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How Instruction, Math Anxiety, and Math Achievement Affect Learning a Novel Math Task: Evidence for Better Instruction

Amy Jane Mcauley
amyjdill@gmail.com

HOW INSTRUCTION, MATH ANXIETY, AND MATH ACHIEVEMENT

AFFECT LEARNING A NOVEL MATH TASK:

EVIDENCE FOR BETTER INSTRUCTION

By

Amy J. McAuley, M.A.

Bachelor of Arts in Psychology
University of Charleston
2008

Master of Arts in Forensic Psychology
John Jay College of Criminal Justice
2010

Master of Arts in Psychology
University of Nevada, Las Vegas
2016

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Amy J. McAuley

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Doctorate of Philosophy - Psychology
Department of Psychology

Mark Ashcraft, Ph.D
Examination Committee Chair

Colleen Parks, Ph.D
Examination Committee Member

David Copeland, Ph.D
Examination Committee Member

Michael Pravica, Ph.D
Graduate College Faculty Representative

Kathryn Hausbeck Korgan, Ph.D.
Graduate College Interim Dean

ABSTRACT

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By

Amy J. McAuley, M.A.

Dr. Mark H. Ashcraft, Examination Committee Chair

Full Professor of Psychology

University Nevada, Las Vegas

The primary goal of this paper is to test how math anxiety, achievement, and instruction affect learning a novel math task. Currently, most research measures achievement and math anxiety on previously learned tasks. A two-part study was proposed to measure the effects of math anxiety on learning modular arithmetic (MA), a novel math task that involves subtraction and division. Participants of varying degrees of anxiety and achievement were randomly assigned to either a specific or vague instruction condition. Participants were either taught how to solve the task or given minimal information about how to solve the task. Before moving on, each participant had to reach criterion (80%) to advance to the rest of the experiment. Results indicated that those in the specific instruction condition reached criterion faster and with fewer errors than those in the vague instruction condition. However, at test, those who received only vague instructions performed significantly faster on large and borrow problems than those who received specific instructions, but also performed significantly worse overall. Math anxiety and math achievement strengthened or weakened how well this skill was mastered but did not alter the overall pattern of results based on instruction type. This research suggests that instruction,

above math anxiety and achievement, plays a significant role in how students learn math, eventually contributing to the pursuit of math in the future.

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Finally, to Padraig and Brigid, one day when you are old enough to read this, may it remind you that your education is never the end goal, but always the beginning to a brighter future.

DEDICATION

For Kevin, you have known that this was my dream since I was 19 and you never wavered in your support during this journey. My dream has always been your dream and for that I am forever thankful. I love you!

For Padraig and Brigid, may this be a reminder that the path you take to reach your goals may not always be direct, but full of wonderful adventure. Thank you for being my greatest adventure.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Introduction

Research as early as the 1970s suggests math anxiety inhibits success in math and may be responsible for low math skill and achievement. Math anxiety was initially defined by Richardson and Suinn (1972) 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 life and academic situations" (p. 551). The current paper attempts to understand the role math anxiety plays in learning. Results from this paper indicate that math anxiety plays a minor role in influencing learning a novel math task, there are other variables, highly related to math anxiety, that could be influencing performance.

The most thorough meta-analyses on math anxiety are still the most widely cited when understanding what math anxiety is related to (Hembree, 1990; Ma, 1999). The meta-analysis uncovers the presence of inverse correlations between attitudes and beliefs that lead to a global avoidance of math. These beliefs range from the perceived usefulness of math, and the lack of motivation to excel in or pursue math. Not surprisingly, there is also an inverse relationship between math anxiety and math achievement. Even grimmer is the finding that early education majors' rate highest in math anxiety, which may lead to teaching practices that perpetuate math-anxious behaviors in their students. Importantly, this relationship between instruction, math anxiety and achievement are present in the current study, suggesting that the three are influencing performance together.

The goal of this paper is to understand how math anxiety and math achievement influence the ability to learn a novel task under different instruction conditions. The goal of using these different teaching instructions is to mimic different teaching styles in the classroom and potentially generalize these results to what is happening in classroom environments. In order to understand how math anxiety and achievement affect learning, this paper will examine different factors that can lead to the relationship between math anxiety, math achievement, and instruction environments.

Factors Influencing Math Achievement and Anxiety

At the beginning of primary education, children report positive attitudes towards learning and school in all domains, including math (Ashcraft & Moore, 2009). Unfortunately, other research has found that these positive feelings towards math decrease as subject material gets more difficult (Lummis & Stevenson, 2001). While this is to be expected in all subject areas, the decline in interest in math is particularly disturbing. Köller, Baumert, and Schnabel (2001) conducted a longitudinal study that examined interest in math along with standardized math scores and math course enrollment with a sample of 7^{th}-, 10^{th}-, and 12^{th}-grade students. Not surprisingly, the results showed that those students who reported higher interest adopted a stronger belief that mathematics is necessary to learn, tended to enroll in more advanced math courses, and achieved higher grades in those courses compared to their less-interested and less-motivated peers. Taken together the results of these studies suggest if students lack interest, they will not pursue math, hurting their overall math achievement.

It is important to understand that interest alone is not enough to continue learning and pursuing math. It is possible that a student could be interested in math, but not motivated to learn. Motivation is another factor that plays a crucial role in pursuing math. Lummis and Stevenson (2001) suggest that interest declines as subject matter increases in difficulty, hurting motivation to pursue math. High levels of self-reported motivation predict individuals' willingness to pursue math-related college majors and career goals (Simpkins, Davis-Kean, & Eccles, 2006). Students are not typically successful in the math field without some degree of motivation. Although separate variables, interest and motivation share similar characteristics that influence the pursuit of math, thus leading to higher math achievement.

Moreover, this research suggests that motivation and interest may be strengthened or weakened in the classroom. The studies discussed are all based on the global pursuit of math, outlining variables that lead to avoidance or pursuit of math. One imperative factor directly related to the current study is the effect of teaching and how that contributes to motivation and interest in math.

Teachers have been cited as one of the most influential persons a child interacts with through their life and crucial in students maintaining interest in school subjects (Wentzel, 1998). Ashcraft, Krause, & Hopko (2007) go on to suggest that susceptibility to public embarrassment (e.g., solving a problem incorrectly on the blackboard), combined with a non-supportive teacher, may be risk factors for developing math anxiety, possibly influencing a lifetime of avoiding math classes. Not surprisingly, Berger and Karabenick (2011) found that a positive classroom environment contributes to maintaining interest and motivation among students pursuing math. Specifically, they found that a helpful teacher and a feeling of overall comfort to ask questions were significant predictors of continued engagement in current math classes. This perceived helpfulness of the teacher also led to a higher likeliness to enroll in more math classes in the future, regardless of the difficulty of the material.

In a qualitative study on the influence of teachers, Turner, Midgley, Meyer, Gheen, Anderman, Kang, and Patrick (2002) found that students with an unsupportive, “cold” teacher avoided in-school behaviors such as making eye contact with the teacher and going to out-of-class help sessions. A "cold" teacher is described as authoritarian and acting in a demeaning manner towards students. Although math anxiety was not a variable measured in this study, the findings suggest that coldness among the teachers can increase math avoidance among the students. This study shows that positive classroom environment can have a substantial impact on how students are motivated to learn. Even more importantly, this study was one of the first to measure the behaviors of students and how it relates to pursuing math while in the classroom. For example, authors found that seeking out of class help from a teacher is a sufficient way to measure motivation while currently enrolled in class. If a student is struggling with content and has a cold teacher, they be less motivated to seek help, possibly creating a vicious cycle leading to less motivation to pursue math in the future.

What role does math anxiety play in all of this? Hembree (1990) found that education majors report the highest rates of math anxiety suggesting that math anxiety among teachers, could influence their teaching behavior as well as their students. Because of this potential relationship, it is essential to examine how anxiety affects teaching.

Some studies have shown that pre-service teachers with high-level mathematics anxiety engage in inappropriate teaching methods (Peker, 2009; Peker & Ertekin, 2011). In a study examining how teaching style was influenced by math anxiety, Bursal & Paznokas (2006) found that those who reported more levels of math anxiety had less confidence in their ability to teach mathematics. It should be noted that this sample did not consist of teachers, or even education majors, but a general sample of individuals. Regardless of sample, this study shows that teaching style is influenced by math anxiety. When examining teachers and math anxiety, Beilock, Gunderson, Ramirez, and Levine (2010) found math anxiety of a female teacher influences the math anxiety of their female students. First- and second-grade teachers' math anxiety ratings were recorded before the school year. Additionally, their student's math anxiety and math achievement scores were recorded at the beginning and end of the year, to measure possible negative effects of teacher anxiety. Not surprisingly, there was no relationship between teachers' anxiety and their students' anxiety at the start of the school year. However; by the end of the year, female students' anxiety increased if their teacher's math anxiety was recorded as high. Interestingly, male student’s math anxiety was unaffected, regardless of their teacher’s math anxiety. Authors suggest that because the teachers in the study were female, their anxiety only influenced their female students. Although this study does not speak to students as a whole (male students remained unaffected), it lays a foundation for the beginning of low interest and motivation among students. These studies coupled with the Turner et. al. (2002) study show the importance of teacher instruction and how it leads to the relationship between math achievement and anxiety.

Summing up the research, classroom environment, including the anxiety and teaching style of the teacher, can affect a student’s interest and motivation in math, in turn affecting their math achievement. Therefore, additional factors, like instruction style should be considered when examining factors that influence math performance. These studies examining interest, motivation, and teacher influence are paramount to the current study. There is a clear relationship between all three factors influencing a global avoidance of math and relating to math anxiety and achievement. The next aim of the current study is to understand how math anxiety and achievement affect math performance. This is also referred to online math performance.

Online Math Performance

The term “online math performance” refers to performance during different math tasks in which error rate and reaction time are measures of performance. Researchers (Ashcraft & Faust, 1994; Faust, 1988; Faust, Ashcraft, & Fleck, 1996) conducted pioneering studies that evaluated how math anxiety affected performance on simple and more complex arithmetic. They discovered many performance differences between high and low math-anxious participants, but one study in particular shed some interesting light on how high math-anxious individuals perform differently than their low math-anxious peers.

When examining performance, Ashcraft and Faust (1994) demonstrated how math anxiety affects performance during an online task. They found that there were no significant differences in performance between high and low math-anxious individuals when they completed basic arithmetic, however; there were performance differences on more complex problems. Specifically, high math-anxious individuals took significantly longer on incongruent problems and made significantly more errors compared to their low anxious counterparts (There was an exception to this finding that will be discussed later on). According to a more recent study, the differences in performance could be explained by examining what is happening in the brain.

Suarez-Pellicioni, Nunez-Pena, and Colome (2014) looked more closely at the performance of high and low math-anxious individuals on a math type Stroop task, while also collecting ERP measurements. Behaviorally, their results yielded similar findings from the early study (Ashcraft & Faust, 1994): High math-anxious individuals took significantly more time to solve a problem as compared to their low math-anxious counterparts. Regarding ERPs, the low math-anxious group showed a greater N450 component for the interference effect. The N450 component is typically associated with detecting conflict. Here, the low math-anxious participants were able to detect the conflict quicker as compared to their low math-anxious counterparts. Essentially, the ability to detect the conflict quicker allowed the low math-anxious individuals to solve the problem faster.

In contrast, the high math-anxious group showed greater Conflict-SP amplitude, typically associated with resolving a conflict, instead of N450. In contrast to the low math-anxious individuals, high math-anxious individuals did not seem to process that a conflict even existed. Instead, it seemed like they were stuck trying to make sense of the solution, not realizing that it was an incorrect solution. As a result, the high math-anxious individuals were slower to solve these problems and also made more errors. This study replicated Ashcraft and Faust, (1994), showing different brain activations responsible for performance differences between high and low math-anxious individuals. More importantly, this study shows there might be inherent differences in brain function between low and high math-anxious individuals when completing math tasks.

