Supplemental Material

Supplemental Materials and Methods

Measures

Woodcock-Johnson III Applied Problems/ Letter-Word Identification. At the beginning of 1st grade and end of 3rd grade, children completed measures of their math and reading achievement using the Applied Problems and Letter Word Identification sub-tests of the Woodcock-Johnson III, respectively (Woodcock, McGrew, & Mathew, 2001). The Woodcock-Johnson is a nationally normed, comprehensive test battery used to assess achievement skills of individuals between the ages of 2 and 90 years. This set of tests is valid and reliable measure of performance for participants between the ages of 2 and 99 (Woodcock, McGrew, & Mathew, 2001). Median reliability coefficient alphas for all age groups for the standard battery of the WJ III ranged from .81 to .94. Form A was used for the fall administration and form B was used in the spring. Testing continued until basal and ceiling were established. The Applied Problems subtest consists of orally presented math word problems that involve arithmetic calculations of increasing difficulty. Children were excluded from the analysis if the examiner failed to establish basal or ceiling levels. The Letter-Word Identification subtest asks students to identify letters and decode words that are of increasing difficulty. Children were excluded for failing to reach basal or ceiling due to experimenter error. However, these children were only excluded in analyses that included reading performance.

Demographic information. When parents completed the initial consent form, they identified their child's gender and race as well as their family income using one of the following six categories: less than $15,000, 15,000 to $34,999, $35,000 to $49,999, $50,000 to $74,999, $75,000 to $99,999, $100,000 or more.

Parents' expectations and value of math for their children. Primary caregivers (N=136) completed measures of parents' expectations and value of math for their children, based on measures used in previous work in this area (Wigfield & Cambria, 2010). Parents were asked how well their child

does in math, as well as their views on how important math is to their child and their expectations of their child's ability and for their child's future performance in math (using the questions "How is your child doing in math?," "How much natural talent does your child have in math?," "How important do you think math is for your child?," "How well do you think your child will do in math in the future?"). Response options ranged from 1-5 with different anchors for each scale (e.g., for "How is your child doing in math?," The scale ranged from "not at all well" to "very well"). Scores ranged from 2.0 to 5.0 with a mean of 4.29 (SD= 0.53) in the fall and ranged from 2.75 to 5.00 with a mean 4.43 (SD=0.49) in the spring. Parents' expectations and value represent similar constructs in early elementary school when many parents have high expectations and value for their children's academic success. As mentioned in the main paper, the Cronbach's alpha for the scale of all four items combined was .74. Further, the group by parent math anxiety interaction was significant for the value item alone and also for the three expectation items considered as a group, consistent with what is found when they are all combined into one scale. Therefore, we believe it was most appropriate to analyze parents' expectations and value as one construct for the age group in our study. See Table S1 for the zero-order correlations between child and parent measures.

App usage. Families had continued access to the app from iPad distribution in 1st grade through the end of 3rd grade, three years later. Average weekly app usage was calculated for each time point (1st grade, summer between 1st and 2nd grade, 2nd grade, summer between 2nd and 3rd grade, and 3rd grade). School year app usage for 1st grade was calculated using the number of times a week the families opened a problem between iPad distribution in the fall of the first year and testing in the spring of the first year. In subsequent years, school year app usage was calculated using the number of times a week the families opened the app between fall testing at the beginning of the academic year and spring testing at the end of the academic year. Summer app usage was calculated by calculating the average of the number of times per week the families opened a problem between spring testing to fall testing in the subsequent year.

App descriptions. After children were tested in the fall of the first year, families were given an iPad mini with the app preloaded. The intervention (math) version of the app was based on the "Bedtime Math" app distributed by the Bedtime Math Foundation, which is freely available for download on iTunes and Android. Families were asked to use the app nightly with their children, preferably four times per week. New problems were delivered to the families daily through the app. In both groups, each nightly passage had five accompanying questions that differed in difficulty. In the intervention group, problems included arithmetic facts, counting skills, fractions, geometry, and patterns. Questions in the control group focused on recalling facts from the passage, vocabulary skills, spelling, and making inferences from information in the passages.

Sample Intervention Passage and Questions. Whipped cream was invented about 500 years ago, and is credited to a bunch of guys with long unpronounceable Italian and French names. But what made them think to whip up cream in the first place? Did they know what would happen? Never mind that there was no electricity back then - they had to whip it by hand. Luckily, it was worth the effort.

