Gender Disparities in Math Anxiety, Mind Wandering, and Learning: An Analytical Study and Educational Implications

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July 31, 2023

Abstract

Previous research has suggested math anxiety, a genuine worry or fear about mathematical situations, might reduce math learning through increased mind wandering with a decrease in interest (Mesghina et al., 2023). Furthermore, gender gaps in math achievement continue to be a persistent issue as past studies have shown higher math anxiety among girls (Devine et al., 2012). Nevertheless, providing effective instructional tools such as worked examples in the classroom may effectively solve this issue by disrupting the complex mechanism of math anxiety. Cognitive Load Theory (Sweller, 1988) suggests such tools can increase students' available working memory resources during problem-solving and math learning - which are a limited set of cognitive attention resources that allow students to learn mathematics concepts and solve word problems. At the same time, many students feel math anxiety when faced with math learning and problem-solving, which can generate worries that engage the same limited set of working memory resources, reducing available resources for problem-solving. We constructed a theoretical path analysis to examine the relationships between situational interests, mind wandering, trait math anxiety, and math achievement (both test scores and perceived understanding) with gender as a mediator, to data taken from a previous study by Mesghina examining the effectiveness of worked examples on math anxiety. No gender differences were found in the effect of trait math anxiety on learning achievements when worked examples were given, signifying that worked examples are effective tools in reducing math anxiety for students of all genders, and may be particularly helpful given that in the general population, trait anxiety tends to be higher in girls. However, our results suggest further precaution for potential gender differences in the impacts of mind wandering on learning outcomes.

1 Introduction

Mathematical problems can leave students feeling excited but also frustrated. When students get stuck on a problem for a long time or struggle to get sufficient help from others, this can leave them frustrated and lead them to have negative feelings toward math (Bekdemir, 2010). A positive attitude towards math is important in developing their interest in pursuing STEM in higher education and other STEM-oriented opportunities. Through the implication of effective instructional tools in the classroom, students will be capable of avoiding feeling lost in math education. One such tool is worked examples, which provide worked-out problems to relevant math topics with step-by-step solutions. Typical worked examples include a statement that addresses a problem and a procedure for solving the problem in a step-by-step manner (Atkinson et al., 2000). By having students learn from worked examples, they can make connections to other problems that are similar to problems from worked examples. Particularly, when two worked examples are presented for comparison, students benefit from learning them as they find connections between different strategies and apply them to new problems. The implementation of worked examples in learning is also effective in improving their analogical reasoning skills in math, which plays a significant role in enhancing students' overall success in math (Richland and Begolli, 2016), and growing their confidence in their own mathematical ability.

Despite their main effects on students' achievement in math education, implementations of effective instructional tools have shown that they have significant effects on cognitive load. Furthermore, worked examples are an example of Cognitive Load Theory, which states that working memory has limited resources and suggests that any instructional tools that may overload students' working memory may be avoided to enhance their learning (Sweller, 1988). Worked examples are one of the instructional strategies that can free up space in working memory to better attain new information. When encountering a new topic in math, students should first review worked examples before working on attempting to solve problems related to the topic as they can learn the necessary skills and strategies required for solving problems similar to those from worked examples (Barbieri et al., 2023). In addition, by reviewing and comparing different worked examples, students can focus only on the relevant information regarding the problem-solving process instead of trying to look for random, irrelevant information while attempting to solve new problems without looking at examples.

Many factors can interfere with cognitive load by overwhelming its capacity. One such factor is math anxiety. Math anxiety is a genuine worry or fear about mathematical situations. Students who show math anxiety often struggle with mathematical operations while solving arithmetic problems as it interferes with their cognitive ability which is required for tasks involving mathematical reasoning (Richardson and Suinn, 1972). Past studies have shown that math anxiety can cause students to perform worse in problems involving number manipulations by limiting the resources in working memory (Ashcraft, 2002). Ashcraft and Kirk conducted two experiments to compare the math performance between highly math-anxious and low math-anxious groups, where in the first experiment, they were only given a task to complete a set of addition problems, and in the second experiment, they were given a secondary task, which asked the participants to recall letters presented before each problem. Their results showed that those with high math anxiety had a substantially higher increase in error during the second experiment compared to the first experiment (Ashcraft and Kirk, 2001). Their findings indicate that math anxiety negatively affects cognitive performance for mathematical problem-solving, particularly by disrupting the limited resources available in working memory.