These studies point to an underlying aspect of math anxiety that suggests there is more at work than merely performing poorly on math tasks. Refer back to Ashcraft and Faust (1994) who found that high math-anxious individuals were typically the slowest to respond but made significantly more errors than their low math-anxious counterparts. There was one exception to this trend: those categorized as a level four for math anxiety (four being the highest level of anxiety) had reaction times that were almost as fast as the participants with the lowest levels of math anxiety. This was surprising given that the results showed reaction time getting slower as math anxiety increased. When error rates were examined, this particular group made significantly more errors compared to the other math anxiety groups. Ashcraft and Faust (1994) suggest that the speed accuracy trade-off was largely due to the fact that the stimuli elicited too many negative emotions. As a result, the highest group of math-anxious individuals chose to avoid putting effort on a task in order to avoid any negative feelings or emotions associated with completing the problems. Understanding how math anxiety affects working memory sheds some light on why the highest math-anxious group was the fastest and made the most errors.

To understand the role math anxiety plays in solving math one must understand how general anxiety works. Eysenck, Derakshan, Santos, and Calvo (2007) state that general anxiety prompts mental ruminations, which in turn, utilizes more working memory resources. Authors outline a series of steps that outline how anxiety affects working memory in different capacities. Ashcraft and Kirk (2001) applied this theory (using the earlier version Eysenck and Calvo, 1992) to math-anxious individuals to see if math anxiety functioned similarly to general anxiety. In a series of studies, Ashcraft & Kirk (2001) thoroughly examined the relationship between math anxiety and working memory. The results from their second study revealed the most compelling evidence for the relationship between math anxiety and working memory.

To begin, they split individuals into their reported levels of math anxiety: low, medium, and high. The math task they used was one and two-column addition, explicitly designed to test performance differences on three types of problem difficulties: low, medium, and high. Ashcraft & Kirk (2001) assumed that small problems, also referred to as basic fact problems, would require fewer working memory resources compared to medium and large problems. To place more demands on working memory, authors required participants to hold either two- or six-letter sequences in their working memory while trying to solve the math problem and then recall the letters after they solved the problem. It takes far less effort to hold a two-letter sequence in working memory compared to a six-letter sequence.

They found that there was a low recall of letters when carrying was required in the problems, and when working memory was loaded more heavily. This combination affected all different levels of math anxiety. The high math-anxious group had a 39% error rate in the toughest condition as compared to the high math-anxious individuals with the low memory load. The high error rate in the hardest condition suggests that the high math-anxious individuals' working memory was taxed to its maximum capacity as a result of their intrusive, math-anxious thoughts, using up any additional working memory resources they may have had. This finding was further supported by the low math-anxious individuals' 20% error rate. Evidence from this second study supports the idea that math anxiety affects working memory just like general anxiety and that the high math-anxious individuals were working without full capacity of their working memory resources, due to ruminations associated with math. These studies consistently show how having high math anxiety affects performance during online math tasks. Additionally, these studies also demonstrate the important role of working memory. Even though working memory was not measured in the current study, it has been shown, to be highly related to many processes (for additional work see Beilock & Carr, 2005).

Ashcraft and Krause (2007) propose three ways working memory is affected when computing math. First, larger problems and problems that require the use of the carry/borrow operation will tax working memory more. Second, the more steps needed to solve a problem (e.g., algebra problems) the more working memory resources are used. Finally, problems that are not directly retrieved from long term memory require more working memory resources. Those with limited processing or storage capacity may have a more difficult time computing a mathematical problem. Each of the stimuli used in the current study involve problems that fit these criteria for taxing working memory.

Most of the research reported thus far suggests that intrusive thoughts combined with different processes (in the brain) used by high and low math-anxious individuals are responsible for a decrease in performance. In some cases, often moderated by working memory capacity, feelings of anxiety can help improve performance in a pressure-induced environment (Beilock & Carr, 2005). It is important to point out that all of the studies outlined thus far have used novel or larger/complex problems when examining math anxiety. Looking at this research alone, it would appear that math anxiety only affects performance on larger, complex problems and is thought to not affect small and simple arithmetic because of the low demand it places on working memory. There is competing evidence that suggests math anxiety is present when trying to solve small, non-complex problems.

Maloney, Risko, Ansari, and Fugelsang (2010b) tested high and low math-anxious participants on a subitizing task. Participants were asked to identify how many filled squares were displayed on a screen. Results showed slower counting by high math-anxious participants as compared to their low math-anxious participants. In another study, Maloney, Ansari, and Fugelsang (2010a) had high and low math-anxious participants perform a number comparison task, deciding whether a number was larger or smaller than five. In their second experiment, two numbers were presented, and participants were asked to indicate the larger of the two numbers. In both studies, high math-anxious participants were slower to judge numbers that were closer together in numerical magnitude (e.g., four and five) as compared to their low math-anxious counterparts. A more recent study supports these findings in that they found similar patterns among high and low math-anxious individuals' ability to differentiate between two numbers in a number comparison task (Nunez-Pena & Suarez-Pellicioni, 2014). This study goes on to show a larger ERP for the numerical distance effect, lending more support to the idea that pre-existing math difficulties, perhaps even low math achievement, lead to more math anxiety.

Taken together, both of these studies suggest that math anxiety does not just affect larger, more difficult problems. In fact, this newer evidence seems to suggest that math anxiety is related to some numerical deficiency. Whether math anxiety is caused by a numerical deficiency or by limited working memory resources, the question still remains: how does math anxiety affect learning?

Up until this point, most of the research described here shows how math anxiety affects performance on math tasks that utilize basic arithmetic. From globally avoiding math to sacrificing accuracy, one thing is clear: math anxiety is a severe detriment to math performance in general. Currently, there is not any research that examines any differences between high and low math-anxious individuals as they learn novel math concepts. Are high math-anxious students just poor at math because they avoid learning the concepts? Alternatively, do ruminations associated with math anxiety interfere with the learning process? There has been one study that has attempted to understand potential inhibitions that occur when learning math. Although it's primary focus was on stereotype threat affecting performance, it is one of the first studies to examine implications of learning math.

For the sake of brevity, there is one study that will be reviewed that examined learning math. Specifically, Mangels, Good, Whiteman, Maniscalco, and Dweck (2012) examined how females learned how to solve difficult math while being placed in a stereotype threat or non-threat situation. The main purpose of this study was to examine how stereotype threat affected learning and math. This study did not examine math anxiety, but is still one of the few that examines aspects of learning and math. The experiment lasted over the course of three days and included a surprise test, that acted as an additional measure of learning. Learning was operationally defined as how much time participants spent seeking additional help from a tutorial. Researchers measured the time each participant spent engaging in the tutorial as a measure of sufficient learning. Female participants were also presented with accuracy feedback after each problem on a GRE-type test. In the presence of negative stereotypes and feedback, females underperformed on a math test compared to their unthreatened peers. Furthermore, those who were under stereotype threat did not seek out additional help from the tutorial. This finding is compelling considering those under threat could have benefitted from additional help on a difficult math task. The authors also suggest that receiving negative feedback in response to errors made, inhibited their willingness to utilize the tutorial for additional help. Interestingly, there were no differences between these two groups on a surprise test on the last day of the experiment.

This study is one of the few that examines learning math. This study also combines the previous research and applies it to performing on an online math task. For example, the authors state that those who were not under threat were motivated to utilize the tutorial, in order to help them perform better on the following test, showing how motivation can affect performance. Although math anxiety was not measured directly, the emotions that accompany stereotype threat were found to inhibit performance, suggesting that math anxiety could have a similar effect when learning a task.

Unfortunately, there are a few confounds associated with the design and method. First, researchers defined learning as the "number of interactions" the participants had with the tutor. As the research here indicated, there are many more factors that could affect this approach to utilizing the online tutor. Using this tutor is not the only, or even best way, to measure learning. It can even be argued that it is not an exact definition of learning. Second, this study's primary focus was also on stereotype threat. Although stereotype threat research is advantageous in understanding how emotions affect solving math concepts, it might be more useful to examine variables such as math anxiety and achievement to have a better understanding of how learning is impacted. Finally, the stimuli used, while challenging, were based on math that has been previously learned. In fact, it could be argued that GRE-type problems do not require any specific calculation and are usually solved using some trick or heuristic, not computing math. Implications for math anxiety in a learning context could produce very different results. For example, the research clearly states that problems that require more steps and are not directly retrieved from long-term memory, tax working memory more. The stimuli used should be something that can be manipulated in order to tax working memory adequately during a learning session.

Current Study

The current study seeks to understand how high math-anxious individuals learn math. task in a lab setting. The best way to test this was to use a novel task called Modular Arithmetic (MA) (Gauss, 1801, as described by Beilock, Holt, Kulp, & Carr, 2004) as the math task. The object of MA is to judge the validity of problems such as $10 \equiv 8 \pmod{2}$. To solve MA, the middle number is subtracted from the first number (i.e., $10 \equiv 8$), and then this difference is divided by the last number (i.e., 2/2). If the answer is a whole number, the problem is "true." If there is a remainder, the answer is "false". MA is a useful novel math task because it can be manipulated using simple and complex problems, essential for taxing working memory, and has not been taught in formal education. Furthermore, MA has been used in various studies, making it well established in the math cognition literature (Beilock & Carr, 2005; Beilock, Kulp, Holt, & Carr, 2004). It is possible that performance could change based on the type of instruction condition participants are in and the type of problems they are completing.

It is hypothesized that high math-anxious and low math achieving individuals will take longer to master the concepts of MA and perform significantly worse on a test of MA compared to their low math-anxious and high math achieving counterparts. The high math-anxious and low math achieving individuals will make more errors and take longer to solve the MA problems on both the practice trials and final test, as compared to their low math-anxious high achieving counterparts. It is also hypothesized that the high math-anxious and low math ability participants will perform significantly worse on more difficult problems as compared to the easier problems. Additionally, it is hypothesized that the high math-anxious and low math achievement individuals will perform significantly worse (slower and will make more errors) than their low math-anxious and high math achieving counterparts on larger problems.

There will also be another manipulation regarding the directions given when solving the MA problem. The purpose of manipulating instruction is to mimic poor teaching that occurs in a classroom environment. As mentioned earlier, poor teaching results in poor attitude towards math, which in turn could affect how well material is learned (Turner et al., 2002). In one condition, there will be vague instructions that mimic poor teaching, and in the other, there will be specific instructions to mimic excellent teaching. It is hypothesized that high math-anxious and low math achievement individuals will perform worse than their counterparts on the vague instructions, as compared to the specific instructions. It is hypothesized that the low math-anxious individuals and high math achievement individuals will perform better than their counterparts in the specific instructions as compared to the vague instructions. Finally, it is hypothesized that low math-anxious and high math achievement individuals will outperform their high math-anxious and low achieving counterparts in both conditions. Of course, these results cannot directly generalize to teaching method, and amount of math learned, but this is the first study of its kind to attempt to look at instruction in a quantitative way and how it could affect learning new material.

Chapter 2: Method

2.1 Participants

One-hundred-forty participants were recruited via the Undergraduate Psychology Subject Pool at the University of Nevada Las Vegas. Fifteen of these individuals were excluded from data analysis for not reaching criterion.

2.2 Materials

Demographic Questionnaire. This questionnaire consists of questions about the subject's age, gender, year in school, level of math achievement, and experiences with math throughout formal schooling.

Shortened Math Anxiety Rating Scale (sMARS, Alexander & Martray, 1989). The sMARS assess an individuals' anxiety about math and math situations using a likert scale that ranges from 0 to 4. Scores range from 0 to 100 by summing the responses to all items. Low anxiety is indicated by a low score on the sMARS.

Wide Range Achievement Test (WRAT). The math portion of the WRAT measures an individual's ability to perform basic math computations in a timed environment. There are 40 problems that range from easy to hard. It is completed using pencil and paper. Correct answers are summed and the total score serves as the math achievement score. The more correct answers, the higher the achievement score, particularly because the problems increase in difficulty, indicating higher math achievement. Typically, 20 min is given to complete the assessment, but some studies have reported using 15 min for the exam.