Whipping air bubbles into cream makes it take up a lot more "volume," or space. In the Bedtime Learning Together test kitchen, 1 cup of heavy cream generated 3 cups of whipped cream. With something as important as dessert, that's a key fact.

Questions: Wee ones (counting on fingers): If you can whip 2 cups of heavy cream into 6 cups of whipped cream, how many cups of air did you whip into it? Little kids: If you're making whipped cream for a party, and 1 cup of heavy cream makes 3 cups of whipped cream, how much whipped cream does 6 cups make? Bonus: If when no one's looking you slurp up 9 cups of the whipped cream, how much heavy cream did it take to make that? Big kids: If a can of whipped cream holds 6 cups, and when you open it, it kind of explodes and squirts 1 1/2 cups on you, how much is left in the can? Bonus: If you then try to squirt half of what's left into your mouth, how much is left after that?

Answers: Wee ones: 4 cups of air. Little kids: 18 cups of whipped cream. Bonus: 3 cups of heavy cream (by the way, at 800 calories per cup, that's 2400 calories - about as much food as a grown-up eats in a day. We don't recommend eating that all at once). Big kids: 4 1/2 cups. Bonus: 2 1/4 cups left.

Sample Control Passage and Questions. Whipped cream was invented a long time ago, and is credited to a bunch of guys with long unpronounceable Italian and French names. But what made them think to whip up heavy cream in the first place? Did they know what would happen? Never mind that there was no electricity back then - they had to whip it by hand. Luckily, it was worth the effort. Whipping air bubbles into heavy cream makes it take up a lot more "volume," or space. In the Bedtime Learning Together test kitchen, just a little heavy cream generated a lot of fluffy whipped cream! With something as important as dessert, that's a key fact!

Questions. Wee ones: How did people make whipped cream before we had electricity? Little Kids: What's the difference between whipped cream and cream? Bonus: Which countries were the inventors of whipped cream from? Big Kids: How does whipping heavy cream turn it into whipped cream? Bonus: In the sentence, "In the Bedtime Learning Together test kitchen, just a little heavy cream generated a lot of fluffy whipped cream," what does the word "generated" mean?

Answers: Wee Ones: It was whipped by hand. Little Kids: Whipped cream has air whipped into it so it is fluffier than cream. Bonus: France and Italy. Big Kids: The whipping process creates air bubbles. Bonus: To "generate" means to make or create.

Supplemental Results

Analysis Approach

The data were analyzed using Hierarchical Linear Modeling (HLM) to account for the nested nature of the data. All analyses on student achievement were performed on students' W scores, a transformation of the students' raw score that results in equal intervals (Woodcock, McGrew, & Mather, 2001). Because of its properties as an interval scale with a constant metric, the W score is recommended for use in studies of individual growth.

Secondary Analysis: Matched and Full Samples

As seen in Table S2, we found significant group by time by parent math anxiety three-way interactions in both the matched and full samples on student math achievement. Highlighting these results, we also see a significant group by parent math anxiety interaction in both the matched and full samples on student math achievement at the end of 3rd grade (Table S3).[1]

Secondary Analysis: Is The Impact of Parents' Math Anxiety specific to the Math Domain?

Next, we examined whether the impact of parents' math anxiety was specific to the math domain (versus reading) by regressing end of 3rd grade reading achievement on pre-intervention reading achievement, parents' math anxiety, group, and the parents' math anxiety by group interaction. Results showed that parents' math anxiety and assignment to the intervention or control group did not predict children's reading performance in the spring of 3rd grade (see Table S4).

Secondary Analysis: Do Parents' Expectations and Value of Math for their Children Mediate Effects of the Math App Intervention on Children's Math Achievement?