Moreover, math anxiety is also a significant factor in causing greater mind wandering as it disrupts their working memory and executive function (Lu et al., 2015). Mind wandering is a shift in attention away from an ongoing event or task from the current environment (Smallwood and Schooler, 2015). Smallwood explains that mind wandering occurs to students from their own private thoughts and feelings that are irrelevant to their external environment (Smallwood et al., 2007), and Randoll and colleagues further describe that such thoughts are generated by fewer limited cognitive resources (Randall et al., 2014). Additionally, Mesghina supports this claim with an experimental study on undergraduate college students where they found that anxieties from online instructions during the COVID-19 pandemic were positively associated with mind wandering, ultimately resulting in lower learning achievement (Mesghina et al., 2021). Math anxiety is often related to lower motivation in learning math (Q. Li et al., 2021), causing students to avoid any activities involving math and lose interest in the subject altogether. As a result of low interest, a negative association between mind wandering and motivation arises, whereby students who have low motivation get higher levels of mind wandering (Brosowsky et al., 2020), which can cause them to struggle with completing problem-solving tasks.

The gender gaps in math anxiety have been studied very broadly. Yet, no concrete findings or conclusive results have been concluded from the studies. For example, some studies have found that girls tended to show higher levels of math anxiety than boys (Devine et al., 2012; Ridley, 2005). In contrast, other studies have found no significant difference in math anxiety between genders (Ma and Xu, 2004; Newstead, 1998). Furthermore, the differences in the effects of instructional tools, such as worked examples, on reducing math anxiety between genders have not been examined thoroughly. Rather than identifying the different effects between genders, most studies stress the importance of early identification of math anxiety in students, especially girls, for closing gender gaps in math achievements (Van Mier et al., 2019). As math anxiety relates to lower motivation, students who show high math anxiety avoid STEM courses and careers in STEM. The gender gap in STEM participation is very significant: only 24% of the STEM workforce was women in 2023 (Piloto, 2023). Therefore, addressing the differences in the effectiveness of instructional tools in reducing math anxiety between genders will be crucial in closing the gender gaps in math achievements and as well as STEM participation.

Research Questions

In this study, we analyzed the dataset from the study that examined the effectiveness of worked examples in reducing math anxiety, and we mainly looked closely at the differences in the effects between genders (Mesghina et al., 2023). We are interested in answering the following research questions:

RQ 1. Are there any gender differences in math anxiety and mind wandering?

RQ 2. Are providing effective instructional tools able to alleviate the effects of math anxiety equally for students of all genders?

RQ 3. What are the impacts of worked examples and gender on the causal relationships between mind wandering and math anxiety?

2 Methods

The study was conducted virtually during the COVID-19 pandemic. All participants were from fifth-grade classrooms in two different schools both at different sites across two different states, Irvine, CA, and Chicago, IL.

Participants

Due to the pandemic, the recruitment of participants for the study was constrained. The study took samples from a total of 285 students. 239 of the total participants were from Irvine and 64 students were from Chicago. For the statistical analysis of the data, we only considered the data of participants who completed the study. Additionally, those who were not assigned to any condition group or did not specify their sex were also removed from the data. The final sample consisted of 224 participants (21% white, 3% black, 18% Asian/Pacific Islander, 18% Hispanic/Latinx, 39% mixed race). There were 109 participants in the no worked example (no WE) group (Irvine: 34 boys and 51 girls, Chicago: 10 boys and 14 girls) and 115 participants in the worked example (WE) group (Irvine: 34 boys and 55 girls, Chicago: 17 boys and 9 girls).

Measures

The study examined the effectiveness of worked examples on students' math anxiety and their learning achievements at two time points, Day 1 and Day 2. The participants were randomly assigned to either the WE or no WE condition. In the WE group, the participants received step-by-step worked-up solutions four times during the lesson, whereas in the no WE group, the participants did not receive any examples during the lesson. Furthermore, the study measured students' math anxiety using the five-item learning subscale of the Modified Abbreviated Math Anxiety Scale (Carey et al., 2017) with a five-point scale (1 = low stress, . . . , 5 = high stress). Besides math anxiety, mind wandering and situational interest were also measured. Mind wandering scores were assessed twice during the study using the five-item Mind Wandering Questionnaire (Mrazek et al., 2013). Participants answered each question using a six-point Likert scale (1 = never,..., 6 = always). The situational interest scores were measured once using Situational Interest Scale (Linnenbrink-Garcia et al., 2010) with a five-point Likert scale (1 = strongly disagree, . . . , 5 = strongly agree). The participants were also tested on their procedural and conceptual understanding of math topics covered in the lesson. The study computed the overall accuracy for every assessment using proportion for how many they answered the question correctly and the total number of questions. The first test was administered during the pretest (Day 1) and the second test was administered during the posttest (Day 2), which was three days after Day 1. In addition, during the lesson, we measured participants' perceived understanding seven times throughout the study by asking them to answer a question on how much information they understood from the video using a continuous sliding scale (0-10).

