Female teachers’ math anxiety affects girls’ math achievement

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People’s fear and anxiety about doing math—over and above actual math ability—can be an impediment to their math achievement. We show that when the math-anxious individuals are female elementary school teachers, their math anxiety carries negative consequences for the math achievement of their female students. Early elementary school teachers in the United States are almost exclusively female (>90%), and we provide evidence that these female teachers’ anxieties relate to girls’ math achievement via girls’ beliefs about who is good at math. First- and second-grade female teachers completed measures of math anxiety. The math achievement of the students in these teachers’ classrooms was also assessed. There was no relation between a teacher’s math anxiety and her students’ math achievement at the beginning of the school year. By the school year’s end, however, the more anxious teachers were about math, the more likely girls (but not boys) were to endorse the commonly held stereotype that “boys are good at math, and girls are good at reading” and the lower these girls’ math achievement. Indeed, by the end of the school year, girls who endorsed this stereotype had significantly worse math achievement than girls who did not and than boys overall. In early elementary school, where the teachers are almost all female, teachers’ math anxiety carries consequences for girls’ math achievement by influencing girls’ beliefs about who is good at math.


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Even more striking is that any relation that may exist between teacher anxiety and student achievement might not be uniform across all students and their teachers. Children are more likely to emulate the behavior and attitudes of same-gender vs. opposite-gender adults (8, 9). Because early elementary school teachers in the United States are almost exclusively female (>90%; 91% across elementary school and even higher at early elementary levels) (10) and gender is a highly salient feature to children at the early elementary school age (11), girls may be more likely than boys to notice their teacher’s negativities and fears about math. This, in turn, may have a negative impact on girls’ math achievement.

The research reported here assessed the math anxiety of 17 first- and second-grade female teachers from a large midwestern urban school district. The math achievement of the students (52 boys and 65 girls) in these teachers’ classrooms, along with students’ beliefs about gender and academic success in domains like math, was also assessed.

Our first hypothesis was that the more math anxiety a female teacher had, the lower her students’ math achievement would be. Our second hypothesis was that this relation would only hold for girls. Finally, our third hypothesis was that any relation between female teachers’ math anxiety and girls’ math achievement that did exist could be accounted for by whether girls in these teachers’ classrooms believed in traditional academic gender stereotypes (i.e., boys are good at math, and girls are good at reading).

To test these hypotheses, we assessed students’ math achievement in the first 3 months of the school year and again in the last 2 months of the year. We predicted that if female teachers are influencing their students, a relation between teacher anxiety and student achievement should be evident at the end of the school year but not at the beginning of the year when children’s classroom exposure to their teachers is minimal. To test our third hypothesis regarding how female teachers’ anxieties might affect girls’ math achievement, we asked students to perform a task that gauged the extent to which they adhered to traditional gender stereotypes that boys are good at math and girls are good at reading. At both the beginning and end of the school year, students were told two gender-neutral stories, one about a student who was good at math and one about a student who was good at reading, and were asked to draw these students (12). We were
interested in the genders of the drawings that children produced for each story. From these drawings, we formed a measure of students’ gender ability beliefs by assigning drawings of boys a score of 1 and drawings of girls a score of 0 and subtracting the reading from the math drawing score (math drawing − reading drawing). The higher the score, the more children ascribed to traditional (or stereotypical) gender roles in school.

Results
As expected, at the beginning of the school year, there was no significant relation between teachers’ math anxiety and students’ math achievement (girls: r = −0.13, P = 0.31; boys: r = 0.12, P = 0.40). However, by the end of the school year, the higher a teacher’s math anxiety, the lower was the girls’ (r = −0.28, P = 0.022) but not the boys’ (r = −0.04, P = 0.81) math achievement.1

Why might female teachers’ math anxiety relate to girls’ math achievement? Gender is an individuating feature that early elementary school-aged children notice (11, 13). Moreover, children at this age are aware of commonly held beliefs about gender and ability (12, 14) and are most likely to embrace behaviors and attitudes that they think are gender-appropriate (9). One possibility is that female teachers’ math anxiety helps to confirm stereotypes about which gender is good at math and this, in turn, has an impact on girls’ math achievement. If so, teachers’ gender anxiety should relate to the beliefs that girls hold about which gender is good at math.

As with math achievement, there was no significant relation between teachers’ math anxiety and the gender ability beliefs of boys (r = −0.04, P = 0.80) or girls (r = 0.20, P = 0.10)2 at the beginning of the school year, before teachers had spent a significant amount of time with their students. This was true for boys at the end of the school year as well (r = 0.09, P = 0.52). In contrast, for girls, by the end of the school year, the higher a teacher’s math anxiety, the more likely girls’ ability beliefs were to fall along traditional gender lines (r = 0.28, P = 0.022). In addition, the more girls at the end of the year endorsed the notion that boys are good at math and girls are good at reading, the lower was their math achievement (r = −0.28, P = 0.025).

