Exploring the Relationship Between Math Anxiety, Working Memory, and Experiences

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introduction

Math anxiety has been described as "a feeling of tension, apprehension, or fear that interferes with math performance" [1]. Math anxiety is all too common in classrooms and can be a barrier to students reaching their fullest potential by limiting their career paths [2], [3]. Studies have shown there are multiple factors which influence the formation and existence of math anxiety such as working memory, math experiences, and the student's interpretation of experiences [4]–[7], but little is known concerning how these relate with each other. In this study, we seek to (1) understand how students with differing math anxiety levels and working memory levels interpret math experiences and (2) identify teaching strategies and math experiences that can be used for math anxiety intervention. We are also piloting this design to help inform future projects and a new conceptual framework for math anxiety. We used a concurrent embedded mixed methods research design wherein a qualitative case study is embedded in a quantitative correlational study. Surveys were distributed to Calculus I students in the Fall 2020 semester. The survey included (1) the Abbreviated Math Anxiety Scale (AMAS) test to assess math anxiety (MA), (2) the Operation Span (OSPAN) test to assess working memory capacity (WMC), and (3) a math experience questionnaire. Four groups of students were identified according to high/low AMAS scores and high/low OSPAN scores. Students were recruited from each of these groups for a semi-structured interview. Qualitative analysis of the interview data explored the effects attributed to both positive and negative math experiences and investigated relationships among the groups. Note that this study is a work in progress with preliminary findings.

Background

Although math anxiety may not be a learning disability in the conventional way of defining a disability, in the words of Ashcraft & Moore [8], "math anxiety functions as a disability in the sense that there are well investigated – and negative – personal, educational, and cognitive consequences of math anxiety." Ashcraft and Moore estimated that 17% of the population has high math anxiety. Betz proposed that 68% of students in mathematics classes experience high levels of math anxiety [9]. This is most unfortunate as research indicates that those with high levels of math anxiety tend to avoid math coursework and college majors known to have a heavy emphasis on math, thus limiting the career paths available to the student [2], [3]. It is a well-established fact that math anxiety is negatively correlated with mathematics performance [4], [8], [10]. This does not necessarily imply that math anxiety is an indicator of lower potential to succeed in mathematics. In her book, *Overcoming Math Anxiety,* Sheila Tobias argues that math anxiety "is not a failure of intellect but a failure of nerve" [3]. She describes the common attitude towards mathematics as more than just a subject for most people – "it is a *relationship* between themselves and a discipline purported to be "hard" and reserved only for an elite and powerful few" (p.9).

Chang & Beilock define working memory as a "limited short-term memory system that enables one to attend to the relevant task at hand while inhibiting irrelevant information" [11]. Math anxiety and stress have been shown to overload working memory resources [4]. When working memory resources are overloaded, the student has less available resources needed for mathematical operations. The same study also showed that those with higher levels of math anxiety tend to have lower working memory capacities than others. When working memory resources are overloaded by the stress associated with math anxiety, mathematical operations become increasingly abstract to the student [8]. In Ashcraft & Moore's model, a student with sufficient math skill, motivation, and working memory should exhibit sufficient performance in math. A deficiency in either math skill, motivation, or working memory can be a risk factor in diminished math performance. While Ashcraft & Moore do not conclude those with poor math abilities are unable to succeed in mathematics, their model does suggest that those with poor math abilities are more at risk for falling behind their student peers, receiving negative feedback, and may develop negative attitudes towards math.

Another key finding of working memory's relationship with math anxiety is that students with higher working memory capacity tend to demonstrate a stronger negative relationship between math anxiety and performance [10], [11]. As a result, those with a higher potential to succeed in mathematics may be the most susceptible to the damages of math anxiety.