Procedures

The study was a 2-day study. On Day 1, all participants completed a pretest where they were questioned on a single word problem about ratios using any strategy that they knew. They received a score of 1 if they used any type of proportional strategy to solve the problem, and received 0 otherwise. After the pretest assessment, the participants were randomly assigned to either the WE group or no WE group. Each group then received video lessons about the equivalent fraction strategy, unit ratio strategy, and comparison between the two strategies. During the video lessons, every participant from each group was asked to answer survey questions on perceived understanding, mind wandering, and situational interest. Day 2 of the study was followed three days after Day 1. During Day 2, posttest items were measured. Participants took assessments that tested their conceptual and procedural understandings of the materials covered in the lesson. Additionally, the participants filled out questionnaires that measured their math anxiety and mind wandering.

3 Results

Previous Results

The results of the study were constructed and thoroughly analyzed initially by Mesghina et al. in 2023. The main findings from their work indicate the effectiveness of worked examples in alleviating the effects of math anxiety on students' learning achievement, particularly their assessment skills. Their findings were generated by three-step linear regression to observe the effects on the learning achievements of students. In the first step of regression, they examined the individual effects of math anxiety with the site and pretest scores as covariate factors. In the second step, they added a worked example as another covariate to see the effectiveness of a worked example on learning achievements. Lastly, in the third step, they added an interaction effect between math anxiety and worked examples to inspect the potential differences in the effect of math anxiety on learning achievement at different levels of worked example conditions. From their analysis, they concluded that worked examples were effective tools in mitigating the effects of math anxiety on student's assessment scores. Moreover, they strongly encouraged the implication of worked examples in classrooms during both remote and in-person instruction to promote effective learning, especially in learning difficult mathematical concepts and contexts.

Analytic Plan

To answer our research questions, we examined math anxiety and learning achievement using ANCOVA tests and path analysis. We used the dataset that was already imputed by the previous analysis, but we created new variables for the average values of trait math anxiety, mind wandering (over 2 days), and situational interest. All quantitative variables were standardized such that all data is a roughly normal Gaussian distribution with zero as its average and one as its standard deviation. All data wrangling and visualization were done with the R tidyverse

RQ 1: Gender Differences in Math Anxiety and Mind Wandering

To examine the differences in the average values of both trait math anxiety and mind wandering, we performed an ANCOVA test for each dependent variable. For each dependent variable, we used the identical set of covariates which included the student's group condition (WE or no WE), gender (boy or girl), site (Chicago or Irvine), and with various interaction effects including group condition and gender, group condition and Chicago, and lastly another interaction term with three variables, group condition, gender, and site.

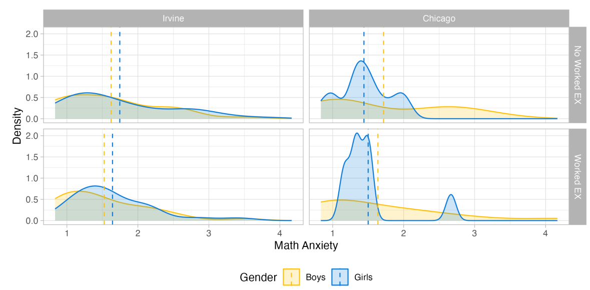

Figure 1: Density plot of average math anxiety scores by gender compared with condition (top: No Worked Example group, bottom: Worked Example group) and sites (left: Irvine, right: Chicago)

First, we looked at differences in math anxiety between genders. From our data, we saw that in Irvine, girls seemed to have a higher math anxiety average than boys in both conditions. On the other hand, in Chicago, boys seemed to have a higher average than girls in both conditions. Our results of the ANCOVA test showed no significant difference. Furthermore, we found no significant difference in the math anxiety between genders even without accounting for differences in condition.