Stimuli. The word *mod* and a congruence sign (≡) each appeared in black letters against a white screen for each trial. Each trial during the learning portion of the condition began with a 500-ms fixation point in the center of the screen followed by a problem that was present until the participant responded. After this, the problem was removed and the word “Correct” on a green screen or “Incorrect” on a red screen was displayed on the screen for 1,000 ms, providing feedback. The screen then went blank for a 1,000-ms interval (Beilock, Holt, Kulp, & Carr; 2004).

The learning portion consisted of 51 trials. Of these trials, 21 were small trials and 30 were large trials. Of those trials, 27 were non-borrow problems and 24 were borrow problems. A total number of 51 trials was arbitrarily chosen because it was decided that those who could not reach criterion by 50 trials would never learn how to properly solve MA. Each of these trials were randomized before being entered into the experiment. This was done because of how the learning trial was programmed. The code used to program the trials to criterion would not allow for E-Prime to set a criterion and randomize trials. Therefore, trials were randomized using Microsoft excel. As a result, each participant saw the same order of trials as the rest of the participants. The testing portion consisted of 80 trials that were randomized using E-prime. Participants did not see the same order of problems. Of these trials, 40 were small and 40 were large and half of each size were non-borrow and half were borrow trials.

2.3 Procedure

Participants were asked to complete a series of MA math problems. Participants were randomly assigned to either a vague or specific instruction condition. Although conditions differed based on the type of instruction participants were given, the general task remained the same. All participants completed a demographic questionnaire followed by the Shortened Math Anxiety Rating Scale. Then each participant completed an instructional tutorial on how to solve MA. For the specific group the instruction read (Rudig, N., 2014):

"During this experiment, you will be solving a series of problems on the computer.

You are going to see problems on the screen that look like the following:

$$20 \equiv 5 \pmod 3$$

Your job is to judge whether the problems are true or false as quickly and accurately as possible.

There are two steps involved in solving problems such as:

$$20 \equiv 5 \bmod 3$$

First: subtract 5 from 20

$$20 - 5 = 15$$

Second: divide the answer 6 by the mod number

$$15/3 = 5$$

5 is a whole number so in this case the answer is true.

It should be noted that those in the specific instruction were also given an example of a false problem that read:

$$17 \equiv 5 \pmod 5$$

Your job is to judge whether the problems are true or false as quickly and accurately as possible.

There are two steps involved in solving problems such as:

$$17 \equiv 5 \bmod 5$$

First: subtract 5 from 17

$$17 - 5 = 12$$

Second: divide the answer 6 by the mod number

$$12/5 = 2 \text{ r}4$$

2 r 4 is not a whole number so the answer is false.

For those in the vague condition the instructions read:

> During this experiment, you will be solving a series of problems on the computer. You are going to see problems on the screen that look like the following:
>
> $$17 \equiv 5 \pmod{6}$$
>
> Your job is to judge whether the problems are true or false as quickly and accurately as possible.
>
> There are two steps involved in solving problems: Subtraction and Division.
>
> If there is a remainder the answer will be false. If there is not a remainder the answer will be true.

Each participant had to reach a criterion before moving on to the rest of the experiment. This criterion meant solving a series of eight out of ten MA problems correctly. This was based on a “moving window” of trials. For example, if a participant got six problems correct, got the seventh problem wrong, but got the eighth and ninth problem correct, they would have reached criterion. Fifty was the maximum number of trials that one could complete. If criterion was not reached during the duration of the learning portion, the data were excluded, and the participant was excused from the session. Once the participants reached criterion, the learning condition ended, and they were asked to type out the method they used to solve MA. After they completed that, they were given a Likert-scale to identify how confident they were in solving MA. This scale ranged from 1 to 6 with 1 being not confident to 6 being very confident. After completing those scales, they were given fifteen minutes to complete the Wide Range Achievement Test (WRAT) in math to measure their math achievement. Finally, all participants were given a final eighty MA problems to solve the testing portion of the experiment. Feedback was provided during both the learning and testing phase.

Chapter 3: Results

Demographics

One-hundred- forty participants participated in this study. Of those participants, 15 did not meet the 80% criterion in the learning phase so they were removed from analysis. One other participant was removed due to a computer error for the test data. Of the remaining one hundred twenty-four participants, 61% were female, 42% were freshman, and 42% were white. Among the participants who reached criterion, 67 were in the specific condition and 59 were in the vague condition. Since analyses were conducted separately for the specific and vague condition, separate demographics will be reported for each group.

Specific Condition. There was a total of 67 participants in the specific group and all of the participants reached criterion. The median math anxiety score was 31. Individuals who scored above the median were labeled as high math-anxious and those who scored below were labeled as low math-anxious. The median math achievement score was 28. Individuals who scored above the median were labeled as high math achieving and those who scored below were labeled as low math achieving.

Vague Condition. There was a total of 74 participants in the vague condition. Of the 74 participants, 15 did not reach criterion. These participants were removed from any further analysis, leaving 59 participants who reached criterion. The median math anxiety score was 37. Individuals who scored above the median were labeled as high math-anxious and those who scored below were labeled as low math-anxious. The median math achievement score was 29.

Individuals who scored above the median were labeled as high math achieving and those who scored below were labeled as low math achieving.

3.1 Trials to Criterion

Before delving into analyses, it is important to understand the differences in trials to criterion between the vague and specific groups. There was a significant main effect of trials to criterion, t (124) = -6.27, p<.001. Individuals who received specific instructions took fewer trials (M= 11.33, SE=.57) to reach criterion as compared to those who received vague instructions (M=20.76, SE=1.47). This suggests that the instruction manipulations were well-designed in that it took those in the vague condition more trials to understand the concept whereas those in the specific condition understood the concept from the beginning. See Table 1 for a further breakdown of the participants in each group. Importantly, all 15 participants who failed to reach criterion were in the vague instruction condition. Of those 15, eight were low math-anxious, and seven were high math-anxious, suggesting that math anxiety status was unrelated to failure to reach criterion. The participants' math achievement status, however, did appear to be related to failure to reach criterion. Only three of those who failed to reach criterion were high achieving individuals, whereas 12 were low achieving individuals. For a breakdown of those who did not reach criterion refer to Table 2. This uneven proportion achieved significance with a Pearson's Chi-square test, $\chi^2 = 5.40$, $p < .02$, suggesting that low math achievement status indeed contributed to individuals' failure to reach the 80% accuracy criterion during learning when given vague instructions. This demographic data suggests that math achievement may play a bigger role in mastery of MA as compared to Math Anxiety.

Finally, it should be noted that low math achievement individuals, in the specific group, took significantly more trials to reach criterion (M=12.78, SE=1.3) as compared to high math achieving individuals (M=10, SE=0), t (57) = 2.26, $p<.05$. Ten was the best possible score that an individual could get, showing perfect performance for the high math achievement individuals. There were no differences between math achievement individuals in the specific condition, t <1, p=.909. There were also no significant differences in trials to reach criterion between high math-anxious and low math-anxious in the specific, t <1, p=.811 and vague, t <1, p=.426 condition.

Table 1. Demographic Criterion

Specific Demographics				
	Age	Trials to Criterion	WRAT	SMARS
Mean	20.12	11.31	28.43	35.57
Median	18	10	28	31

Vague Demographics				
	Age	Trials to Criterion	WRAT	SMARS
Mean	20.24	20.76	29.12	38.88
Median	19	14	29	37

Table 2. Demographic No Criterion

Math Anxiety-No Criterion		
	Frequency	Percent
Low	8	53.3
High	7	46.7
Total	15	100

Math Achievement-No Criterion		
	Frequency	Percent
Low	12	73.3
High	3	20
Total	15	100

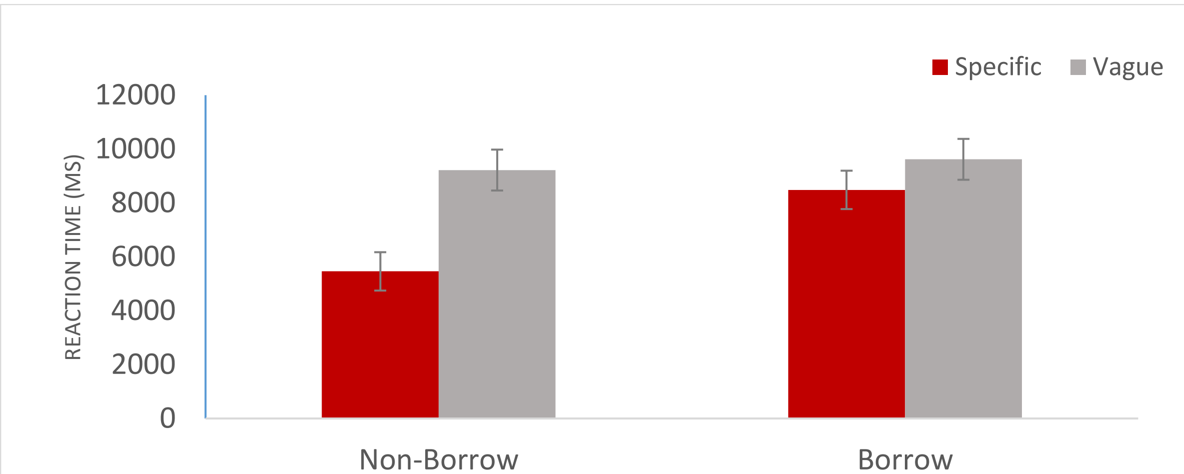
3.2 Instruction Condition-Group

Overall analyses (i.e., ANOVA's for MA performance) were completed for the learning portion of the experiment. A 2 (Problem Size: Small vs Large) x 2 (Problem Type: Non-borrow vs Borrow) x 2 (Group: Specific and Vague) mixed ANOVA, with group as the between subject's variable, was completed to test for performance on MA problems. It should be noted that there was a significant difference of trials presented in each of these instruction conditions.

Reaction Time. For this analysis, only reaction times on correct trials were analyzed. There was a main effect of problem size, F (1, 124) = 14.84, p<.001, η_p^2 = .107, in that people were faster on small problems (M=7433 ms, SE=504) as compared to large problems (M=9037 ms, SE=541). Participants were significantly faster on non-borrow problems (M=7340 ms, SE=520) as compared to borrow problems (M=9051 ms, SE= 486), F (1, 124) = 9.94, p<.001, η_p^2 = .201. There was also a main effect of group in that people were significantly faster in specific condition (M=6972 ms, SE=649) as compared to the vague condition (M=9419 ms, SE=692), F (1, 124) = 7.18, p<.0001, η_p^2 = .057. This is presumably due to the superior instruction that individuals in the specific condition received as compared to the vague instruction those in the vague condition received.