Arnsten [12] and Diamond et al. [13] have shown that moderate levels of anxiety can help focus attention and enhance working memory which is known to be a major factor in math competence. It has also been shown that the negative correlation between math anxiety and math performance is strongest for those with high working memory capacity [10]. Though there has been much research on working memory and situational factors associated with math anxiety [2], [7], [8], [14]–[19], to our knowledge there is minimal research which synthesizes the data on working memory with classroom experiences relating to math anxiety. Furthermore, few studies on math anxiety include participants with a broad range of math anxiety levels [20], [21]. Understanding the relationship between working memory, situational factors, and anxiety may provide more insight into the causes of math anxiety in order to better identify indicators of math anxiety and construct better, more appropriate interventions for math anxiety.

quantitative analysis

Methods

Surveys were distributed to students enrolled in Calculus I at an R1 institution at the beginning of the Fall 2020 semester. Participants were each awarded a $5 Amazon gift card. We collected responses from 100 students, and after excluding incomplete surveys and outliers, 76 total participants (M_{age} = 18.30, SD_{age} = 1.45; 39 females, 36 male, 1 gender-fluid) completed the surveys. The software program G*Power 3.1 was used to conduct power analysis. The goal was to obtain .80 power to detect a medium effect size of .15 at the standard .05 alpha error probability. With the variables of experiences, math anxiety, and working memory spans, we needed a sample size of 77 to reach .80 power.

We measured four predictor variables: (1) OSPAN scores - proxy for working memory capacity [22] (2) experience - level of reported significance of positive math experience (3) experience - level of reported significance of negative math experience (4) experience - categories defined by coding responses (e.g. teacher-related, peer-related, parent-related, etc . . .). The outcome variable was AMAS score, a proxy for math anxiety [14].

Measures

Abbreviated Math Anxiety Scale (AMAS) [14]: a 9-item Likert-scale questionnaire to measure math anxiety.

Operation-Span Working Memory Assessment (OSPAN) [23]**:** a test in which the participant is asked to hold information while completing simple computation tasks. On each trial, a simple arithmetic problem is presented, such as "(8/2) + 1 = 2", and participants must indicate whether the answer provided is true or false. Participants must respond within four seconds, or their response is counted as incorrect. Upon responding to the arithmetic problem, participants are shown a letter for two seconds. After viewing strings of 3 - 7 letters, participants are asked to recall the letter strings in order. Instructions stated that the goal of the task was to try to maintain at least 85% accuracy on the arithmetic problems while also recalling the letters in order. Participants completed three practice trials, and then completed 75 total test trials (three trials for each letter string length). The OSPAN score was operationalized as the total number of letters recalled in order correctly. Scores could range from 0 - 75.

Math Experience Questionnaire (Table 1)**:** a 10-item questionnaire which assessed perceptions and attitudes toward math, significant positive and negative math experiences, and the level of significance participants attributed to these experiences in shaping their views toward math. The questionnaire was designed specifically for this pilot study.

Table 1
Math Experience Questionnaire

Prompt	Response Type
Q1: Why do you think mathematics is important for society? (Open-ended)	Open-ended
Q2-Q4: How do you feel about the following general mathematics aspects of your schoolwork: Computation, Theory & Logic, Word Problems & Applications.	Dislike Very Much, Dislike a Little, Like a Little, Like Very Much
Q5: How prepared by your previous math courses do you feel for your current math courses? I feel ___% Prepared.	0-100%, Intervals of 10
Q6: Please describe an experience in which someone did something to INCREASE your math confidence.	Open-ended
Q7: How significant was this experience in affecting your math confidence?	It made NO difference (0) to

	It GREATLY affected my math confidence (10)
Q8: Please describe an experience in which someone did something to DECREASE your math confidence.	Open-ended
Q9: How significant was this experience in affecting your math confidence?	It made NO difference (0) to It GREATLY affected my math confidence (10)
Q10: Are there events at home that stand out for you in shaping your feelings about math? If so, please describe the events.	Open-ended

Results

Descriptive Statistics. OSPAN working memory capacity scores ranged from 48 - 75 (M = 64.81, SD = 6.52), and AMAS math anxiety scores ranged from 12 - 39 (M = 26.19, SD = 5.97).

Correlational Results among OSPAN Working Memory Capacity, Math Anxiety (AMAS), and Likeability of Math Aspects. Correlation results indicated that AMAS math anxiety scores were negatively associated with each likeability of mathematical computation, theory and logic, and word problems (Table 2), which suggests that math anxiety decreases student likeability of math in general. Additionally, high working memory capacity was associated with greater likeability of theory and logic problems. Working memory capacity and AMAS scores were not significantly related, $r = -.04$, $p=.75$.