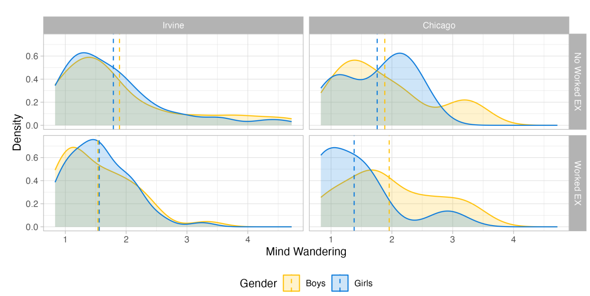

Figure 2: Density plot of average mind wandering by gender compared with condition (top: No Worked Example group, bottom: Worked Example group) and sites (left: Irvine, right: Chicago)

Next, we looked at potential gender differences in the average mind wandering. Our empirical results from the study showed an overall low average mind wandering for each site. In Irvine, both girls and boys seemed to have higher average mind wandering than students in the WE group. In Chicago, we observed that in the WE group, boys had a higher average than girls, but no difference between condition groups regardless of gender. The results of the ANCOVA test showed no evidence of gender differences in mind wandering. However, it showed a significant difference in mind wandering between WE and no WE groups. Moreover, our results showed higher average mind wandering for the no WE group than the WE group.

RQ 2: Gender Difference in the Effect of Math Anxiety on Learning Achievement

Learning achievements were examined using two measurements, posttest accuracy scores and perceived understanding. For each measurement, we utilized a multigroup analysis with path analysis to examine the gender difference in the impact of worked examples on math anxiety and learning achievements. The gender effect was examined by adding gender as a moderation effect to our path analysis model instead of testing the model to each gender subgroup data to avoid losing statistical power.

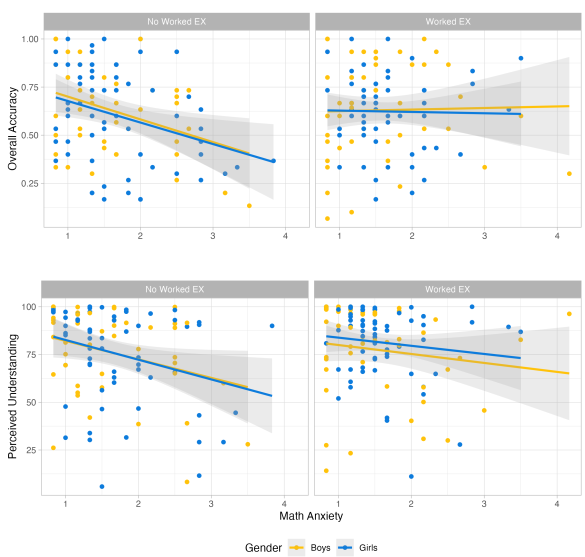

Figure 3: Scatterplot between average math anxiety scores and overall posttest accuracy scores (top) and perceived understanding (bottom) colored by gender and compared with different conditions (left: no worked example group, right: worked example group).

We observed from Figure 3 that in the no WE group, girls had a negative effect of math anxiety on their accuracy score whereas boys had a positive effect. In the worked example groups, both boys and girls seemed to have a negative effect on accuracy scores by math anxiety. Additionally, we saw similar characteristics from the perceived understanding data where both gender groups seemed to have a negative relationship between math anxiety and perceived understanding in both conditions and sites.

We constructed two different path analysis models for each learning measurement based on the theoretical assumptions about the relationships between each variable of our interest. Each model has identical covariates and structures, except for the primary endogenous variable, posttest accuracy scores, or perceived understanding. Figure 4 shows the structures of our proposed path analysis model.

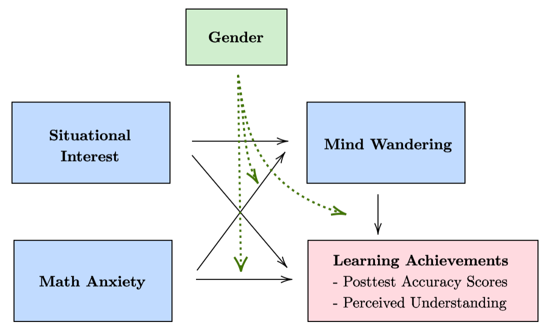

Figure 4: Path diagram of the proposed path analysis model for examining the effects on both learning achievement measures: posttest accuracy scores and perceived understanding.