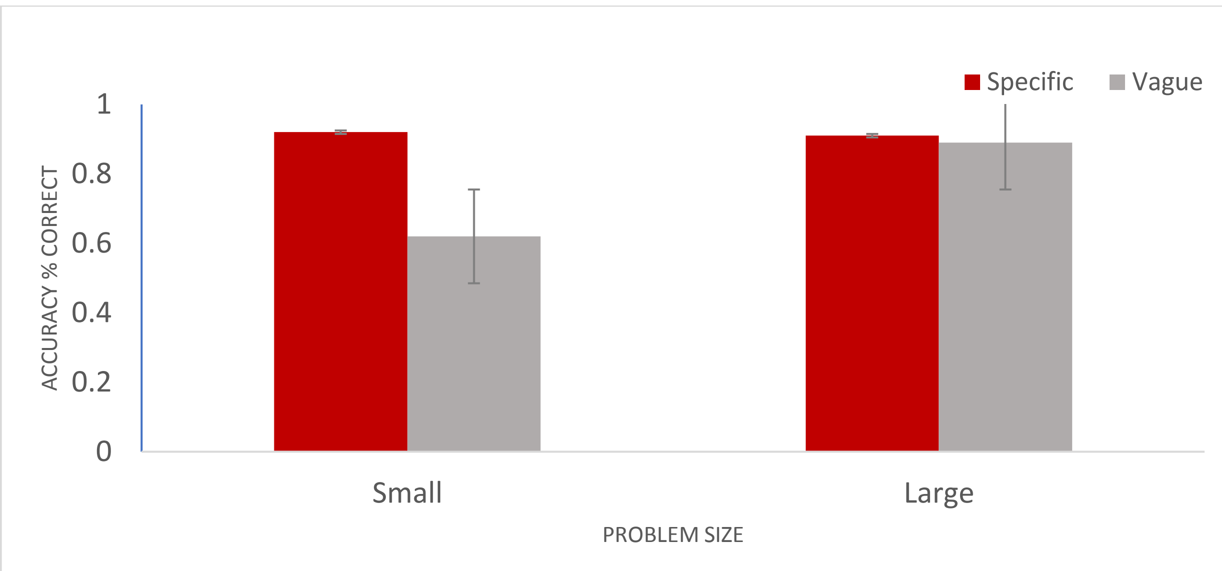
The Instruction group factor also interacted with problem type, F (1, 124) = 14.83, p <.0001, η_p^2 = .192. The interaction is shown in Figure 1. As the figure shows, there was a large speed advantage for non-borrow problems for participants in the specific instruction group (M=5460 ms, SE = 718), compared to the same problems as performed by those in the vague instruction group (M = 9220 ms, SE = 759). In contrast, the speed advantage for the specific group was much smaller for borrow problems (M = 8484 ms, SE = 665) compared to the how participants in the vague condition performed on the same problems (M = 9619 ms, SE=623). Clearly, borrow problems require extra processing time due to the difficult subtraction involved, regardless of the instruction condition. Further interpretation of these results is provided below, after considering the accuracy results on the problems.

Figure 1. Group and Problem Type Interaction



Accuracy. Accuracy was analyzed with the same design as reaction time. Interestingly, the main effect of problem size disappeared when the dependent variable was accuracy, F<*1*. The main effect of problem type remained in that individuals performed better on non-borrow problems (M=.80, SE= .02) as compared to borrow problems (M=.77, SE=.02), F (1,124) = 12.83, p<.001, η_p^2 = .096. Interestingly there was an interaction in which problem size interacted with group, F (1,124) = 25.24, p<.0001, η_p^2 = .096. The interaction, in Figure 2, shows the accuracy disadvantage was particularly pronounced in the small condition where those in the vague condition performed worse on small problems (M=.60, SE=.03) compared to large (M=.82, SE=.03). To understand these findings better a paired samples t-test was run to compare the number of small and large problems seen in the vague condition. Here, there was a significant difference in the number of small problems (M=11.31, SD=9.46) compared to the number of large problems (M=9.46, SD=5.7) seen by those in the vague group; t (59) = -6.28, p=.000. The finding suggests that performance was worse on small problems because those in the vague condition saw a disproportionate number of small problems in the learning condition as compared to large problems, explaining the poorer performance on small problems.

Figure 2. Group and Problem Size Interaction



Taken together, the results from the learning phase of the experiment showed that participants in the specific instruction condition mastered MA quickly, averaging 11 trials to criterion (minimum number of 10 needed), responding to the problems fairly quickly and accurately. In contrast, those in the vague condition were at a disadvantage when learning the novel task. It appears that those in the vague condition were still learning how to solve MA, even though they met the 80% criterion; they took more than twice as many trials to reach criterion, their solution times were slower, and their accuracy was lower.

In general, these results support the notion that instruction type can matter when it comes to learning and performance. Those in the specific condition outperformed those in the vague condition in both reaction time and accuracy (problem size). This becomes even more important when individual factors, like math anxiety or achievement, are at play.

3.3 Instruction Condition-Math Anxiety

Overall analyses (ie; ANOVA's for MA performance) were completed for the learning portion of the experiment. A 2 (Problem Size: Small vs Large) x 2 (Problem Type: Non-borrow vs Borrow) with 2 (Group: Specific and Vague) mixed design ANOVA was completed to test for performance on MA problems. Math Anxiety (high and low) was included in this analysis as the between subject's factor. Because there were different math anxiety medians for each group, analyses were run for each instruction condition separately, rather than using condition as a between subject's factor.

Reaction Time-Specific Group. There was a main effect of problem size, F (1,61) = 17.91 $p<.001$, $\eta_p^2 = .227$, in that performance was better on small problems (M=6142 ms, SE=325) as compared to large problems (M=8149 ms, SE=534). There was also a main effect of problem type, F (1, 61) = 55.06, p <.001, η_p^2 =.474, in that participants were faster on non-borrow problems (M=5606 ms, SE=423) as compared to borrow problems (M=8685 ms, SE=430). There was a main effect of math anxiety, F (1,61) = 8.43, $p<.01$, η_p^2 =.122 in that low math-anxious individuals were faster (M=6060 ms, SE=532) overall compared to their high math-anxious counterparts (M=8231 ms, SE=524). There were no interactions among problem size, problem type, and math anxiety, all Fs <1.

These results show support for the Ashcraft and Krause (2007) study which shows how problems of greater difficulty require more working memory resources, and therefore result in a longer amount time spent on each problem. Furthermore, it is apparent that those high in math anxiety took longer, presumably because anxiety also used up more of their working memory capacity (Ashcraft & Kirk, 2001). Although it should be noted that working memory was not measured, so it cannot be said for certain how working memory was affected.

Accuracy-Specific Group. For accuracy, the main effect of problem type remained, F (1,61) = 16.41, p<.001, η_p^2 = .212, in that individuals were more accurate on non-borrow problems (M=.96, SE=.02) as compared to borrow problems (M=.87, SE=.02). The main effect of problem size and math anxiety was no longer significant, F<1.

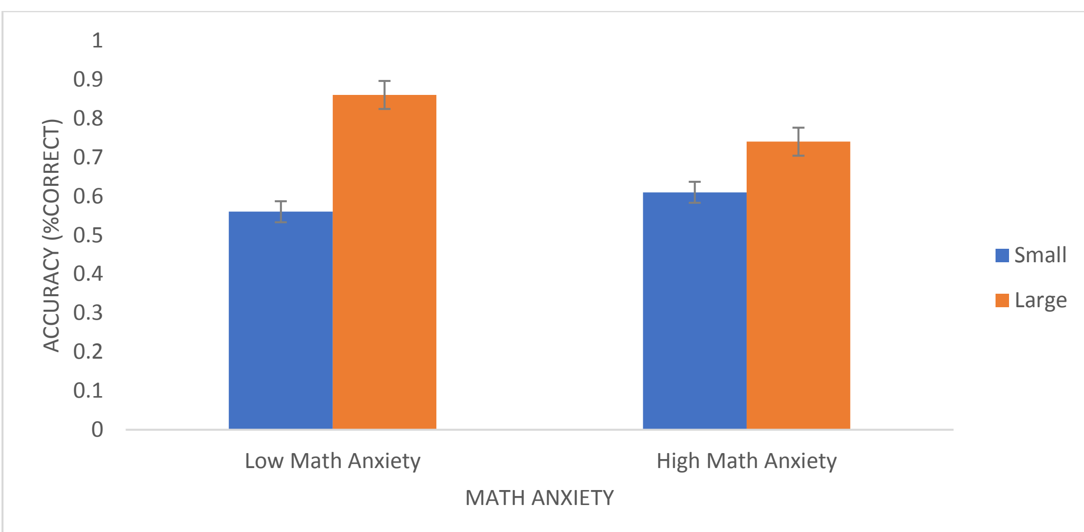
Reaction Time-Vague Group-. Here, only the main effect of problem size remained, F (1, 54) = 9.43, p<.*01*, η_p^2 =.149, in that participants were faster on small problems (M= 8122 ms SE=812) as compared to large problems (M= 9694 ms, SE=955). The main effects of problem type and math anxiety were not significant, all Fs < 1.

Accuracy-Vague Group. There was a main effect of problem size, F (1,54) = 45.45 p<.001, η_p^2 = .457. Interestingly, performance on small problems was worse (M=.59, SE=.02) as compared to large problems (M=.81, SE=.02). Recall that there was a disproportionately large number of such problems in the early sequence of trials in the vague condition. Thus, participants in the vague instruction condition, who struggled to understand how to do MA, made more frequent errors, especially on the small problems.

There was also a main effect of problem type, F (1,54) = 8.06, p<.01, η_p^2 =.130 in that participants performed better on non-borrow problems (M=.73, SE=.02) as compared to borrow problems (M=.67, SE=.02). There was no main effect of math anxiety, F<1. Perhaps the most questionable finding was the significant interaction between problem size and math anxiety, F (1, 54) = 5.704, p <.05, η_p^2 =.096, shown in Figure 3. The questionable aspect of the result is the low accuracy on small problems for the low anxious (M = .55, SE = .03) and high anxious (M = .63, SE = .04) groups. As noted earlier, these means are artifactually low due to the overrepresentation of small problems during the learning phase for participants in the vague condition. On the other hand, note that the low anxious group was noticeably higher in accuracy (M = .85, SE = .04) than the high anxious group (M = .77, SE = .04) on the large problems.

One unusual individual may have been responsible for the significant interaction. Of the low math-anxious participants, there was one participant who took 40 trials to reach criterion. This participant also performed had 20% accuracy on the small non-borrow problems. Taking 40 trials to reach criterion was more than the average (M=20) trials it took participants in the vague condition. It should be noted that no outlier test was administered but that this was determined by graphing the data. Interestingly, there was also a high math-anxious participant who scored perfectly on small problems and who took fewer (M=10) trials than average to reach criterion. Once these individuals were taken out of the analysis, the interaction between problem size and math anxiety disappeared, F<1, suggesting that the interaction was a spurious effect.

Figure 3. Math Anxiety and Problem Size Interaction



Taken together, the results suggest that math anxiety had the biggest effect on reaction time in the specific condition, where low math-anxious individuals were significantly faster on problems than their high math-anxious counterparts. Interestingly, when examining the vague condition, math anxiety did interact with problem size in that high and low math-anxious individuals performed better on large problems compared to small problems. However, further investigation showed that this was not due to math anxiety, rather, it was due to a large proportion of small problems that appeared first during the learning portion of the experiment. The lack of findings suggests that math anxiety effects were masked in the vague condition, due to the participants' struggles with learning the procedures of MA. When taught those procedures clearly, in the specific condition, then the effects of math anxiety are visible.

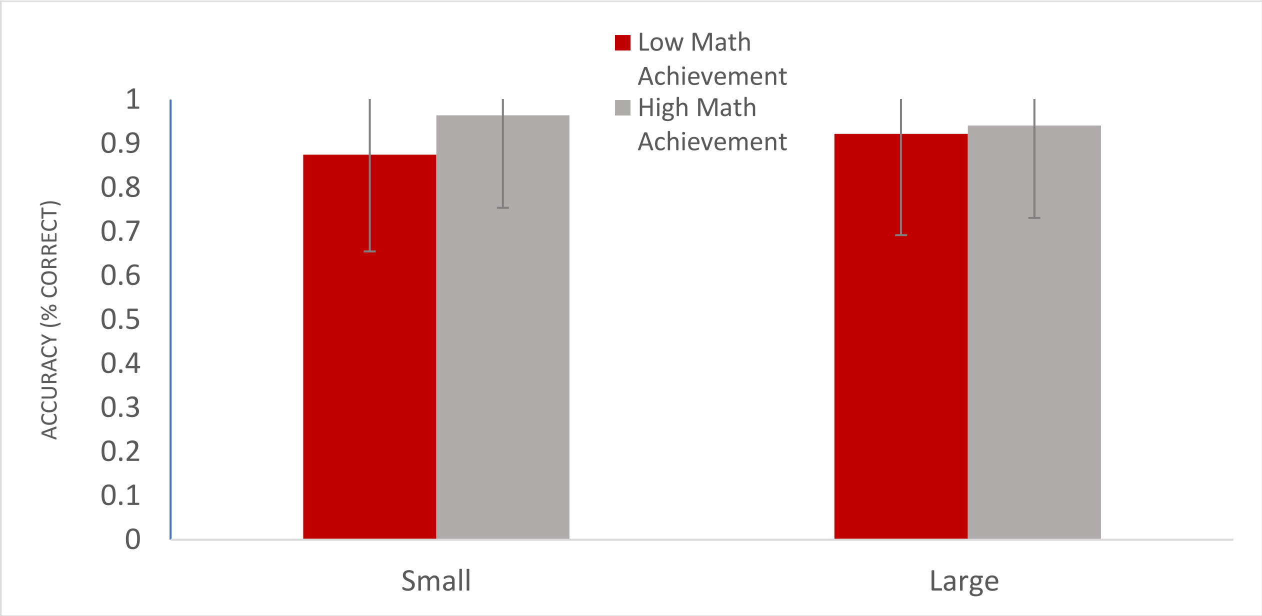
3.4 Instruction Condition – Math Achievement

Overall analysis (ie; ANOVA's for MA performance) were completed for the learning portion of the experiment. A 2 (Problem Size: Small vs Large) x 2 (Problem Type: Non-borrow vs Borrow) x 2 (Math Achievement: High vs Low) mixed ANOVA, with math achievement as the between subject's variable, was completed to test for performance on MA problems.