Female teachers’ math anxiety negatively relates to girls’ math achievement and also to girls’ gender ability beliefs at the end of the school year. If this link between teacher anxiety and student math achievement occurs because teachers influence girls’ gender ability beliefs and this, in turn, has an impact on girls’ math performance, the relation between teacher and student should be mediated (or accounted for) by girls’ gender ability beliefs. As seen in Fig. 1, the relation between teacher math anxiety and girls’ math achievement at the end of the school year became nonsignificant when girls’ gender ability beliefs at the end of the year were also used to predict student math achievement. Only a strong negative relation between girls’ gender ability beliefs and their math achievement remained. This relation did not hold for boys.

1Controlling for teachers’ math knowledge did not alter these results (see SI Methods for more detail).

2One might notice that this relation approached significance. Because it is unlikely that students are deliberately assigned to classrooms based on the teacher’s math anxiety, this relation likely occurred by chance. Nonetheless, to ensure that it was not influencing our end-of-year findings, we ran an alternate version of our mediation model controlling for girls’ beginning-of-year gender ability beliefs. Girls’ end-of-year beliefs significantly continued to mediate (or account for) the relation between teachers’ math anxiety and girls’ end-of-year math achievement (95% CI: −2.84 to −0.61; P < 0.05). In contrast, girls beginning-of-year gender ability beliefs were not a significant predictor (β = −0.02, t = −0.17, P = 0.862), suggesting that this factor was not driving our end-of-year mediated effects.

By the school year’s end, female teachers’ math anxiety negatively relates to girls’ math achievement, and this relation is mediated by girls’ gender ability beliefs. We speculate that having a highly math-anxious female teacher pushes girls to confirm the stereotype that they are not as good as boys at math, and this, in turn, affects girls’ math achievement. If so, it follows that girls who confirm traditional gender ability beliefs at the end of the school year (i.e., draw boys as good at math and girls as good at reading) should have lower math achievement than girls who do not and that boys more generally. This is exactly what we found. As seen in Fig. 2, students’ math achievement at the end of the year depended on their gender and whether they confirmed common gender ability beliefs [a student gender × gender ability belief interaction; F(1, 113) = 3.79, P = 0.05].

By the school year’s end, female teachers’ math anxiety negatively relates to girls’ math achievement, and this relation is mediated by girls’ gender ability beliefs. We speculate that having a highly math-anxious female teacher pushes girls to confirm the stereotype that they are not as good as boys at math, which, in turn, affects girls’ math achievement. If so, it follows that girls who confirm traditional gender ability beliefs at the end of the school year (i.e., draw boys as good at math and girls as good at reading) should have lower math achievement than girls who do not and that boys more generally. This is exactly what we found. As seen in Fig. 2, students’ math achievement at the end of the year depended on their gender and whether they confirmed common gender ability beliefs [a student gender × gender ability belief interaction; F(1, 113) = 3.79, P = 0.05].

Girls who confirmed traditional gender ability beliefs had significantly lower end-of-year math achievement than girls who did not [M = 107.84, SE = 1.61; 95% confidence interval (CI): 104.66–111.03; Cohen’s d = 0.66]. Moreover, girls who confirmed traditional gender ability beliefs had significantly lower math achievement than boys overall at the end of the year as well (M = 107.69, SE = 1.62; 95% CI: 104.49–110.90; d = 0.37). Boys’ end-of-year math achievement did not differ as a function of gender ability beliefs (Don’t Confirm: M = 106.14, SE = 1.80; Confirm: M = 109.25, SE = 2.69; 95% CI: 103.92–114.58).

Importantly, these differences were not seen at the beginning of the school year; at that point, teachers presumably had not had ample time to influence gender ability beliefs or relations between gender ability beliefs and math achievement. Indeed, in terms of the four groups displayed in Fig. 2, there were no significant differences in math achievement at the beginning of the school year [no gender × gender ability belief interaction; F(1, 113) = 2.11, P = 0.15; girls: Don’t Confirm: M = 101.44, SE = 1.86; Confirm: M = 106.14, SE = 1.80; boys: Don’t Confirm: M = 107.84, SE = 1.61; Confirm: M = 108.25, SE = 1.75].

When controlling for beginning-of-year gender ability beliefs, the correlation between teachers’ math anxiety and girls’ end-of-year gender ability beliefs remained significant (r = 0.31, P = 0.012).

Fig. 1. (A) Regression analysis established that teachers’ math anxiety had a significant negative effect on girls’ math achievement at the end of the school year (β = −0.21, t = −2.17, P = 0.034). (B) Teachers’ math anxiety also had a significant effect on girls’ endorsement of common gender ability beliefs (i.e., drawing a boy as good at math and a girl as good at reading) at the end of the year (β = 0.31, t = 2.22, P = 0.030). Finally, girls’ gender ability beliefs (β = −0.23, t = −2.81, P = 0.007) were a significant predictor of their end-of-year math achievement. When teacher math anxiety and girls’ gender ability beliefs were simultaneously entered as predictors of end-of-year math achievement, teacher anxiety no longer significantly predicted girls’ math achievement (β = −0.16, t = −1.59, not significant [ns]), whereas girls’ gender ability beliefs (β = −0.19, t = −2.24, P = 0.029) remained significant in the equation. The reduction in the direct relation between teacher anxiety and girls’ math achievement was significant (95% CI: −2.4143 to −0.0045; P < 0.05, as tested by a bias-corrected bootstrapping procedure) (28). This provides support for our conclusion that teachers’ math anxiety hinders girls’ math achievement through girls’ relatively increased acceptance of traditional gender norms in school (see SI Methods for more details).
especially elementary school anxieties would have an impact of negative stereotypes on achievement lead us to speculate that female teachers model commonly held gender stereotypes to their female students through their math anxieties. These findings open a window into gender differences in math achievement and attitudes that emerge over the course of schooling.