Our results for the model are shown in Table 1 and Table 2. From Table 1, we saw that in each model, gender did not seem to have a significant impact on altering the effect of trait math anxiety on learning achievements as none of the interaction terms with gender did not show any significance. This main result from the path analysis indicated that worked examples are effective instructional tools in alleviating the effects of math anxiety on both assessment scores and perceived understanding for students of all genders.

RQ 3: Impacts of Gender on the Causal Relationship between Mind Wandering and Math Anxiety

From Table 1, we see that in each group, trait math anxiety was a strong positive predictor of mind wandering ($\beta_{noWE} = 0.293$, $\beta_{WE} = 0.299$). We ran a multigroup analysis test to inspect a potential difference in the effect of trait math anxi-

Table 1: Coefficient estimates of each predictor from the path analysis model for predicting overall posttest accuracy scores and perceived understanding for both conditions (left: no WE, right: WE). An asterisk represents significant predictors.

	Independent Variables					
Dependent Variables	*Trait Math Anxiety*	*Situational Interest*	*Mind Wandering*	*Gender*	*Gender* Trait Math Anxiety*	*Gender* Mind Wandering*
Mind Wandering	0.293* 0.299*	-0.291* -0.057	-	-0.136 -0.243	0.197 -0.212	-
Posttest Accuracy Scores	-0.289 0.080*	-0.080 0.009	-0.225* -0.180	-0.117 -0.033	0.001 -0.098	0.100 0.144
Perceived Understanding	-0.044 0.067	0.157 0.288*	-0.412* -0.537*	-0.098 0.275	0.019 -0.188	0.071 0.436*

Left: No worked EX group
Right: Worked EX group
Gender: 0 = boys, 1 = girls

Table 2: Coefficient estimates of each predictor from the path analysis model for predicting overall posttest accuracy scores and perceived understanding across all samples. An asterisk represents significant predictors.

	Independent Variables					
Dependent Variables	*Trait Math Anxiety*	*Situational Interest*	*Mind Wandering*	*Gender*	*Gender* Trait Math Anxiety*	*Gender* Mind Wandering*
Mind Wandering	0.306*	-0.203*	-	-0.212	0.059	-
Posttest Accuracy Scores	-0.071	-0.007	-0.207*	-0.085	-0.088	0.077
Perceived Understanding	0.015	0.212*	-0.439*	0.054	-0.094	0.186*

Gender: 0 = boys, 1 = girls

ety on mind wandering between WE and no WE groups. However, we did not find a significant difference in their relationship. Regardless of whether students received worked examples or not, greater math anxiety still caused greater mind wandering. Other than trait math anxiety, situational interest negatively predicted mind wandering where the effect for no WE group was significant ($\beta_{noWE} = -0.136$, $\beta_{WE} = -0.243$). Moreover, we observed no gender differences in the direct effects of any of the covariates on mind wandering.

The effect of trait math anxiety for the WE group on posttest accuracy scores was positive and statistically significant ($\beta_{WE} = 0.080$). On the other hand, for no WE group, its effect was negative ($\beta_{noWE} = -0.289$), but not statistically significant. This result reflects the previous analysis' results with the three-step regression models, where they found that worked examples were effective in reducing the effect of math anxiety on students' accuracy scores. Furthermore, mind wandering had negative effects on accuracy scores for each group, but only the WE group with statistically significant results ($\beta_{noWE} = -0.225$, $\beta_{WE} = -0.180$). The statistical significance in the direct effect of mind wandering on accuracy scores suggests significant indirect effects on accuracy by trait math anxiety for both groups and situational interest for no WE group. There was no significance in the gender differences of trait math anxiety and mind wandering.

For the perceived understanding model, the mind wandering had higher negative direct effects than the accuracy scores ($\beta_{noWE} = -0.412$, $\beta_{WE} = -0.537$), and each result showed statistically significant results for both groups. Similarly, these results imply significant indirect effects of trait math anxiety and situational interests on perceived understanding. In the WE example group, we detected significance in the interaction effect between gender and mind wandering ($\beta_{WE} = 0.436$). This significance in the interaction effect derived different coefficient estimates for boys and girls, in which boys had more negative effects on perceived understanding by mind wandering than girls ($\beta_{boys} = -0.537$, $\beta_{girls} = -0.101$). From the results obtained from the perceived understanding model, we observed potential gender differences in mind wandering and its effect on students' comprehension of mathematical concepts.