Reaction Time-Specific Group There was a main effect of problem size, F (1,56) = 14.73, p<.001, η_p^2 =.119, showing that participants were faster on small problems (M = 6000 ms, SE = 313) compared to large problems (M = 8191 ms, SE = 577). There was a main effect of problem type, F (1,56) = 20.29, p<.001, η_p^2 =.157 in that participants were faster on non-borrow problems (M=5609 ms, SE=444) compared to borrow problems (M=8582 ms, SE=451). Finally, there was a main effect of math achievement, F (1,56) = 10.50, p<.001, η_p^2 =.158 in that low math achieving individuals were significantly slower (M=8371 ms, SE=575) than their high math achieving counterparts (M=5820 ms, SE=537). There was no interaction between math achievement and on problem type or problem size, all F's <1.

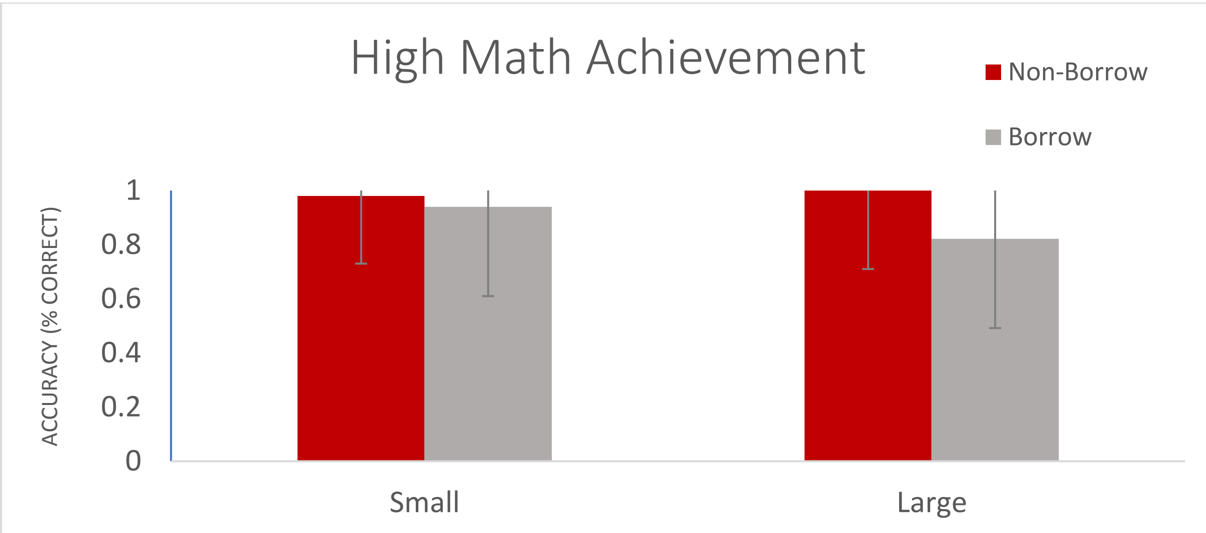
Accuracy Specific Group. The main effect of problem size disappeared, and math achievement did not interact with problem type, all F's <1. There was a main effect of math achievement, F (1,56) = 4.25, p<.05, η_p^2 =.072. in that low math achieving individuals (M=.90, SE=.02) performed worse overall compared to their high math achieving counterparts (M=.95, SE=.02). Interestingly, problem size did interact with math achievement, F (1,56) = 4.28, p<.05, η_p^2 =.071. The interaction, in Figure 4, shows the accuracy advantage for the high math achieving individuals on small problems (M=.92, SE=.02) whereas, the low math achieving individuals were at a disadvantage on these problems (M=.87, SE=.02). The figure shows that there were no differences between these achievement groups on large problems, magnifying the performance disadvantage of those low math achieving individuals on small problems, despite being given specific instruction on how to solve MA.

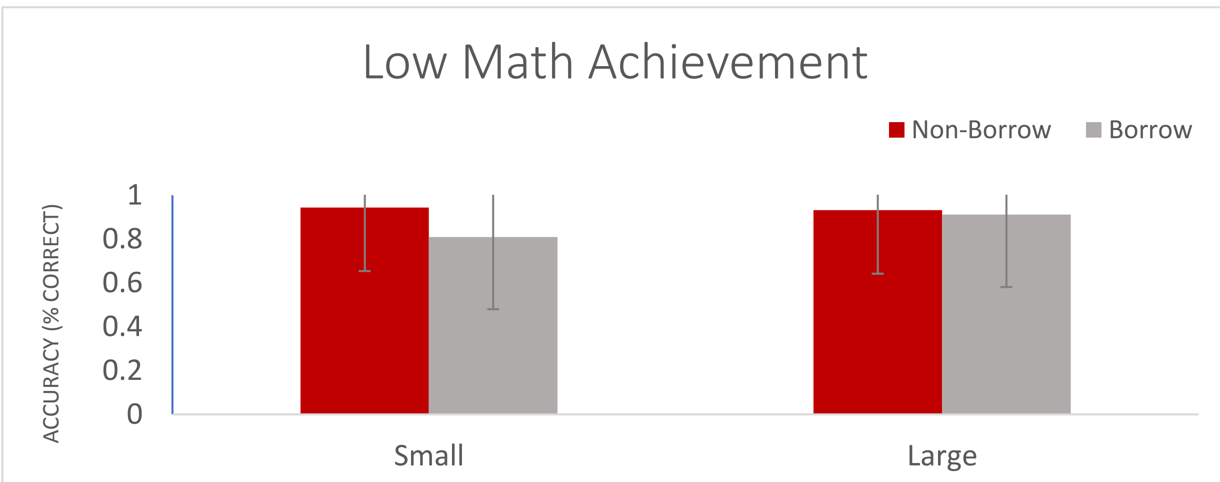
Figure 4. Math Achievement and Problem Size Interaction



Furthermore, the figure shows that the low math achievement individuals' performance on small problems mirrors their performance on large problems, suggesting that MA was overall difficult, regardless of the difficulty of the problems. There was also a significant three-way interaction between math achievement, problem size, and problem type, F (1,56) = 8.21, p<.01, η_p^2 =.125. The interaction, shown in Figure 5, shows low achieving individuals performed poorly on small borrow problems (M=.86, SE=.04) as compared to their high achieving counterparts (M=.98, SE=.02). Taken together, regardless of how well low math achieving individuals were taught, they performed worse overall and on easier problems. Taken with the evidence that low achieving individuals did take significantly more trials to reach criterion, these results suggest that even when given superior instruction, low math achievement can account for a drop in performance.

Figure 5. Math Achievement, Problem Size, and Problem Type Interaction





Reaction Time-Vague Group. There were no main effects of problem size, type, or achievement in the vague group, all F*'s*<1. Math achievement did not interact with problem size or problem type, all F*'s*<1.

Accuracy Vague Group. The main effect of problem size remained, F (1,53) = 34.75, p<.000, η_p^2 =.363 which showed that people made more errors on small problems (M=.61, SE=.02) as compared to large problems (M=.81, SE=.03). This reflects the same findings that the math anxiety data showed earlier: participants performed worse on small problems compared to large problems, because of how the problems were randomized prior to the experiment. The main effect of problem type also remained, F (1,53) = 12.27, p<.000, η_p^2 =.188 in that participants performed better on non-borrow problems (M=.74, SE=.02) compared to borrow problems (M=.68, SE=.02). Math achievement was nonsignificant, all F's <1.

In general, the learning portion of the experiment showed that instruction group had the biggest influence on performance. Interestingly, there does not seem to be much difference between high and low math achieving individuals in the vague condition. In contrast, there were significant differences between achievement groups in the specific group on small problems. Math anxiety did not appear to affect performance in the vague condition, aside from the spurious effect, but interacted with problem type in the specific condition. It appears that performance was more variable in the vague condition which explains the lack of individual differences among the math achievement and math anxiety groups.

Before examining the results of the testing portion, confidence and strategy among the participants will be reviewed.

3.5 Confidence and Strategy

After everyone completed the learning session, confidence and strategy were assessed. Confidence was assessed on a Likert-type scale that ranged from 1 to 6 with 1 being low confidence and 6 being high confidence. Two participants were excluded for not entering a number to represent confidence. An independent t-test was conducted to compare confidence ratings among participants in the specific and vague conditions. Confidence was significantly higher in the specific condition ($M=4.81$, $SD=1.29$) as compared to the vague condition ($M=2.58$, $SD=1.39$), $t(119) = 8.91$, $p<.0001$. See Figure 6. This suggests that after criterion was met, those in the specific condition were more confident going into the testing portion. Interestingly, even though those in the vague group also hit criterion, they were not as confident, suggesting that they may have not understood how to solve MA.

Next, participants were asked to explain how they solved MA. Two research assistants separately coded, using the numbers 1 (for correct) and 2 (for incorrect). A rough inter-rater reliability rating was taken by counting the number of ratings each research assistant agreed on (121) out of the total number of ratings (124) for 97% agreement. In the vague condition, method was considered correct

Figure 6. Confidence Ratings Among Groups

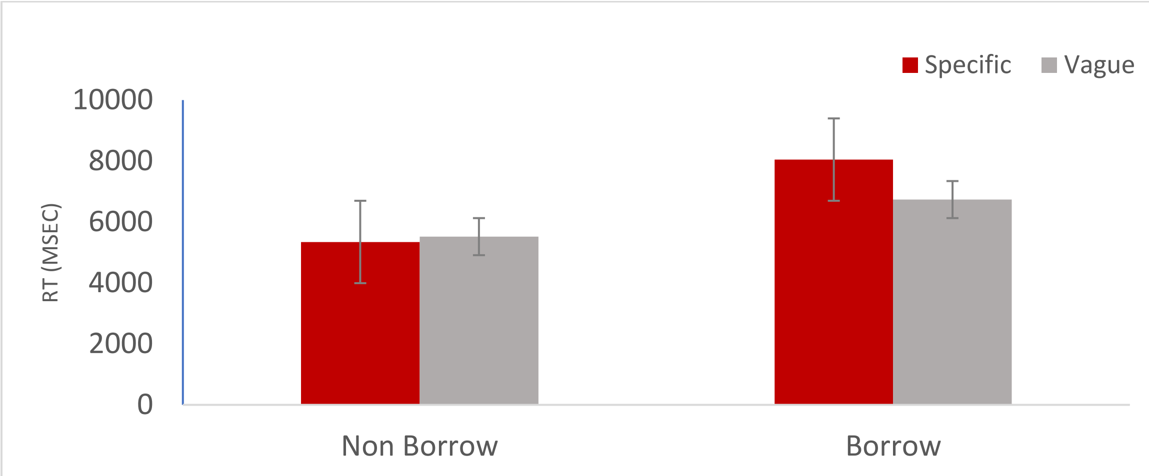
If participants mentioned any aspect of MA (even if it was out of order or not specifically how one was supposed to solve MA) the method was counted as correct. This was done because every participant counted in the study reached criterion, suggesting that some algorithm was used by the vague group to reach criterion. Three participants were removed from this analysis for not writing out how they solved MA. There was no significant difference between how each group solved MA $t(124) = -.057$, $p=.954$. This suggests that participants in both groups correctly knew how to correctly complete MA, despite differences in instruction. These results provide additional support that some sort of algorithm was used among participants in the vague condition.