Interestingly, math anxiety can be reduced through math training and education (17–19). This suggests that the minimal mathematics requirements for obtaining an elementary education degree at most US universities need to be rethought. If the next generation of teachers—especially elementary school teachers—is going to teach their students effectively, more care needs to be taken to develop both strong math skills and positive math attitudes in these educators.

Methods

Teachers. Seventeen female first- and second-grade teachers (12 first-grade teachers and 5 second-grade teachers) from five public elementary schools in a large midwestern school district participated in this study. The teachers had an average of 13 years of teaching experience (SD = 9.20).

Teachers’ math anxiety and math knowledge were assessed during the last 2 months of the school year. Math anxiety was assessed using the short Mathematics Anxiety Rating Scale (mMARS) (20), which is a 25-item version of the widely used 98-item MARS (21). Teachers responded to questions about how anxious different situations would make them feel (e.g., “reading a cash register receipt after you buy something,” “studying for a math test”). Responses were recorded on a Likert scale from 1 (low anxiety) to 5 (high anxiety). All analyses were performed on the average of the 25 items.

Teachers’ math knowledge was assessed using the Elementary Number Concepts and Operations subtest of the Content Knowledge for Teaching Mathematics measure (22). This task measures teachers’ facility in using mathematics knowledge for classroom teaching, including the ability to explain mathematical rules, assess the validity of unusual algorithms produced by students, and illustrate mathematical equations using diagrams or word problems. The content areas included addition, subtraction, multiplication, and division with whole numbers and fractions. The task consisted of 26 multiple-choice questions. Items that were left blank were considered incorrect. All analyses were performed on raw scores (the number of items correct of a total of 26).

Fig. 2. Math achievement scores (standardized based on students’ age) at the end of the school year for boys and girls as a function of whether they confirmed common gender ability beliefs (drew a boy to depict a student good at math and a girl to depict a student good at reading; Confirm) or did not (Don’t Confirm) (girls: Confirm: n = 20; Don’t Confirm: n = 45; Boys: Confirm: n = 16; Don’t Confirm: n = 36).

99.0, SE = 2.74; boys: Don’t Confirm: M = 98.83, SE = 2.04; Confirm: M = 103.56, SE = 3.06]. In concert with the mediation analysis above, these data suggest that girls’ math achievement is, at least in part, related to their confirmation of traditional academic gender beliefs—beliefs that are affected by the math anxiety levels of their female teachers.

Discussion

Using a mediation analysis that depicts a model of a causal chain of events, we showed that female students’ math achievement at the end of the school year is negatively affected by the way in which their teachers’ math anxieties alter these girls’ gender ability beliefs.

Similar to previous work (15), we did not find gender differences in math achievement at either the beginning (t(115) = 0.18, P = 0.86) or end (t(115) = 0.44, P = 0.66) of the school year. However, as Fig. 2 clearly shows, by the school year’s end, girls who confirmed traditional gender ability roles performed worse than girls who did not and worse than boys more generally. We show that these differences are related to the anxiety these girls’ teachers have about math.

If it is simply the case that highly math-anxious teachers are worse math teachers, one would expect to see a relation between the anxiety and the math achievement of both boys and girls. Instead, teachers with high math anxiety seem to be specifically affecting girls’ math achievement—and doing so by influencing girls’ gender-related beliefs about who is good at math.

This study explores the relation between female teachers’ math anxieties and their students’ math achievement. Thus, it is an open question as to whether there would be a relation between teacher anxiety and student math achievement if we had focused on male instead of female teachers. In one sense, the lack of male elementary school teachers in the United States makes this a hard question to answer. Yet, it is an important question, given research suggesting that girls are more socially sensitive than boys in early elementary school (16). Thus, it is possible that even with male teachers, a relation between teacher anxiety and female student achievement might occur. Nevertheless, the literature on math anxiety, gender modeling, and the impact of negative stereotypes on achievement lead us to speculate that any relation between male teacher anxiety and girls’ math achievement would be obtained through a different route than the one proposed here. Moreover, in the current work, the relation between female teachers’ math anxieties and girls’ math achievement was mediated (or accounted for) by girls’ beliefs that boys are better at math. Hence, it seems unlikely that a male teacher’s math anxiety would affect girls’ math achievement by pushing girls to confirm that boys are good at math.