Next, we looked at the overall results of our path analysis model without accounting for differences in the condition since we saw from the multi-group analysis that there were no significant differences in the effects of mind wandering on learning achievements. Table 2 displays the coefficients of all the causal paths defined in our model for the overall data. Similarly, trait math anxiety persisted as a strong positive predictor for mind wandering ($\beta = 0.306$) while situational interest also maintained to be a strong negative predictor for mind wandering ($\beta = -0.203$). Neither the gender nor the interaction term between gender and trait math anxiety showed any significant effects on mind wandering. Although trait math anxiety did not seem to have a significant effect on both learning achievement measures, mind wandering was again a significant negative predictor of both posttest accuracy scores ($\beta = -0.207$) and perceived understanding ($\beta = -0.439$). This result indicates that both trait math anxiety and situational interest have indirect effects on learning achievement. Additionally, situational interest had a significant direct positive effect on perceived understanding ($\beta = 0.212$), but not post-test accuracy scores. As we also observed from the multi-group analysis test, we saw that the interaction effect between gender and mind wandering was significant only on the perceived understanding ($\beta = 0.186$). Further dissecting this result indicates that girls have a less negative effect on perceived understanding by mind wandering than boys ($\beta_{boys} = -0.439$, $\beta_{girls} = 0.253$).

4 Discussion

In this analytical study, we investigated potential gender differences in both students' trait math anxiety and trait mind wandering, examining the causal effects between both factors and their ultimate impact on students' learning achievements in math. We extended the previous results by implementing a new path analysis model that focused more closely on the relationship between math anxiety and mind wandering, and their effects on students' assessment scores and perceived understanding levels. As previously discovered, worked examples are highly recommended instructional tools for mitigating the effect of math anxiety. Our path analysis model indicated no gender differences in the worked examples effect, highlighting that worked examples are effective tools for reducing the impact of math anxiety on learning achievements. Furthermore, we observed no significant difference in students' math anxiety between boys and girls, in each condition and as well across conditions. This work adds to an ongoing discussion about gender differences in math anxiety, a topic marked by controversial perspectives. Some have found that girls tended to be more highly math-anxious than girls (Devine et al., 2012) whereas others found no gender differences (Ma and Xu, 2004). Our findings, however, demonstrate the effectiveness of instructional tools such as worked examples for addressing and preventing gender gaps in math for K-12 students. Particularly, this suggestion is relevant in scenarios where girls are exhibiting higher math anxiety than boys.
Additionally, math anxiety was a significant and positive predictor of mind wandering, implicating that higher math-anxious students are more likely to have greater mind wandering while learning math in the classroom. This effect of math anxiety does not depend on whether or not the students received worked examples during math education as we saw from our results from the multi-test analysis. Critically, there could be potential gender differences in the effect of mind wandering on students' perceived understanding of mathematical topics as we observed from our analysis that girls have a more positive effect on their perceived understanding by mind wandering than boys. When their mind wanders, students struggle to maintain information that they are not paying attention to (Pachai et al., 2016). This can be extended to the math education context, in which students who frequently drift their attention beside the main mathematical task show poor retention of information, resulting in a low level of perceived understanding. Our findings alarm for potential gender differences in mind wandering and its effect on students' learning comprehension of mathematical concepts. Future studies should consider for difference in the level of mind wandering between girls and boys while designing new educational curriculums and tools to ensure equality in mathematical learning achievements.

The sampling of our participants could have played a crucial role in altering the results of our study. Participants from Irvine and Chicago came from different academic backgrounds. Most of the participants from Irvine knew how to solve ratio problems more than the participants from Chicago, which may have affected their levels of math anxiety as previous knowledge in math is considered one of the strong predictors of math anxiety (T. Li et al., 2023). The imbalanced pretest knowledge background in math between our samples from Chicago and Irvine had significant impacts on the results of our study by possibly causing different levels of math anxiety at the end of the study. Furthermore, the smaller sample size in Chicago data could have also altered the study results by affecting the results of statistical tests that we utilized for the study, which required a large sample size. Future studies should be critical about making sure that baseline measures are balanced between different sample groups in order to produce more reliable results. Another limitation that should be considered for future studies is the measurements of math anxiety scores. Math anxiety was only measured at the end of the study, which occurred three days after the video lessons. Future studies should consider the following suggestions: 1) have participants exposed to worked example conditions for longer periods of time and 2) measure their math anxiety levels immediately after the video lesson in order to improve the posttest difference between the groups. By incorporating these suggestions, we can have better measurements that best reflect the state anxiety of students, which can further help with investigating the gender gaps in math achievements.

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