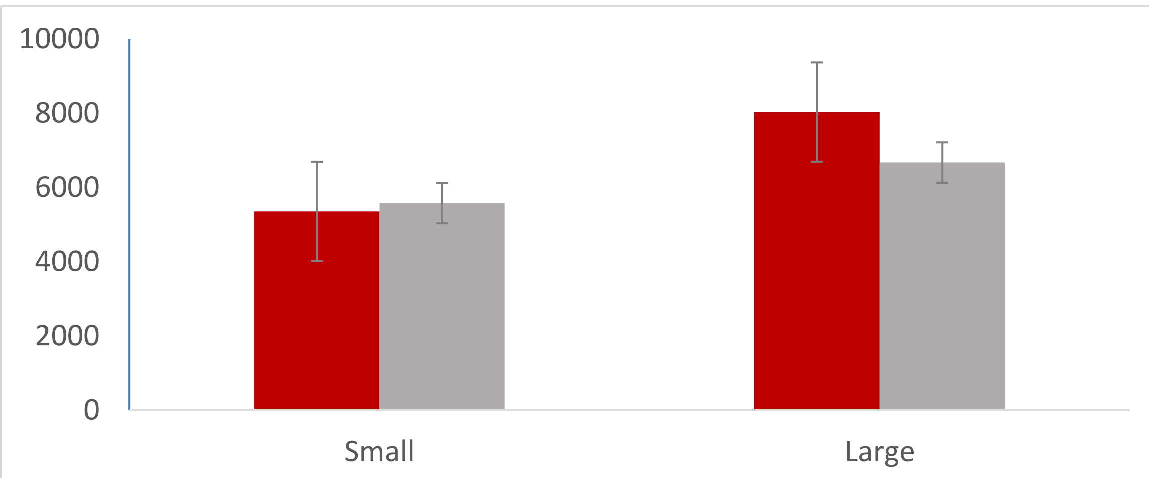
3.6 Test Condition – Group

A mixed design ANOVA 2 (Problem Size: Small vs Large) x 2 (Problem Type: Non-borrow vs Borrow) with 2 (Group: Specific vs Vague) was completed to test for performance on MA problems. Only correct reaction times were analyzed for the test portion.

Reaction Time-Group. There was a main effect of problem size, F (1, 124) = 102.37, $p<.001$, $\eta_p^2 = .456$, in that participants were faster on small problems (M=5533 ms, SE=355) compared to large problems (M=7632 ms, SE=265). There was a main effect of problem type, F (1, 124) = 43.06, $p<.001$, $\eta_p^2 = .261$, in that participants were significantly faster on non-borrow problems (M=5886 ms, SE=303) compared to borrow problems (M=7926 ms, SE=230). There was no main effect of group, $F<1$. Interestingly, group interacted with problem size, F (1, 124) = 9.73, $p<.001$, $\eta_p^2 = .07$, and problem type, F (1, 124) = 21.12, $p< .0001$, $\eta_p^2 = .15$. The **i**nteractions, in figure 8, show that those in the vague condition were significantly faster on large problems (M=7173 ms, SE=523) as compared to those in the specific group (M= 7955 ms, SE=490) and that participants in the vague condition were significantly faster on borrow problems (M=7069 ms, SE= 520) as compared to those in the specific condition (M=8194 ms, SE=404). There were no differences in performance between the two groups on small problems, $F<1$. These results are surprising given that those in the vague condition were significantly slower during the learning trials. Next, accuracy will be examined to compare performance between the two groups.

Figure 7. Group and Problem Size Interaction





Accuracy-Group. Here, there was a main effect of problem type, F (1, 124) = 12.83, p<.001, η_p^2 =.096, where participants made more errors on borrow problems (M=.79, SE=.016) as compared to non-borrow problems (M=.82, SE=.016). There was also a main effect of group, F (1, 124) = 4.56. p<.05, η_p^2 =.036, showing that those in the specific condition (M=.819, SE=0.2) outperformed those in the vague condition (M=.746, SE=.03). There was no main effect of problem size, F<1. Group also interacted with problem size and problem type, F (1, 124) = 5.85, p<.05, η_p^2 =.017. The interaction, as shown in figure 9, demonstrates that those in the specific group performed superior on small borrow problems (M=.80, SE=.02) as compared to those in the vague condition (M=.73, SE=.03). Additionally, those in the specific group performed better on large non-borrow problems (M=.84, SE=.02) as compared to those in the vague group (M=.76, M=.03). These results show that the speed advantage for the vague group came at the expense of their accuracy.

Even though those in the vague condition were significantly faster than those in the specific condition, their performance was much worse, suggesting that, at test, they avoided solving MA. These results suggest that superior instruction is not only essential for superior performance, but essential for motivation to continue to perform well.

3.7 Test Condition – Math Anxiety

A mixed design ANOVA 2 (Problem Size: Small vs Large) x 2 (Problem Type: Non-borrow vs Borrow) with 2 (Math Anxiety: High vs Low) with in each group (Specific and Vague) a was completed to test for performance on MA problems.

Reaction Time Specific Group. There was a main effect of problem size, F (1,61) = 110.05, p <.001, η_p^2 = .487, in that participants were faster on small problems (M=5470 ms, SE=265) as compared to large problems (M=7331 ms, SE=355). There was a significant main effect of problem type F (1,61) = 92.49, p<.001, η_p^2 = .44 in that participants were significantly faster on non-borrow problems (M=5486 ms, SE=283) compared to borrow problems (M=7315 ms, SE=346). There was no main effect or interaction with math anxiety, all F's <1.

Accuracy Specific-Group. Only the main effect of problem type remained when accuracy became the dependent variable, F (1,61) = 11.480, p<.05, η_p^2 =.091. Here, participants performed better on non-borrow (M=.80, SE=.02) as compared to borrow problems (M=.73, SE=.03). There was no main effect of problem size, all F's<1. Additionally, math anxiety did not interact with problem size, all F's<1.

The lack of results suggests that after reaching criterion, differences in anxiety no longer mattered when sufficient instruction was given. Perhaps the results are an indication that sufficient instruction is enough to master a concept.

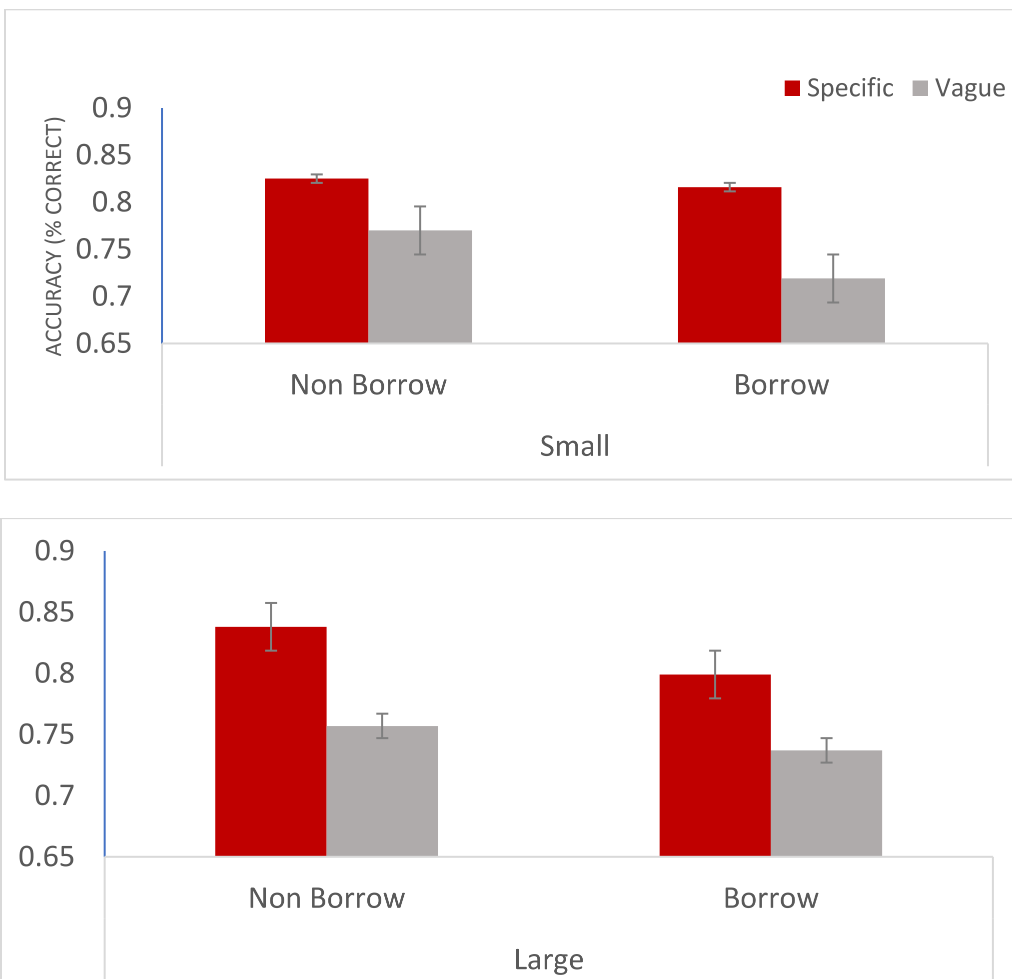
Reaction Time Vague Group. When examining the vague group, there was a main effect of problem type F (1,54) = 43.98, p<.0001, η_p^2 = .46, in that participants were faster on small problems (M=4651 ms, SE=561) as compared to large problems (M=6296 ms, SE=320). There was also a main effect of problem type, F (1,54) = 53.90, p<.0001, η_p^2 = .62 in that participants were faster on non-borrow problems (M= 4994 ms, SE=315) as compared to borrow problems

(M=6382 ms, SE=423). There were no other interactions or main effects with math anxiety, all F's<1.

Accuracy Vague Group. Only the main effect of problem type remained when accuracy was the dependent variable, F (1,54) = 5.96, p < .05, η_p^2 = .061. Participants performed better on non-borrow problems (M=.77, SE=.02) as compared to borrow problems (M=.74, SE=.03).

The lack of results in both the vague and specific group among math-anxious participants suggest that math anxiety may have only been present during the learning portion. Furthermore, these results indicate that instruction type was not enough to induce anxiety at test.

Figure 8. Group, Problem Type, and Problem Size Interaction



3.8 Test Condition – Math Achievement

A mixed design ANOVA 2 (Problem Size: Small vs Large) x 2 (Problem Type: Non-borrow vs Borrow) with 2 (Math Achievement: High vs Low) was completed to test for performance on MA problems. An additional between subject factor, 2 (Math Achievement: high and low) was included in this analysis.

Reaction Time Specific Condition. There was a main effect of problem size, F (1,56) = 62.52, p<.0001, η_p^2 = .510, in that participants were faster on small problems (M=6006 ms, SE=784) as compared to large problems (M=7854 ms, SE=512) problems. There was also a main effect of problem type, F (1,56) = 52.51, p < .0001, η_p^2 = .467, in that participants were faster on non-borrow problems (M=6022 ms, SE=784) as compared to borrow problems (M=7838 ms, SE=512) problems. There was no main effect of math achievement nor did math achievement interact with problem size or problem type, all F*'s*<1.

Accuracy Specific Condition. There was a main effect of problem type, F (1,56) = 4.46, p< .05, η_p^2 =.058, in that participants performed better on non-borrow problems (M=.82, SE=.02) as compared to borrow problems (M=.80, SE=.02). There was no longer a main effect of problem size or math achievement, all F's<1. Math achievement did not interact with problem type or problem size, all F's<1.