Table 2
Pearson Correlation Matrix for OSPAN, Math Anxiety, and Likeability of Math Aspects

	Computation	Theory & Logic	Word Problems
OSPAN Working Memory Capacity	0.03	0.26*	0.01
Math Anxiety (AMAS Scores)	-0.25*	-0.24*	-0.39**

Note. *indicates significance at the p<.05 level
** indicates significance at the p<.01 level

Additionally, regression analyses were performed to examine interaction effects between OSPAN working memory and AMAS scores on likeability of each of the math aspects. Results revealed a marginally significant interaction for Word Problems (β = -2.01, p=.08), but not for computation (p=.97) or theory and logic (p=.24). Examination of the OSPAN X AMAS interaction was conducted by performing median splits (Mdn=65) for OSPAN scores and conducting correlations between AMAS scores and likeability of word problems within the high and low OSPAN groups. Results showed that among those with high working memory capacity (*n*=37), AMAS was strongly negatively correlated with likeability of word problems, r = -.51, p=.001. In contrast, the correlation between AMAS and word problem likeability did not reach statistical significance (r = -.22, p=.18) among participants with low working memory capacity (*n*=37). Figure 1 shows these results.

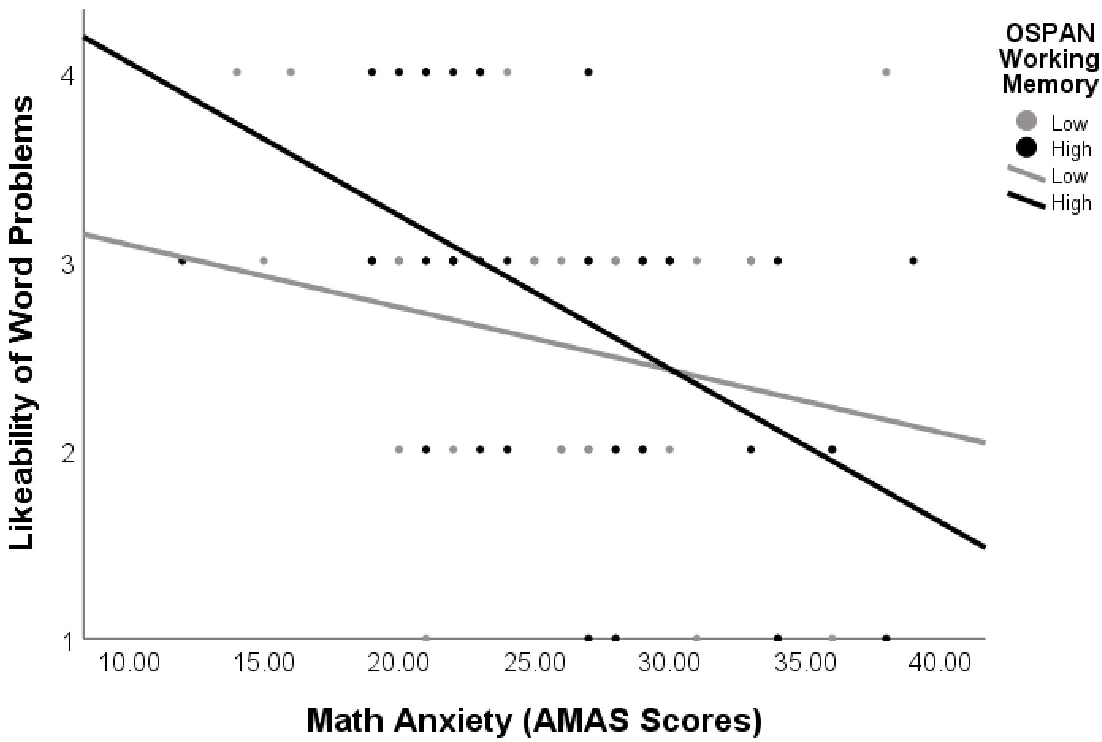

Figure 1. The relationship between math anxiety and likeability of mathematical word problems in individuals with high (black line) and low (gray line) working memory capacity.