In addition, children do not blindly imitate adults of the same gender. Instead, they model behaviors they believe to be gender-typical and appropriate (9). Thus, it may be that first- and second-grade girls are more likely to be influenced by their teachers’ anxieties than their male classmates, because most early elementary school teachers are female and the high levels of math anxiety in this teacher population conform a societal stereotype about girls’ math ability (2). This match between teacher math anxiety and societal norms would not hold for male teachers exhibiting math anxiety. However, if such a correspondence is important in influencing student achievement, we would expect that for school subjects for which girls are stereotyped to excel (e.g., language arts), male teachers’ anxieties would have an impact on male more than female students’ achievement.

It is important to note that the effects reported in the current work, although significant, are small. There are likely many influences on girls’ math achievement and gender ability beliefs over and above their current teachers’ anxieties. For instance, previous teachers, parents, peers, and siblings who either do or do not model traditional academic gender roles may play an important part in shaping girls’ gender ability beliefs and their math achievement more generally. Exploring these relationships—in addition to the influence of both male and female teachers—will help to elucidate the full range of social influences on student achievement.

In conclusion, we show that female teachers’ math anxiety has consequences for the math achievement of girls in early elementary school grades. Given that this relation is mediated by girls’ gender ability beliefs, we speculate that female teachers model commonly held gender stereotypes to their female students through their math anxieties. These findings open a window into gender differences in math achievement and attitudes that emerge over the course of schooling.
Students. A total of 117 students (65 girls and 52 boys) participated. The number of girls and boys was fairly evenly distributed across the two grades (girls: 40 first graders and 25 second graders; boys: 38 first graders and 14 second graders) and including grade as a factor did not alter the significance of the mediation analyses reported above in any way.

Students’ math achievement and gender ability beliefs were assessed during the first 3 and last 2 months of the school year. Math achievement was measured using the Applied Problems subtest of the Woodcock–Johnson III Tests of Achievement (23). The Applied Problems subtest consists of orally presented word problems involving arithmetic calculations of increasing difficulty. Students were assessed at school during a one-on-one session with an experimenter. A different version of the Woodcock–Johnson tests was used for each assessment. Testing continued until basal (six items correct in a row) and ceiling (six items incorrect in a row) levels were established. All analyses within gender were performed on students’ W scores, a transformation of the students’ raw score into a Rasch-scaled score with equal intervals (a score of 500 is the approximate average performance of a 10-year-old) (24, 25). Because of its properties as an interval scale with a constant metric, the W score is recommended for use in studies of individual growth (26, 27). All between-gender analyses were performed on students’ raw scores standardized as a function of their age (a score of 100 means that a student is at the average achievement level for his or her age). This was done to account for a marginally significant difference in age as a function of gender (F(1, 115) = 3.47, P = 0.065).

Students’ gender ability beliefs were assessed after the math achievement task. Children were read two gender-neutral stories, one about a student who is really good at math and another about a student who is really good at reading. After each story, children were asked to draw a picture of the student in the story and were then asked whether the student they drew was a boy or a girl. The order of the math and reading stories was counterbalanced across students within classrooms.

The combined measure of gender ability beliefs was formed by assigning a score of 1 to drawings of a boy and a score of 0 to drawings of a girl, and then subtracting the reading drawing score from the math drawing score (math drawing – reading drawing). Thus, a score of 1 indicates that a child drew a boy as being good at math and a girl as being good at reading, a score of 0 indicates that a child drew the same gender for each story, and a score of −1 indicates that a child drew a girl as being good at math and a boy as being good at reading. In other words, the higher the gender ability belief score, the more children ascribed to the traditional gender belief that boys are good at math and girls are good at reading (see SI Methods for more details).

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Supporting Information

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SI Methods

Teacher Participants. Teachers’ math anxiety and math knowledge were assessed during the last 2 months of the school year along with other measures of cognitive ability and social attitudes for a separate project not discussed further.

Example items of the Elementary Number Concepts and Operations subtest of the Content Knowledge for Teaching Mathematics measure (1) used to assess teachers’ math knowledge can be found in Appendix.

Student Participants. At the beginning of the school year, parent consent forms were distributed in the classrooms of the 17 teachers described in the text. Consent forms were returned for 133 students. Eight girls and eight boys were excluded from the study: four (two girls and two boys) because they did not complete the math achievement task, five (four girls and one boy) because they transferred to a different school between the sessions at the beginning and end of the year, and seven (two girls and five boys) because their end-of-year math achievement scores were more than 2 SDs below the mean for their gender or for students as a whole. The remaining 117 participants consisted of 65 girls and 52 boys.

Yearly household income was reported by parents for 104 of the children. The mean household income was $40,553 (SE = $2,693). The poverty line for a household of four in the United States, which is set annually by the US Department of Health and Human Services, was $22,050 in 2009.

Race was reported by parents for 117 of the children: 41% were Hispanic, 33% were black or African American, 15% were white, 5% were Asian, and 6% were other or multiple races. Including race as a factor did not alter the significance of the mediation analyses reported in the main text in any way.