To understand one mechanism through which the math app intervention reduces the negative association between parents' math anxiety on children's math achievement, we measured parents' expectations and value for math for their children at the end of 1st grade. We assessed mediation in two steps: (a) we tested whether there was a group by parents' math anxiety interaction on parents' expectations and value for their children in math at the end of 1st grade, and (b) we tested whether there was a significant indirect effect of the group by parents' math anxiety interaction on children's math achievement through parents' expectations and value for their children. For part A, we used similar multilevel models as we do elsewhere in the analysis. However, for part B, in order for the model to

[1] As mentioned in the main paper, we also excluded twins from our main analysis, as twins typically were in different elementary school classrooms, but were always given the same app (even when students in one of the twin's classrooms were randomly assigned to another app condition). We conducted exploratory supplemental analyses on math achievement to analyze whether results changed if we added back the twin (in each pair) who could be considered randomly assigned to condition only. When we include twins who were randomly assigned to condition (N=10), we do not see any changes in results of our analyses.

converge, we run this model outside of the multilevel context used previously to allow us to examine the indirect effect of parents' math anxiety on children's achievement. We used beginning of 2nd grade math achievement as our outcome in this analysis because it was the next measure of math achievement in the study following our measure of parents' expectations and value of math for their children. Given the recursive process model of intervention effects, which predicts that attitudes affect achievement which then affect later achievement in a recursive process (Cohen et al., 2009), we hypothesized that parents' attitudes at the end of 1st grade would be most strongly linked to the subsequent measure of performance and that improved performance might predict later improved performance.

First, we found that there was a significant interaction between group and parents' math anxiety on parents' math expectations and value for their child (t=3.29, p<.001, b=3.49, SE=1.08, Figure 4, Table S5). In the control group (r=-.49; t=-6.52, p<.001, b=-.17, SE=.06) but not the math app intervention group (r=-.16; t=-0.21, p=.84, b=.03, SE=.04), parents' math anxiety negatively predicted their math expectations and value for their child (Table S6). As a point of information, higher-math-anxious parents in the intervention group (+1SD above the mean) showed significantly higher levels of math expectations and value compared to math anxious parents (+1SD above the mean) in the control group (t=2.28, p=.02).[2]

Next, we tested whether there was a significant indirect effect of parents' math anxiety. Specifically, was the effect of the parents' math anxiety by group interaction on children's beginning of 2nd grade math achievement accounted for by parents' math expectations and value for their child? We used bootstrapping procedures to estimate the indirect effect, which required using single-level multiple regression procedures for the model to converge. Results indicated a significant indirect effect of parents' math anxiety to children's fall of 2nd grade math achievement through parents' EV, 95% CI

[2] To create the most parsimonious model, we chose not to include the initial measurement of expectancies and value. However, when we run the analysis while also controlling for initial expectations and value, the results do not change. The results also remain when parents' previous expectations and value and when post-treatment math achievement are also included in the model.

[.45, 4.12]. Additionally, we found evidence for mediated moderation, such that there was only a significant indirect effect in the reading control condition, 95% CI [-4.24, -.63], but not in the math app intervention condition, 95% CI [-1.15, .56]. This is consistent with our hypothesis that the math app intervention changed the negative association between parents' math anxiety and parents' EV, and parents' math anxiety and children's math achievement.

Based on the recursive process model (Cohen et al., 2009), which posits that attitudes change achievement, and changes in achievement mediate later improvements in achievement, we next tested whether fall of 2nd grade achievement significantly predicted spring of 2nd grade math achievement. In a model regressing spring of 2nd grade math achievement on group, parents' math anxiety, the interaction between parents' math anxiety and group, fall of 1st grade math achievement, parents' spring of 1st grade expectations and value for their children, and fall of 2nd grade math achievement, we found that only fall of 1st grade and fall of 2nd grade math achievement were significant predictors of children's later math achievement in at the end of 2nd grade (t=3.51, p<.001 and t=8.21, p<.001, respectively). This finding suggests that the math app intervention works by starting a positive recursive cycle involving improving parents' math expectations and value for their children.

Another way to test this hypothesis is to conduct a serial mediation analysis. To do this, we used model 6 in Preacher and Hayes (2008) PROCESS macro, which allows for two or more sequential mediators to serve as mechanisms underlying effects on a particular outcome. In our case, we ran two models: one for reading control group families and one for math app intervention group families. These models tested the indirect effects of parents' math anxiety on children's end of 2nd grade math achievement through parents' expectations and value at the end of 1st grade and children's math achievement at the beginning of 2nd grade. These models also allowed for effects of parents' EV to flow through fall 2nd grade math achievement to spring of 2nd grade math achievement.