Reaction Time Vague Condition. There was a main effect of problem size F (1,53) = 52.01, p< .0001, η_p^2 = .566, in that participants were faster on small problems (M=4780 ms, SE=311) as compared to large problems (M=6532 ms, SE=472). There was also a main effect of problem type, F (1,53) = 41.53, p <.0001, η_p^2 = .439, in that participants were faster on non-borrow problems (M=4810 ms, SE=325) as compared to large problems (M=6502 ms, SE=467) problems. There was no main effect of math achievement, F<1. Math achievement did not interact with problem size or problem type, all F's <1.

Accuracy Vague Condition. There was a main effect of problem type when accuracy was the dependent measure, F (1,53) = 5.96, p <.05, η_p^2 = .058. Participants performed better on non-borrow problems (M=.77, SE=.03) as compared to borrow problems (M=.74, SE=.03). There was no longer a main effect of problem size or math achievement, all F's <1. Math achievement did not interact with problem type or problem size, all F's <1.

It seems as if the effects found in the learning condition are no longer present in the testing condition. This could be because MA was mastered or that the instruction group washed out potential effects in the testing portion of the experiment. To better understand the possible impact each of these variables had in both conditions, regressions were run.

3.9 Regression – Instruction Condition

Reaction Time Specific Condition. A step-wise multiple regression was calculated to predict reaction time, with predictor variables of Trials to Criterion (T2C), Math Achievement (WRAT), Math Anxiety (SMARS), Problem Size (Small coded as 0, Large coded as 1), and Problem Type (Non-Borrow coded as 0, Borrow coded as 1). These predictor variables will be used throughout the regression analyses. The analysis yielded a significant regression equation, F (1, 226) = 5.61, $p < .05$, with an R^2 of .02. The significant predictor was Trials to Criterion, t (226) = 2.37, $p < .05$, with a slope of 205. Thus, more trials it took to reach criterion showed longer reaction times (by 205 ms) when completing the trials demonstrating a lack of understanding of how to solve modular arithmetic. Note that the Math Achievement, Math Anxiety, Problem Size, and Problem Type variable were non-significant. This was most likely due to the fact that the average trials it took to reach criterion was 10, therefore making it less likely that additional factors influenced performance.

Reaction Time Vague Condition. A stepwise multiple regression was calculated to predict reaction time. The analysis yielded a significant two factor regression equation, F (2, 233) = 5.87, $p < .01$, with an R^2 of .05. The significant predictors were Math Achievement, t (234) = 2.58, $p < .05$, with a slope of 235 and Problem Type, t (233) = 2.25, $p <.05$, with a slope of 1883. Thus, for every increase in WRAT score, showed longer reaction times (by 235 ms). This is very different from what is found in the literature. Typically, high WRAT scores are associated with faster reaction times, here, the opposite was found. This odd result could be due to the amount of trials in the learning portion, or the vagueness of the instruction condition. For example, high math achieving individuals may have taken more time to figure out how to solve MA, simply because of the vagueness of the instruction condition. Reaction times were also longer (by 1883 ms) for problems that involved a borrow operation. Note that trials to criterion, problem size, and Math Anxiety were non-significant. This could be due to the vague nature of the instructions created more variability in performance.

Accuracy Specific Condition. A stepwise multiple regression was calculated to predict accuracy. The regression analysis yielded a significant three factor regression equation, F (3, 264) = 9.33, $p < .0001$ with an R^2 of .096. The significant predictors were Problem Size, t (266) = 3.57, p <.0001, with a slope of .102; Math Anxiety t (265) = -2.76, p <.01, with a slope of -.002; and Problem Type, t (264) = -2.618, p <.01, with a slope of -.07. Interestingly, participant's performance got better as problems got larger (by .10). This is contrary to what is typically found in the literature. This could be due to the fact that problems in the learning condition were not randomized, as a result, smaller problems were produced first, and more errors were made on those compared to larger problems. As participants SMARS score increased their performance on problems decreased (by -.002) the typical result shown in the literature. Finally, there was a decrease in performance on problems that required borrowing (by -.073) also a typical result. When accuracy was the dependent variable, Math Achievement and Trials to criterion were no longer significant, possibly because of the direct nature of the instruction condition. It was typical for participants in this condition to take the minimum trials to reach criterion, negating any prediction value it has in this particular condition.

Accuracy Vague Condition. A stepwise multiple regression was calculated to predict accuracy. The regression analysis yielded a significant two factor regression equation, F (2, 233) = 7.899, $p < .0001$ with an R^2 of .063. The significant predictors were Problem Size, t (234) = 3.273, $p <$ .001 with a slope of .102 and Problem Type, t (235) = -2.215, p <.001, with a slope of -.069. Interestingly, performance got better as problems got larger (by .102). These results mimic similar results from the ANOVA's in that superior performance on larger problems was in part due to the amount of large problems that appeared in the beginning of the learning portion. There was a decrease in performance on borrow problems (by -.069) a typical result shown in the literature. Trials to Criterion, Math Achievement, and Math Anxiety were not significant predictors of performance.

3.10 Regression – Testing Condition

A step-wise multiple regression was calculated to predict reaction time and accuracy, with predictor variables of Trials to Criterion (T2C), Math Achievement (WRAT), Math Anxiety (SMARS), Problem Size (Small coded as 0, Large coded as 1), and Problem Type (Non-Borrow coded as 0, Borrow coded as 1).

Accuracy Specific Condition. The analysis yielded a significant four factor regression equation, F (4, 259) = 46.27, $p < .0001$, with an R^2 of .42. The significant predictors were Math Achievement, t (259) = 2.73, $p < .01$, with a slope of .139; trials to criterion, t (259) = -10.15, $p < .001$, with a slope of -.516; Problem Size, t (259) = -4.19, $p < .001$, with a slope -.199; and Problem Type, t (259) = -4.15, $p < .001$, with a slope of -.197. Thus, participants with higher WRAT scores showed superior performance (.139 slope), the typical relationship shown in the literature. Performance was also worse for those who took more trials to reach criterion (by -.516), suggesting that those who took more than the average trials to reach criterion struggled during test. And performance was worse (by -.199) for large problems and for problems that involved a borrow (by -.197). Note that the Math Anxiety variable was non-significant, a different pattern that emerged compared to the learning condition. This could be due to the fact that the specific nature of the instruction condition did not affect accuracy.

Accuracy Vague Condition. The analysis yielded a significant one factor regression equation, F (1, 231) = 30.56, $p < .0001$, with an R^2 of .12. The significant predictor was trials to criterion, t (231) = -5.53, $p < .0001$, with a slope of -.342. Performance was worse (by -.342) for those who took more trials to reach criterion. Note that the Math Anxiety, Math Achievement, Problem Size and Type variables were non-significant. Interestingly, trials to criterion was the only significant predictor of performance in that those who reached criterion, using fewer trials, most likely figured out the correct solution in solving MA. It is surprising that there were no other predictors in the vague condition. Next, reaction time will be examined to help understand the results from the testing condition.

Reaction Time Specific Condition. The analysis yielded a significant four factor regression equation, F (5, 258) = 38.19, $p < .0001$, with an R^2 of .43. The significant predictors were Math Anxiety, t (258) = 3.201, $p < .01$, with a slope of 30; Math Achievement, t (259) = -6.74, $p < .0001$, with a slope of -222; Trials to Criterion, t (258) = -3.819, $p < .0001$, with a slope of -146; Problem Size, t (258) = 7.33, $p < .0001$, with a slope 2449; and Problem Type, t (258) = 7.45, $p < .0001$, with a slope of 2927 . Thus, participants with higher WRAT scores were faster on problems (by -222 ms), the typical relationship shown in the literature. Performance was also faster for those who took fewer trials to reach criterion (slope -146 ms), suggesting that those who took fewer than the average trials to reach criterion were faster during test. And performance was worse (by 2449 ms) for large problems and for problems that involved a borrow (2927 ms). Interestingly, when reaction time was the dependent variable, math anxiety was a significant predictor in that those who scored high in math anxiety were slower (by 30 ms), suggesting that math anxiety only affected processing speed.

Reaction Time Vague Condition. The analysis yielded a significant four factor regression equation, F (4, 231) = 10.03, $p < .0001$, with an R^2 of .15. The significant predictors were Math Achievement, t (231) = -3.90, $p < .0001$, with a slope of -230; trials to criterion, t (231) = -3.84, P < .0001, with a slope of -98; Problem Size, t (231) = 2.62, $p < .001$, with a slope 1422; and Problem Type, t (231) = 2.24, $p < .05$, with a slope of 1215. Thus, participants with low WRAT scores were significantly faster on problems (-230 ms slope), the typical relationship shown in the literature for reaction time. Participants who took fewer trials to reach criterion were also faster (by -98 ms), suggesting that those who took fewer than the average trials to reach criterion did not struggle during test. And performance was slower (by 1422 ms) for large problems and for problems that involved a borrow (by 1215 ms), which is standard in the literature. Math Anxiety was not a significant predictor in the vague condition, suggesting that the vagueness of the instruction condition erased any effect anxiety could have on performance.

Chapter 4: Discussion

The purpose of this experiment was to build a foundation for understanding how math anxiety and math achievement impact learning a novel math task. Results partially confirm that there is a relationship. The general finding of this study suggests that math anxiety and math achievement do not solely affect learning and that instruction plays a key role in overall performance, during the learning process and when being tested on the material.

The design of the current study's instruction condition was inspired by Turner et al.'s, (2002) account of the warm teacher vs. cold teacher. Often the description of the cold teacher was one who was vague in instruction style and was often authoritarian in demeanor, making them unapproachable. Students in this teacher's class were more likely to withdraw and avoid engaging in other behavior that leads to understanding math concepts better. The specific condition was designed to mimic the warm teachers teaching style and the vague condition was designed to mimic the cold teachers teaching style. Results from this study support these findings, evidenced by the speed accuracy tradeoff in the vague condition at test. Students who received poor instruction were more likely to sacrifice accuracy for speed, suggesting that they no longer felt motivated to complete the problems. Additionally, participants were still willing to sacrifice accuracy for speed even though they were given feedback in the testing portion of the experiment. Results from the ANOVA indicate that avoidance often occurred in the "test" condition, however; results from the regression analysis show some evidence of it occurring in the learning condition. It was as if the insufficient instruction was enough to deter participants from putting forth more effort in learning.

These results are even more compelling considering everyone in the study reached criterion, suggesting that everyone should have mastered the concepts of how to solve MA.

Presumably, reaching criterion would indicate a sufficient mastery of the concept. The speed accuracy trade-off found in the vague condition in the test portion mimics the results from Ashcraft & Faust (1994) who found a similar speed accuracy trade off among their highest math-anxious individuals. The key difference was that it was not math anxiety that contributed to the speed accuracy trade-off but different instruction conditions. Results from the current study showed that math anxiety only impacted those in the specific condition, suggesting that vague instruction possibly erased any effects from the individual factors of math anxiety and math achievement. The current study showed that the high math-anxious individuals were slower and made more errors than their low math-anxious peers. Even in the vague condition, there was not any indication that the high math-anxious individuals sacrificed accuracy for speed.

What do the current study's findings say about how anxiety impacts learning? The results indicate that there is no relationship between performance and math anxiety in the vague condition at test. Poor instruction seems to erase or mask any possible math anxiety effects; however, it did not erase the impact math achievement had on performance. Throughout the study, math achievement affected performance consistently, suggesting that a mastery of math concepts was a better predictor of performance, regardless of instruction condition. Regardless, math anxiety and math achievement were inversely related (r (134) = -.237, p=001 for specific condition, r (118)=-.295, p=.001 for the vague condition) suggesting that together, they both should influence performance. The effects of math anxiety only affected performance in the specific condition, where superior instruction contributed to superior mastery of MA. Furthermore, the basics of MA are simply subtraction and division, two pieces of arithmetic that have been (presumably) learned in elementary school. Perhaps those with high math anxiety performed worse (at test) in the specific condition because they have experienced chronic math anxiety from a young age. For example, Young, Wu, and Menon (2012) found that children as young as 2nd grade can experience physiological reactions to math problems. Using fMRI technology, the authors found the activation patterns among the low math-anxious participants involved regions known to be involved in mathematical processing. In contrast, activations in the high math-anxious participants involved regions known to be involved with emotional regulation of learned fear responses. If math anxiety is present at such a young age it is possible that high math-anxious children never reach the same math achievement level as their low math-anxious peers, which could be why math achievement is such a strong predictor of performance in this current study.