Finally, the number of girls and boys was fairly evenly distributed across the two grades (girls: 40 first graders and 25 second graders; boys: 38 first graders and 14 second graders). Including grade as a factor did not alter the significance of the mediation analyses reported in the paper in any way.

Student Tasks. Students’ math achievement and gender ability beliefs were assessed during the first 3 months and the last 2 months of the school year along with other measures of cognitive ability and social attitudes for a separate project not discussed further. Math achievement was measured using the Applied Problems subtest of the Woodcock–Johnson III Tests of Achievement (2). The Applied Problems subtest consists of orally presented word problems involving arithmetic calculations of increasing difficulty. Students were assessed at school during a one-on-one session with an experimenter. A different form of the Woodcock–Johnson Applied Problems subtest was used for each assessment. Testing continued until basal (six items correct in a row) and ceiling (six items incorrect in a row) levels were established. Because of experimenter error, some subjects only completed between three and five items for the basal or ceiling level. These subjects were scored as if they had completed the full basal or ceiling level.

Students’ gender ability beliefs (3) (Appendix) were assessed after the math achievement task. Given the early grade level of the children in this study, we thought that an indirect assessment of the beliefs students held about who should succeed in particular academic domains (i.e., our drawing task) would elicit a better measure of girls’ and boys’ gender ability beliefs than explicitly asking students for their views about gender and ability. Moreover, given that we were interested in how female teachers’ anxieties might differentially influence girls’ math achievement relative to that of boys, we expected these gender-related measures of ability beliefs to provide optimal explanatory power regarding the relation between teacher math anxiety and girls’ and boys’ math achievement—as opposed to, for example, a domain general measure of students’ fear or anxiety about math (and/or other subjects in school) that does not tap into students’ gender beliefs in these areas.

Data Analysis

Descriptive Analysis. Teacher math anxiety scores ranged from 1.6 to 4.2 of a possible 5 (M = 2.4, SD = 0.85). Teacher math knowledge scores ranged from 3 to 22 of a possible 26 (M = 10.0, SD = 5.0). No differences were found between first- and second-grade teachers in math knowledge (t(15) = 0.31, P = 0.76) or math anxiety (t(15) = 0.54, P = 0.60). Teacher math anxiety was negatively correlated with teacher math knowledge but did not reach statistical significance (r = −0.35, P > 0.15).

As mentioned in the main text, we did not find gender differences in math achievement at either the beginning [t(115) = 0.18, P = 0.86] or end [t(115) = −0.44, P = 0.66] of the school year (beginning of the year: girls: M = 100.69, SE = 1.29; boys: M = 100.29, SE = 1.98 and end of the year: girls: M = 106.20, SE = 1.04; boys: M = 107.10, SE = 1.85). On the measure of gender ability beliefs, the number of students who fell into each of the three categories (1: boy is good at math, girl is good at reading; 0: same gender for math and reading; −1: girl is good at math, boy is good at reading) was as follows. At the beginning of the year, 25% of students received a score of 1, 55% received a score of 0, and 19% received a score of −1 (two students did not complete this measure in the fall). At the end of the year, 31% of students received a score of 1, 46% received a score of 0, and 23% received a score of −1. These distributions did not differ as a function of students’ gender (beginning of the year: χ² = 0.09, P = 0.96; end of the year: χ² = 0.23, P = 0.89) or grade (beginning of the year: χ² = 1.66, P = 0.44; end of the year: χ² = 0.29, P = 0.86).

Predictive Models. As reported in the main text, there was no significant relation between teacher math anxiety and student math achievement at the beginning of the school year (girls: r = −0.13, P = 0.32; boys: r = 0.12, P = 0.40). Thus, we focused our predictive models on the relation between teacher math anxiety and student math achievement at the end of the school year, where a significant relation for girls (r = −0.28, P = 0.022) but not for boys (r = −0.04, P = 0.81) existed. Here, we performed analyses for girls and boys separately.

Simple mediation model. For girls, a regression analysis established that teachers’ math anxiety had a significant negative effect on their math achievement at the end of the school year, controlling for teachers’ math knowledge and girls’ math achievement at the beginning of the year (β = −0.21, t = −2.17, P = 0.034). As one might expect, in this regression model, girls’ beginning-of-year math achievement did predict their end-of-year achievement (β = 0.70, t = 7.97, P < 0.01). In contrast, teachers’ math knowledge did not relate to girls’ end-of-year math achievement (β = −0.04, t = −0.39, P = 0.70). This is somewhat surprising, given that previous work has shown that teachers’ math knowledge relates to students’ end-of-year math achievement (4). However, this previous work did not take into account the math anxiety of students’ teachers. In the current work, when both teacher math knowledge and math anxiety are used to predict girls’ end-of-year math achievement...
achievement, only teacher math anxiety shows a relation to girls’ achievement.