Overall, we found that there was significant serial mediation in the reading control group, 95% CI [-.23, -.03] (Figure S1), but not the math app intervention group, 95% CI [-.21, .04] (Figure S2). This

supported our hypothesis in that the negative association between parents' math anxiety and children's math achievement over time was mediated by parents' EV in the reading control group. However, in the math app intervention group, there was not a significant negative association between parents' math anxiety and parents' EV or parents' math anxiety and children's math achievement; thus, there was no effect to mediate.

Table S1. *Correlation Matrix of Parent and Children Measures.*

	1	2	3	4	5	6	7	8
1. Parents' Math Anxiety		-0.49***	-0.18	-0.24	-0.42**	-0.39**	-0.28*	-0.42**
2. Parents' EV	-0.16		0.40**	0.28*	0.50***	0.32*	0.41**	0.54***
3. 1st Grade Fall Math Achievement	-0.09	0.55***		0.76***	0.68***	0.66***	0.71***	0.65***
4. 1st Grade Spring Math Achievement	-0.05	0.56***	0.74***		0.75***	0.71***	0.70***	0.75***
5. 2nd Grade Fall Math Achievement	-0.08	0.59***	0.74***	0.80***		0.79***	0.75***	0.79***
6. 2nd Grade Spring Math Achievement	-0.02	0.52***	0.72***	0.78***	0.81***		0.80***	0.85***
7. 3rd Grade Fall Math Achievement	-0.11	0.54***	0.75***	0.79***	0.84***	0.83***		0.78***
8. 3rd Grade Spring Math Achievement	-0.02	0.47***	0.62***	0.72***	0.74***	0.78***	0.77***	
Mean (Standard Deviation)	2.20	4.43	459.58	475.99	479.42	493.86	496.38	501.41
	(0.81)	(0.49)	(17.35)	(20.54)	(17.86)	(18.34)	(20.01)	(20.08)

Note. Correlations above the diagonal are for participants in the reading control group, and correlations below the line are for participants in the math app intervention group. The sample size for correlations with parents' EV differs from the sample size of participants with remaining variables due to higher missingness on parent survey responses. *p < .05, **p < .01, ***p < .001.

Table S2. *Testing the effect of the intervention, time, and parents' math anxiety on students' achievement.*

	Matched Sample	Full Sample
Group	1.71 (1.38)	1.54 (1.27)
Parents' Math Anxiety	-2.10 (1.00)*	-2.53 (0.92)**
Time	8.27 (0.16)***	8.35 (0.16)***
Parents' Math Anxiety X Group	0.80 (1.00)	0.30 (0.92)
Parents' Math Anxiety X Time	-0.38 (0.19)	-0.39 (0.17)*
Group X Time	-0.19 (0.16)	-0.15 (0.16)
Group X Time X Parents' Math Anxiety	0.46 (0.19)*	0.45 (0.17)**

Note. *p < .05, **p < .01, ***p < .001, ~p=0.05. Each column is a single multilevel multiple regression. Column headers are the outcomes for each model, and the left hand column includes the predictors. Unstandardized coefficients and standard errors are reported for each predictor (standard errors are reported in parentheses). Group is coded as +1 for intervention group and -1 for control group.

Table S3. *Testing the effect of the intervention and parents' math anxiety on 3rd grade math achievement.*

Predicting 3rd Grade Math Performance		
	Matched Sample	Full Sample
Group	-0.33 (1.27)	0.86 (1.13)
1st Grade Fall Achievement	0.68*** (0.08)	0.67*** (0.06)
Parents' Math Anxiety	-3.32** (1.09)	-3.68*** (0.97)
Group X Parents' Math Anxiety	3.49** (1.08)	3.14** (0.96)

Note. *p < .05, **p < .01, ***p < .001. Each column is a single multilevel multiple regression. Column headers are the outcomes for each model, and the left hand column includes the predictors. Unstandardized coefficients and standard errors are reported for each predictor (standard errors are reported in parentheses). Group is coded as +1 for intervention group and -1 for control group.

Table S4. *Testing the effect of the intervention and parents' math anxiety on 3rd grade reading achievement.*

Predicting 3rd Grade Reading Performance		
	Matched Sample	Full Sample
Group	-0.03 (1.8)	0.11 (0.86)
1st Grade Fall Reading Achievement	0.44*** (0.03)	0.45*** (0.02)
Parents' Math Anxiety	1.43 (1.67)	0.79 (0.96)
Group X Parents' Math Anxiety	-0.01 (2.16)	-0.69 (0.98)

Note. *p < .05, **p < .01, ***p < .001. Each column is a single multilevel multiple regression. Column headers are the outcomes for each model, and the left hand column includes the predictors. Unstandardized coefficients and standard errors are reported for each predictor (standard errors are reported in parentheses). Group is coded as +1 for intervention group and -1 for control group.

