D.B. (1987). *Multiple Imputation for Nonresponse in Surveys*. New York: John Wiley and Sons.

Schaeffer, M. W., Rozek, C. S., Berkowitz, T., Levine, S. C., & Beilock, S. L. (2018). Disassociating the relation between parents' math anxiety and children's math achievement: Long-term effects of a math app intervention. *Journal of Experimental Psychology: General*, *147*(12), 1782. https://doi.org/10.1037/xge0000490

Shevlin, M., Miles, J. N., Kulesza, M., Ewing, B., Shih, R. A., Tucker, J. S., & D'Amico, E. J. (2015). Moderated mediation analysis: An illustration using the association of gender with delinquency and mental health. *Journal of criminal psychology.*

Smith, J. L., Handley, I. M., Zale, A. V., Rushing, S., & Potvin, M. A. (2015). Now hiring! Empirically testing a three-step intervention to increase faculty gender diversity in STEM. *BioScience*, 65(11), 1084-1087.

Stewart, C., Root, M., Koriakin, T., Choi, D., Luria, S., Bray, M., & Courville, T. (2017). Biological gender differences in students' errors on mathematics achievement tests. *Journal of Psychoeducational Assessment*, *35*(1-2), 47-56. https://doi.org/10.1177/0734282916669231

Van Langen, A., Bosker, R., & Dekkers, H. (2006). Exploring cross-national differences in gender gaps in education. *Educational Research and Evaluation*, *12*(02), 155-177. https://doi.org/ 10.1080/13803610600587016

Walen, S. B., & Williams, S. R. (2002). A matter of time: Emotional responses to timed mathematics tests. *Educational Studies in Mathematics*, *49*(3), 361-378.

Welton, L. (2019, November 2). *Are women destroying academia? Probably.* The Unz Review: An Alternative Media Selection. https://www.unz.com/article/are-women-destroying-academia-probably/

Whyte, J., & Anthony, G. (2012). Maths anxiety: The fear factor in the mathematics classroom. *New Zealand Journal of Teachers' Work*, 9(1), 6-15.