Teachers’ math anxiety (controlling for teachers’ math knowledge) also had a significant effect on girls’ endorsement of common gender ability beliefs (i.e., drawing a boy as good at math and drawing a girl as good at reading) at the end of the year ($\beta = 0.31, t = 2.22, P = 0.030$). Finally, girls’ gender ability beliefs ($\beta = 0.20, t = -2.81, P = 0.007$) were a significant predictor of their math achievement at the end of the school year, controlling for girls’ math achievement at the beginning of the year. When teacher math anxiety and girls’ gender ability beliefs were simultaneously entered as predictors of math achievement, teacher math anxiety no longer significantly predicted girls’ math achievement ($\beta = -0.16, t = -1.59$, not significant), whereas girls’ gender ability beliefs ($\beta = -0.19, t = -2.24, P = 0.029$) remained significant in the equation. Note that teachers’ math knowledge and girls’ beginning-of-year math achievement (i.e., beginning-of-year correlate to the dependent variable) were also entered into this equation.

We used bias-corrected bootstrapping (a nonparametric sampling procedure) to test whether girls’ gender ability beliefs significantly mediated the relation between teacher math anxiety and girls’ math achievement (recommended over other popular procedures, such as the Sobel test) (5). Bootstrapping results based on 1,000 resamples showed that the indirect effect was estimated to lie between $-2.4143$ and $-0.0045$, with 95% confidence. Because zero was not included in this 95% CI, girls’ gender ability beliefs can be said to be a significant mediator of the association between teachers’ anxiety and girls’ math achievement ($P < 0.05$).

To rule out other explanations for this relation (e.g., model misspecification), we also conducted a reverse mediation analysis with girls’ end-of-year math achievement serving as the mediator and girls’ gender ability beliefs serving as the dependent variable. In contrast to the primary mediation analysis (where the effect of teachers’ math anxiety on girls’ end-of-year math achievement was significantly mediated by girls’ gender ability beliefs), the effect of teachers’ math anxiety on girls’ gender ability beliefs was not significantly mediated by girls’ end-of-year math achievement. Note that teachers’ math knowledge and girls’ beginning-of-year gender ability beliefs (i.e., beginning-of-year correlate to the dependent variable) were also entered into this equation. Bootstrapping results based on 1,000 resamples showed that the indirect effect in our reverse mediation was estimated to lie between $-0.0061$ and $0.2265$ with 95% confidence. Because 0 was included in this 95% CI, girls’ math achievement was not a significant mediator.

These analyses provide greater support for the hypothesis that girls’ gender ability beliefs mediate the effect of teachers’ anxieties on girls’ end-of-the-year math achievement than for an alternative model in which girls’ end-of-year math achievement mediates the effect of teachers’ anxieties on girls’ beliefs. Nonetheless, it is important to note that even if the reverse model were to hold, it would still be the case that teachers’ math anxiety is negatively affecting girls’ (but not boys’) end-of-year math achievement. If this relatively lower math achievement, in turn, has an impact on girls’ gender ability beliefs, the result would still be the same: namely, having a female elementary school teacher who is relatively higher in math anxiety results in a decrease in girls’ math achievement and affects these girls’ beliefs about their ability, as female students, to succeed in math.

For boys, a regression analysis established that teachers’ math anxiety did not have a significant effect on boys’ math achievement at the end of the school year, controlling for teachers’ math knowledge and boys’ math achievement at the beginning of the year ($\beta = -0.04, t = -0.40, P = 0.69$). Similar to girls, boys’ math achievement at the beginning of the year did predict their end-of-year achievement ($\beta = 0.82, t = 8.56, P < 0.01$). Moreover, teacher math knowledge also predicted boy’s math achievement in this equation ($\beta = 0.22, t = 2.09, P < 0.05$). The higher teachers’ math knowledge, the better was end-of-year math achievement of boys (4).

In contrast to girls, teachers’ math anxiety (controlling for teachers’ math knowledge) did not have a significant effect on boys’ endorsement of common gender ability beliefs (i.e., drawing a boy as good at math and a girl as good at reading) at the end of the year ($\beta = 0.11, t = 0.73, P = 0.47$). Finally, boys’ gender ability beliefs were not a significant predictor of their math achievement at the end of the school year (controlling for their math achievement at the beginning of the year) ($\beta = 0.11, t = 1.14, P = 0.26$).

Hierarchical linear model. It is also possible to use hierarchical linear models (HLMs) to model our data. An HLM accounts for the fact that students are nested within classrooms (6). Because, in our dataset, the HLM and simple regression model yielded similar results, for simplicity and to avoid excessive jargon in the main text, we confine the HLM analysis to the supplementary methods presented here.

Our HLM consisted of two levels: (i) a student-level model that predicted individual students’ outcomes based on student-level covariates, and (ii) a classroom-level model that used teacher characteristics to predict differences across classrooms. As in the simple regression, each HLM was run separately for girls and for boys. Because only boys returned permission slips in one classroom (although all classrooms were coeducational), the number of classrooms in the sample is 17 for boys and 16 for girls.