Table S5. *Testing the effect of the intervention and parents' math anxiety on parents' expectations and value for math for their children.*

Predicting Parents' Expectations and Value		
	Matched Sample	Full Sample
Group	0.02 (0.04)	-0.02 (0.04)
1st Grade Fall Achievement	0.01*** (0.00)	0.01*** (0.00)
Parents' Math Anxiety	-0.07 (0.04)	-0.07 (0.03)
Group X Parents' Math Anxiety	0.08* (0.03)	0.08* (0.03)

Note. *p < .05, **p < .01, ***p < .001. Each column is a single multiple regression. Column headers are the outcomes for each model, and the left hand column includes the predictors. Unstandardized coefficients and standard errors are reported for each predictor (standard errors are reported in parentheses). Group is coded as +1 for intervention group and -1 for control group.

Table S6. *Predicting parents' expectations and value for their child with parent math anxiety and student achievement within the math and reading groups, respectively.*

Predicting Parents' Expectations and Value

	Math App Intervention Group	Reading App Control Group
1st Grade Fall Achievement	0.02*** (0.00)	0.01*** (0.00)
Parents' Math Anxiety	0.03 (0.04)	-0.17*** (0.06)

Note. *p < .05, **p < .01, ***p < .001. Each column is a single multiple regression. Column headers are the outcomes for each model, and the left-hand column includes the predictors. Unstandardized coefficients and standard errors are reported for each predictor (standard errors are reported in parentheses).