Correlational Results among OSPAN Working Memory Capacity, Math Anxiety (AMAS), and Perceived Preparedness for Math Courses. Students were asked to indicate at what percent they feel prepared for the math course. There was significant association found with this variable and the AMAS scores (r = -.38, p=.001).

Participants were also asked if they had a negative math experience that decreased their confidence in mathematics and were asked to assign a level of significance to this experience. This level of significance was significantly associated with the AMAS scores (r = .31, p = .007), although when asked if they had a positive math experience that increased and their confidence, the assigned level of significance was not associated with the AMAS scores (r = -.01, p = .93.).

qualitative analysis

Methods

12 semi-structured interviews were conducted with participants selected according to their math anxiety (AMAS) and working memory capacity (OSPAN) scores. The goal was to interview four students for each group, but we were unable to interview 4 students for Groups 2-4 (See Tables 3, 4).

Table 3

Groups interviewed according to AMAS and OSPAN scores

	Low OSPAN	High OSPAN
Low AMAS	**Group 1** Student 7 Student 8 Student 11 Student 12	**Group 2** Student 1 Student 2 Student 5
High AMAS	**Group 3** Student 6 Student 10	**Group 4** Student 3 Student 4 Student 9

Table 4

Quantitative Characteristics of each of the Groups Interviewed

	Low AMAS, Low WMC	High AMAS, Low WMC	Low AMAS, High WMC	High AMAS, High WMC
OSPAN Math Score	65.5	69	71.7	70.7
Computation	2.25	4	4	3.33
Theory & Logic	3.25	2.5	3.33	2
Word Problems	3	2.5	4	2.33

Pct Prepared for Math Classes	67.5	70	93.3	70
Pct Increase in Confidence	7.75	7	9.7	6.7
Pct Decrease in Confidence	5	6	3	7.3

Interview prompts were divided into two parts: (1) General Stress/Anxiety Relating to School and (2) Math Experiences. The first set of prompts dealt with general stress or anxiety relating to school and investigated time management, study skills, and perceptions of anxiety, and aspects of school the student enjoys. The second set of prompts dealt with math anxiety, anxiety management, perceptions of the use of math proofs in the classroom, and significant math experiences, both positive and negative.

Qualitative analysis of the data was conducted as part of an undergraduate creative inquiry course where students were involved in coding the data, analyzing the data, and writing up a final report of the findings. The semester project was purely qualitative and dealt only with the topics of math anxiety and experiences. The interview data from Students 9-12 were not included in the creative inquiry course as the interviews were conducted too late in the semester to be included in the semester project. Student 10 was coded and analyzed separately by the project supervisor to compensate for the lack of data in Group 3. As such, data from Students 9, 11, and 12 are not represented in this paper.

The general coding process followed Saldaña's Coding Manual [24]. The creative inquiry class conducted all coding and analysis in Google Suite, piloting a method for collaborative coding which is both cost effective and accessible for students. Collaborative coding was conducted through moderation wherein one student would code a transcript, another student would code the same transcript with their own codes, and a third student would moderate between the two codes. Codes went through multiple cycles of revision and development. The final cycle of coding yielded five themes: (1) Learning (2) Anxiety (3) Perceptions (4) Positive Impacts and (5) Negative Impacts. Upon completion of this final cycle of coding, students conducted a preliminary analysis which focused mainly on summarizing the data through the five major themes. The goal was to complete a thorough analysis of the second cycle codes at a later time.

Following the semester course, researchers investigated differences between the defined groups based on MA and WMC. This analysis was initiated by stating a priori questions concerning what distinguishes one group from another. Having these questions at hand, researchers analyzed the summary of findings on the qualitative data to answer these questions. We present some preliminary findings from this analysis, but we would be interested in hearing ideas and suggestions concerning this method of analysis.

Preliminary Findings: Qualitative Analysis of Interviews

Five major themes were identified in the interview data: (1) Anxiety (2) Learning (3) Perceptions (4) Negative Impacts (5) Positive Impacts. Qualitative analysis was conducted irrespective of both math anxiety and working memory capacity.