Model 1: Teacher Math Anxiety as a Predictor of Student Math Achievement

The first HLM model used teacher math anxiety to predict differences in students’ end-of-year math achievement scores, controlling for students’ beginning-of-year math achievement and for teachers’ math knowledge. In the student-level model, the outcome variable was the students’ end-of-year math achievement scores, controlling for students’ beginning-of-year math achievement scores:

$$
\text{EndMath}_i = \beta_3 + \beta_4 \times (\text{BeginningMath}_i) + \gamma_j,
$$

where $\text{EndMath}_i$ is the end-of-year math achievement score for student $i$ in classroom $j$ and $\text{BeginningMath}_i$ is the beginning-of-year math achievement score for student $i$ in classroom $j$ (centered at the overall mean for all students). $\beta_3$ is the expected end-of-year math achievement score in classroom $j$ for a student of average beginning-of-year math achievement, $\beta_4$ is the expected increase in end-of-year math achievement score associated with a one-point increase in beginning-of-year math achievement (for a student in classroom $j$), and $\gamma_j$ is the random variation between students not otherwise accounted for by the model.

The classroom-level model used the teachers’ math anxiety (controlling for teachers’ math knowledge) to predict differences across classrooms in students’ end-of-year math achievement:

$$
\beta_3 = \gamma_{00} + \gamma_{01} \times (\text{TMMathAnxiety}_j) + \gamma_{02} \times (\text{TMMathKnowledge}_j) + \epsilon_j,
$$

where $\text{TMMathAnxiety}_j$ is the math anxiety score of teacher $j$ and $\text{TMMathKnowledge}_j$ is the math knowledge score of teacher $j$ (both centered at the overall mean). The term $\gamma_{00}$ is the average end-of-year math achievement score for all students, $\gamma_{01}$ is the expected change in students’ end-of-year math achievement associated with a one-unit increase in teacher math anxiety, $\gamma_{02}$ is the expected change in students’ end-of-year math achievement associated with a one-unit increase in teacher math knowledge.
and \( u_0 \) is the random variation in end-of-year math achievement across classrooms not otherwise accounted for by the model.

The classroom-level model also predicted the relation between students’ beginning-of-year and end-of-year math achievement scores using the following model:

\[
\beta_{ij} = \gamma_{10} + u_{ij}, \tag{S3}
\]

where \( \gamma_{10} \) is the average increase in students’ end-of-year math achievement associated with a one-unit increase in beginning of the year math achievement and \( u_{ij} \) is the random variation in this increase across classrooms.

The results of model 1, as defined by Eqs. S1–S3, are shown in Table S1. The results of central interest indicate that the higher the teachers’ math anxiety, the lower girls scored on the test of end-of-year math achievement, even after controlling for teachers’ math knowledge and students’ beginning-of-year math achievement. This association did not hold for boys.

**Model 2: Teacher Math Anxiety as a Predictor of Student Gender Ability Beliefs**

Model 2 used teachers’ math anxiety as a predictor of students’ end-of-year gender ability beliefs. In this model, the outcome variable was students’ end-of-year gender ability beliefs and no covariates were entered at the student level:

\[
\text{GenderBeliefs}_{ij} = \beta_{00} + \gamma_{10} \cdot \text{Math Anxiety}_{ij} + u_{ij}, \tag{S4}
\]

where GenderBeliefs\(_{ij}\) is students’ end-of-year gender ability beliefs, \( \beta_{00} \) is the average gender ability beliefs in classroom \( j \), and \( u_{ij} \) is the random variation between students in gender ability beliefs.

At the classroom level, teachers’ math anxiety and math knowledge were entered as predictors of students’ gender ability beliefs:

\[
\beta_{01} = \gamma_{00} + \gamma_{01} \cdot (\text{TMath Anxiety}_{j}) + \gamma_{02} \cdot (\text{TMath Knowledge}_{j}) + u_{0j}, \tag{S5}
\]

where \( \gamma_{00} \) is the average gender ability belief across all students, \( \gamma_{01} \) is the change in students’ gender ability beliefs associated with a one-unit increase in teacher math anxiety, \( \gamma_{02} \) is the change in students’ gender ability beliefs associated with a one-unit increase in teacher math knowledge, and \( u_{0j} \) is the remaining variation across classrooms in gender ability beliefs.

The results of model 2, as defined by Eqs. S5 and S6, are presented in Table S2. Teachers’ math anxiety was a significant predictor of end-of-year gender ability beliefs for girls but not for boys, even after controlling for their math knowledge.

**Model 3: Student Gender Ability Beliefs as a Predictor of Student Math Achievement**

Model 3 predicted students’ end-of-year math achievement from their end-of-year gender ability beliefs, controlling for beginning-of-year math achievement:

\[
\text{EndMath}_{ij} = \beta_{00} + \beta_{01} \cdot (\text{Beginning Math}_{ij}) + \beta_{02} \cdot (\text{GenderBeliefs}_{ij}) + \beta_{ij}, \tag{S6}
\]

where \( \beta_{00} \) is the expected end-of-year math achievement score for a student with average beginning-of-year math achievement and gender ability beliefs in classroom \( j \), \( \beta_{01} \) is the increase in end-of-year math achievement score associated with a one-unit increase in beginning-of-year math achievement score for a student in classroom \( j \), \( \beta_{02} \) is the change in end-of-year math achievement score associated with a one-unit increase in students’ end-of-year gender ability beliefs for a student in classroom \( j \), and \( \beta_{ij} \) is the remaining random variation between students in end-of-year math achievement.