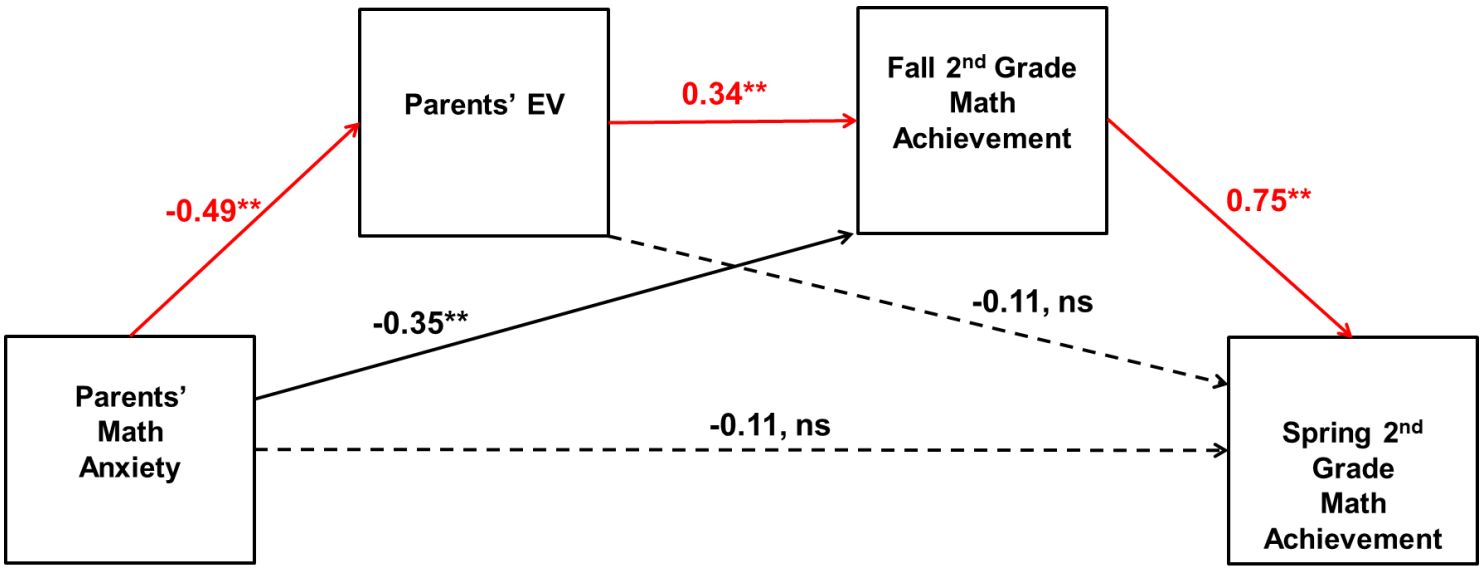

Figure S1. The negative indirect effects of parents' math anxiety on students' math achievement over time in the reading app control condition. Using a serial mediation model, we found support for a recursive process model in which the negative association between parents' math anxiety and children's math achievement at the end of 2nd grade was mediated through a negative association between parents' math anxiety and parents' expectations and value (EV) for their children in math at the end of first grade. Parents' EV at the end of 1st grade was positively associated with children's math achievement at the beginning of 2nd grade, which was, in turn, positively associated with children's math achievement at the end of 2nd grade. This was consistent with the hypothesis that positive parents' attitudes (i.e., EV) would predict better children's math achievement, which would then predict higher later levels of children's math achievement. *Note*: ns = not significant, * = $p < .05$, ** = $p < .01$, *** = $p < .01$.

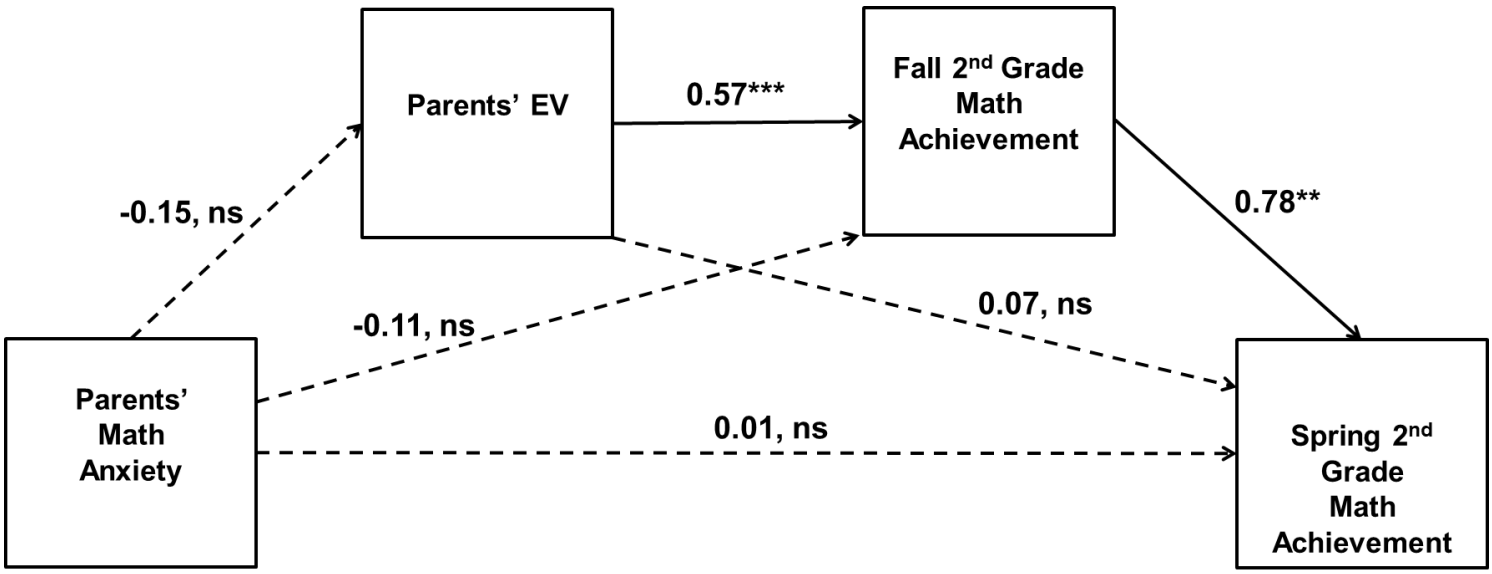

Figure S2. No indirect effects of parents' math anxiety on students' math achievement over time in the math app intervention condition. Using a serial mediation model, we found no support for a lasting negative association between parents' math anxiety and children's math achievement in the math app intervention condition, supporting our hypothesis that the negative association between parents' math anxiety and children's math achievement was reduced in this condition. *Note*: ns = not significant, * = $p < .05$, ** = $p < .01$, *** = $p < .01$.