Recent research supports this idea showing that children's math achievement (measured by math fluency tests) was inversely related to negative feelings regarding math among students as young as second grade (Sorvo et. al., 2017). Even more compelling results from this study show that anxiety about math situations was less prevalent in their older sample (5th grade). In general, the authors found that aspects of math anxiety seem to disappear with age. They assume that aspects of math anxiety are more prevalent in younger children because they may have more anxiety about learning new math. Evidence seems to suggest that math anxiety about learning new concepts also disappears with age. Based on the early prevalence of math anxiety, it is possible that the college students in the current sample may not identify with having strong feelings of math anxiety but may have a lifetime of math anxiety that has hindered their math achievement. It could also mean that math anxiety and learning a novel task is best assessed at a younger age.

This study was also the first to measure performance while learning a novel math task. Most studies examine constructs like anxiety and achievement on concepts that have already been learned, like basic arithmetic. For the studies that do use novel tasks like MA, there is often an intense practice session that includes detailed instruction on how to complete MA. Even though all participants in the current study did have to meet a specific criterion, there was variation in the type of instruction they were given, making this study different from previous studies. Results from both the ANOVA and regression analyses suggest that constructs like math anxiety and math achievement play vital roles in performance during the learning and testing portion. Even though math anxiety was a predictor at test for the specific condition, it was not as strong as a predictor as math achievement.

4.1 Limitations and Future Directions

While the experiment was first of its kind, there are a few limitations that exist in this study. The speed accuracy trade-off that occurs in the vague condition suggests that those with poor instruction no longer felt the need to "try" during the test condition. It can be argued that participants giving up in a laboratory task is not the same as students giving up in a classroom. Students may not be willing to give up as easily when there are greater things at stake (e.g, college entrance exams, grades in a class). When there is more pressure to perform, there could be differences in perseverance. Future studies could implement an incentive and examine how pressure affects learning and mastering a novel task (Beilock, Kulp, Holt, & Carr, 2004). Often times, these types of studies include a variable that induces pressure, which could simulate a high stakes environment, thus provide more evidence about the impact of instruction type.

Additionally, a measure of working memory would have made this study stronger. In a study investigating choking under pressure, Beilock & DeCaro, 2007 found those who had high working memory capacity were more susceptible to choking, whereas those who were low in working memory capacity were not affected by pressure. A measure of working memory capacity may have aided in understanding some of the differences in performance in the instruction conditions. It is possible that large/borrow problems coupled with extra thought processes required to understand how to solve MA (in the vague condition) taxed working memory to a degree that was unrelated to math anxiety. A measure of working memory would add additional information about the impact of poor instruction and how people with different working memory capacities learn. One of the main findings here was that math anxiety was a predictor in the specific condition but not in the vague during test. Including a working memory measure may help understand why math anxiety was not a predictor in the vague condition.

An additional measure of motivation could also add a few interesting points to this study. For example, Turner, et. al. (2002) showed that students were motivated to seek out of classroom help when being instructed by a warm teacher. Other research has also shown a relationship between math anxiety and motivation in children with math anxiety (Wang et. al., 2015). This study found that children who reported high levels of math anxiety and high levels of math motivation demonstrated superior performance in math as compared to those low in motivation and high in math anxiety. There may not be a lot of motivation among college students completing a study for credit, however; a measure of motivation could help explain some of the performance differences between the vague and specific conditions. Additionally, this study did not have a way for motivated students to seek additional help. For example, motivated students in the vague condition may have wanted to ask additional questions, but were not given the opportunity, thus enabling avoidant behavior at test.

Aside from adding different measures, this study could benefit from including a physiological measure in a future design. Perhaps an elevated heart rate, dilated pupils, or Galvanic Skin Response would be apparent during the learning condition, especially for those who received vague instruction. Furthermore, these physiological responses may disappear in the following session, suggesting that participants were wholly avoiding the task at hand. Many studies have examined what performance looks like on common arithmetic math problems using fMRI and cortisol testing. However, this is one of the first, if not only study that has implemented the learning of a novel math task with different instruction conditions. Understanding what is occurring at a neurological level during learning and test could help understand what areas of the brain are engaged during learning and testing.

Overall, this study shows that inefficient instruction can harm performance at test when learning a novel math task. The results show that students were more likely to give up when asked to solve more novel math problems if they were given vague instructions. This persisted regardless of individual factors like math achievement and math anxiety. The novelty of this experiment was that it was the first one to show how instruction style can disrupt learning at a local level and possibly hinder the motivation to do well on certain tasks. Furthermore, this is the first study that measured what is occurring during the learning portion. The findings from this study and future studies can be used to bring about meaningful change in how math is taught in the education system.

APPENDIX I: DEMOGRAPHIC FORM

Math Demographics

The following questions are designed to determine your math/statistics history. Please place your answers in the spaces provided.

______ 1. What is your age?

______ 2. What is your gender: M or F?

______ 3.Did you enroll in pre-requisite math courses before taking this course: Y or N?

______ 4. If Yes, how many times did you complete these courses?

______ 5. How many times have you enrolled in Statistics (If this is your first time please write 1)?

______ 6. Have you completed statistics: Y or N?_

_______7.. What year are you now: Freshman, Sophomore, Junior or Senior?

_______8. What is your racial/ethnic background: African-American, Hispanic/Latino, Native American, Asian/Pacific Islander, Caucasian (white) or Other?

______ 9. On a scale from 1 to 10, with 1 being "not at all" and 10 being "very much," how much do you enjoy math (not just statistics)?

______ 10. On a scale from 1 to 10, with 1 being "not at all" and 10 being "very much," how math anxious are you?

______ 11. Was the lack of math courses required a reason you choose to major in Psychology?

APPENDIX II: SHORTENED MATH ANXIETY RATING SCALE

Short Mathematics Anxiety Rating Scale

Instructions: The items in the questionnaire refer to things and experiences that may cause tension, apprehension, or anxiety. For each item, mark the response that describes how much <u>you would be made anxious by it</u>. Work quickly, but be sure to think about each item.

Responses:

(0) Not at all
(1) A little
(2) A fair amount
(3) Much
(4) Very much

Item

1. Receiving a math textbook.
2. Watching a teacher work an algebra problem on the blackboard.
3. Signing up for a math course.
4. Listening to another student explain a math formula.
5. Walking to math class.
6. Studying for a math test.
7. Taking the math section of a standardized test, like an achievement test.
8. Reading a cash register receipt after you buy something.
9. Taking an examination (quiz) in a math course.
10. Taking an examination (final) in a math course.
11. Being given a set of addition problems to solve on paper.
12. Being given a set of subtraction problems to solve on paper.
13. Being given a set of multiplication problems to solve on paper.
14. Being given a set of division problems to solve on paper.
15. Picking up your math textbook to begin working on a homework assignment.
16. Being given a homework assignment of many difficult math problems, which is due the next time the class meets.
17. Thinking about an upcoming math test one week before.
18. Thinking about an upcoming math test one day before.
19. Thinking about an upcoming math test one hour before.
20. Realizing that you have to take a certain number of math classes to meet the requirements for graduation.
21. Picking up a math textbook to begin a difficult reading assignment.
22. Receiving your final math grade on your report card.
23. Opening a math or statistics book and seeing a page full of problems.
24. Getting ready to study for a math test.
25. Being given a "pop" quiz in a math class.

APPENDIX III: IRB APPROVAL

UNLV

INFORMED CONSENT (A)
Department of Psychology

Title of Study: Advanced Mathematical Thinking, Expertise, and Math Anxiety
Investigators: Mark H. Ashcraft, Gabriel Allred, AmyJane McAuley, David Copeland, Krystal Kamekona
Contact Phone Number: 895-0175 or 895-3168 or 895-1278

Purpose of the Study
You are invited to participate in a research study on the relationships among math skills, attitudes, and memory, conducted for Dr. Ashcraft in the Psychology Department. The purpose of the study is to understand better how attitudes and math skills influence performance on various measures of math performance.

Participants
You are being invited to participate in this study because you are a student in psychology, math, or mathematics education.

Procedures
In our studies, subjects complete several different tests, some paper and pencil, some on the computer; the tests are listed below. The entire testing session never lasts more than 90 minutes, but usually averages about 45 min to 1 hour. We tape record the tasks that ask you to speak out loud, just so we can check our data records for accuracy after the session; after checking the accuracy, these tapes are then erased.
We will be administering the following tests today: a math anxiety test, a working memory test, a pencil-and-paper math test, a computer-based math test, and a short reading test.

Benefits and Risks of Participation
Although there are no direct benefits of this testing to you, most students find it interesting to see what a real psychology experiment is like. You may ask the experimenter any questions you might have about these procedures, at any time during the experiment. At the end of the session, the experimenter will provide you with a full explanation of the reasons for this research; you may also ask questions then, or you may call Dr. Ashcraft at 895-0175.

There are no risks beyond those of everyday life associated with this testing.

Costs/Compensation
There are no costs to you for participating in this study. You will not be compensated for participating, although your participation will be

reported in order for you to fulfill the research participation requirement of the Psychology Department Subject Pool.

Contact Information

If you have any questions or concerns about the study, you may contact Dr. Ashcraft at 895-0175. For questions regarding your rights as a research subject, or for any complaints or comments regarding the manner in which the study is being conducted, you may contact the UNLV Office for the Protection of Research Subjects at 702-895-2794.

Voluntary Participation

Your participation is entirely voluntary, of course; you may withdraw your participation at any time, if you wish, and there will be no penalty.

Confidentiality

Your results will be recorded confidentially, and only Dr. Ashcraft will have access to the list that links your name to your i.d. number. Dr. Ashcraft will keep this list so that a future follow-up study might be possible; if you are contacted for such a follow-up, you of course would again be free to participate or not, as you wish at that time. All results of the experiment are reported anonymously, so your name will never be part of any report on these results. All records will be stored in a locked facility at UNLV for at least 3 years after completion of the study. After the storage time, the information gathered will be added to an anonymous archive, for future reference in continuing research projects on this topic.

Participant Consent: I have read the above information and agree to participate in this study. I am at least 18 years of age.

_____ Yes, I agree to participate.

_____ No, I choose not to participate.

_____ Yes, I agree to having the session tape recorded so that the data can be checked for accuracy.

_____ No, I do not agree to having the session tape recorded so that the data can be checked for accuracy.

_____ Yes, you may contact me for a follow-up study.

_____ No, do not contact me for a follow-up study.

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CURRICULUM VITAE

Graduate College University of Nevada, Las Vegas

Amy J. McAuley
Email Address: amyjdill@gmail.com

Degrees:
Master of Arts, Experimental Psychology, 2016 UNLV

Master of Arts, Forensic Psychology, 2010 John Jay College of Criminal Justice

Bachelor of Arts, Psychology, 2008 University of Charleston

Special Honors and Awards:

Graduate and Professional Student Association Travel Grant, 2016

Liberal Arts Ph.D. Student Summer Faculty Research Award, 2015

Publication:

Moore, A.M., McAuley, A.J.**,** Allred, G.A., & Ashcraft, M.H. (2014). Mathematics

Anxiety, Working Memory, and Mathematical Performance: The Triple Task Effect and the Affective Drop in Performance. Appears in S. Chinn (Ed.), *The International Handbook for Mathematical Difficulties and Dyscalculia*. Routledge.

Dissertation Examination Committee:
Chairperson, Mark H. Ashcraft, PhD.
Committee Member, David Copeland, PhD. Committee Member, Colleen Parks, PhD.
Graduate Faculty Representative, Michael Pravica, PhD.