Anxiety

In defining anxiety, common terms used were "stress," "worry," and "nervousness." One student defined anxiety in terms of random physiological processes and shared their struggles with anxiety attacks. Other ways of defining anxiety linked anxiety to fear of failure or judgment. When asked to define math anxiety, several students equated it with test anxiety, an anxiety where the subject has feelings of nervousness relating to tests. In discussing math anxiety, all but one of the participants mentioned how the anxiety can make the math problem seem overwhelming and cause them to either lose their place or give up. Several students attributed their math anxiety to the pressures of expectation to maintain good grades. A key term that was used to describe these instances was the word, "Lost." In the words of one student, "And when you're lost, you don't want to even look at the problem anymore. You're like, 'I don't even know where to begin with this, so I don't want to learn it.' " Another student described, "I think math anxiety comes up when I just look at a problem and I don't know what it's asking. I see all the symbols and I'm just lost." In these examples, a key idea was that discouragement leads to defeat. Discouragement was often brought up when discussing repeated failures and struggles on a math problem. One student mentioned their discouragement in having their confidence crushed when the answers they were confident about were marked wrong. In response to this the student said, "my confidence just gets absolutely crushed . . . and my math anxiety shoots through the roof." Two students describe the discouragement they encountered when they followed along with a teacher on a problem only to find out the teacher made a significant mistake. In many of these cases, discouragement often decreased their motivation and led to feelings of defeat. Suggestions given for managing math anxiety through study habits included working out practice problems, working with friends, and seeking out help from teachers outside of class. One student mentioned breathing techniques. Another student mentioned focusing that energy elsewhere by being aware of the anxiety and purposefully redirecting the thoughts in another direction. When asked to provide recommendations for teachers, several students emphasized the need to work through examples thoroughly, focusing on algorithmic, step-by-step demonstrations linking to and building upon previous topics. Some students recommended that teachers be aware of stress-inducing language prior to tests. Other recommendations were to promote a classroom environment conducive to asking questions, explaining topics in different ways, and making office hours accessible.

Learning

When asked, "Describe aspects of school that you enjoy most," several students mentioned studying with peers and the confidence they obtained by studying with peers. In describing the confidence that resulted, students mentioned how studying with peers helped in affirming answers and gaining recognition by helping others. Some of these students appreciated being taught by peers at their own level. In the words of one student, "I feel like your peers sometimes teach better than the instructor because they know your struggles." While studying with peers was a recurring theme for some students, others preferred independent learning. In providing recommendations for teachers in alleviating anxiety in the math classroom, students recommended teachers focus on being approachable, available, and relatable.

Perceptions

Students were very open about their own struggles with procrastination, poor study habits, fear of not knowing enough, and fear of judgment. Empathy from instructors was highly valued and may have helped alleviate struggles with anxiety. One student offered, "…he doesn't assume we know anything; he goes over it no matter how simple it is. Which is helpful for those of us who may not have a strong background." In discussing changes in study habits, some students attributed a positive change in perspectives of the future to the support networks (friends, classmates, teachers, parents) they developed in college. Conflicting opinions were expressed in regard to how the pandemic had impacted higher education. While one respondent underscored the "lack of value" in the online format, another individual praised the more thorough video lectures in contrast to the in-person format.

Negative Impacts

Fears of being judged were described by several students. One student described this fear as "the fear of doing something wrong or being judged for being wrong." These encounters, the students admitted, often caused them to not ask questions which in turn made them fall behind. In relation to math anxiety, these actions are similar to what Ashcraft and Krause describe as "avoidance-like" efforts that are a result of math anxiety [2]. This avoidance often has detrimental accumulating effects that lead to other instances of math avoidance such as avoiding math courses in general and careers perceived as math-heavy [25]. The fear of failure was another negative impact on students' anxiety or success in the math class. Some students described their concession to defeat even before class started. As described by one student, "Last class was really hard. I'm not ready. I'm going to fail." Students were very open about their discouraging experiences in math classes. One recurring experience was that of failing tests which the students felt adequately prepared for. Several students mentioned that negative language often increased anxiety in the classroom or prior to a test. One student recalled a time where they asked the instructor for help and the reply was, "You don't get it, that's dumb." Another negative impact was distraction outside of the classroom. Students mentioned struggles with family, finances, and jobs that affected how much time they were able to spend on schoolwork and practicing math skills essential to doing well in the class.

Positive Impacts

Most positive experiences were described in terms of motivators which were of many diverse forms. A major recurring motivator was praise. Praise received from parents, peers, and teachers was greatly valued in positive math experiences. One student described an instance in high school in which the teacher complimented the student for solving a problem in a unique but still valid way. Another student acknowledged the positive impact of recognition from fellow students when helping others with homework and study outside of class. While grades were also mentioned as another positive motivator, the majority of recurring motivators were intrinsic. Students often mentioned the satisfaction in problem-solving or tackling tough challenges. Several students described the joys and satisfaction of "light-bulb moments."

Emergent results through lenses of math anxiety and working memory capacity

After qualitative analysis of interview data, questions were raised about what distinguished one group of students from another. Researchers noted these questions as they went back through the coded data to look for distinguishing characteristics.

Comparisons Between Low MA and High MA
In comparing the low MA and high MA groups, two a priori questions were proposed: (1) What past math experiences may have helped lessen or prevent math anxiety? (2) Have students learned methods to manage their math anxiety? Although we were unable to answer these questions, preliminary analysis yielded one interesting observation. All of the interviewed math anxious students had negative views of mathematical proofs. All but one of the low MA students had positive views toward proofs. In reflecting upon the regression analysis of AMAS scores and likeability of various math aspects, there was no significant correlation between AMAS and the theoretical aspects of math. It is important to note that there was some confusion in the interviews as to what mathematical proofs were although all of them had in fact encountered them in the calculus course. It is possible that students were not aware what all "theory and logic" encompassed in the likeability survey prompt. Those who had negative math experiences involving proofs often described them as overwhelming and confusing.

Comparisons between Low WMC and High WMC
In investigating the relationships between the low and high WMC groups, we came up with one question: What strategies would help those with high math anxiety in relation to their WMC? For math anxious students with Low WMC, effective strategies may need to be centered on accommodating working memory as opposed to math anxious students with High WMC for whom strategies may need to focus on anxiety management techniques.

Two areas of interest were noted for comparisons between the low WMC and high WMC groups. One student who performed well on the OSPAN test but also demonstrated high math anxiety on the AMAS assessment attributed poor study skills to minimum effort in primary school. For this student, it is possible that having high WMC was influential in early academic success, but in not developing study skills, which may have been otherwise developed in those with lower WMC, the student was unable to accommodate for the deficit in working memory caused by anxiety. This issue may be an interesting area for future research.

Another area of interest was in relation to study habits. Some students valued working with others while others preferred independent learning. When examining these differences in relation to working memory, we found that all of the students with low WMC and only one of the students with high WMC valued studying with others. The one student with high WMC who mentioned studying with others also valued independent learning as well. Research has indicated that there is a stronger negative relationship between math anxiety and performance for those with higher working memory capacity. Viewing these findings through the lens of our main question for these groups, it is possible that the students with high WMC have developed strategies to both take advantage of their working memory resources and accommodate for anxiety through independent learning. Furthermore, it is possible that those with low WMC have accommodated for their anxiety by studying with others. This would be an interesting area to explore in future research.

conclusion

This study mainly served as a springboard for various directions researchers may need to consider in investigating the relationship between math anxiety, experiences, and working memory. The students represented in this study were diverse in learning habits and experiences. What strategies do those with low WMC need to develop for college success? What strategies do those with high WMC need to develop? How can math anxiety be managed or prevented in the classroom? As this study progressed, it became increasingly clear that understanding positive impacts required understanding the diversity in student learning. For teachers, this is very important in being able to meet the needs of students. Anxiety was often described by students in terms of preventable actions of teachers. Understanding and being aware of math anxiety may be a first step for teachers in learning to be an advocate for their students' success.

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