At the classroom level, no teacher predictors were entered in this model. Random variations between classrooms were allowed in the mean end-of-year math achievement and in the relation between beginning-of-year and end-of-year math achievement. The relation between end-of-year gender beliefs and end-of-year math achievement was assumed to remain constant across classrooms:

\[
\beta_{00} = \gamma_{10} + u_{0j}, \tag{S7}
\]

\[
\beta_{01} = \gamma_{10} + u_{1j}, \tag{S8}
\]

\[
\beta_{02} = \gamma_{20}. \tag{S9}
\]

where \( \gamma_{10} \) is the mean end-of-year math achievement score across all classrooms, \( u_{0j} \) is the random variation between classrooms in end-of-year math achievement, \( \gamma_{10} \) is the mean relation between beginning-of-year and end-of-year math achievement across classrooms, \( u_{1j} \) is the random variation between classrooms in this relation, and \( \gamma_{20} \) is the mean relation between end-of-year gender ability beliefs and end-of-year math achievement across classrooms. The results of model 3, as defined by Eqs. S6–S9, are reported in Table S1. The results indicate that girls who were more likely to subscribe to traditional gender ability beliefs scored lower on the test of end-of-year math achievement, even after controlling for their beginning-of-year math achievement. Again, this association did not hold for boys.

**Model 4: Teacher Math Anxiety and Student Gender Ability Beliefs as Predictors of Student Math Achievement**

Model 4 was identical to model 3, except that teachers’ math anxiety and ability were added as predictors of students’ end-of-year math achievement. The results of model 4 are shown in Table S1. For girls, the results indicate that teachers’ math anxiety was no longer a significant predictor of girls’ end-of-year math achievement after girls’ end-of-year gender ability beliefs were entered as a predictor (the coefficient of teacher anxiety was reduced from \( \gamma_{01} = -3.33, t = -0.96, P < 0.05 \) to \( \gamma_{01} = -2.48, t = -0.88, P = 0.15 \)), whereas girls’ gender ability beliefs remained significant \( \gamma_{20} = -3.03, t = -2.40, P < 0.05 \). In contrast to girls, there was no association between gender ability beliefs or teacher anxiety and students’ math achievement for boys.
Table S1. Impact of teacher math anxiety, teacher math knowledge, and student gender ability beliefs on students' end-of-year math achievement

<table>
<thead>
<tr>
<th></th>
<th>Girls (n = 65)</th>
<th></th>
<th></th>
<th>Boys (n = 52)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model 1</td>
<td>Model 3</td>
<td>Model 4</td>
<td>Model 1</td>
<td>Model 3</td>
<td>Model 4</td>
</tr>
<tr>
<td>Intercept</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept, $\gamma_{00}$</td>
<td>470.7*** (1.12)</td>
<td>470.8*** (1.12)</td>
<td>470.7*** (1.18)</td>
<td>467.9*** (1.62)</td>
<td>467.7*** (1.76)</td>
<td>468.0*** (1.66)</td>
</tr>
<tr>
<td>Teacher math anxiety, $\gamma_{01}$</td>
<td>$-3.33^* (1.53)$</td>
<td>$-2.48 (1.64)$</td>
<td>$-0.63 (2.02)$</td>
<td>$-0.63 (2.02)$</td>
<td>$-0.40 (2.12)$</td>
<td>$-0.40 (2.12)$</td>
</tr>
<tr>
<td>Teacher math knowledge, $\gamma_{02}$</td>
<td>$-0.22 (0.23)$</td>
<td>$-0.21 (0.24)$</td>
<td>$0.68^* (0.35)$</td>
<td>$0.68^* (0.35)$</td>
<td>$0.72 (0.32)$</td>
<td>$0.72 (0.32)$</td>
</tr>
<tr>
<td>Student beginning math achievement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept, $\gamma_{10}$</td>
<td>0.51*** (0.07)</td>
<td>0.51*** (0.06)</td>
<td>0.50*** (0.07)</td>
<td>0.69*** (0.08)</td>
<td>0.64*** (0.09)</td>
<td>0.69*** (0.09)</td>
</tr>
<tr>
<td>Student gender ability beliefs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept, $\gamma_{20}$</td>
<td>$-3.38^* (1.22)$</td>
<td>$-3.03^* (1.26)$</td>
<td>$2.79 (2.26)$</td>
<td>$2.79 (2.26)$</td>
<td>$2.95 (2.18)$</td>
<td>$2.95 (2.18)$</td>
</tr>
</tbody>
</table>

Numbers in parentheses are SEs. Teacher math knowledge, teacher math anxiety, student beginning-of-year math achievement, and student end-of-year gender ability beliefs are centered at their mean values.

*P < 0.05; **P < 0.01; ***P < 0.001.

Table S2. Model 2: Impact of teacher math anxiety and teacher math knowledge on student end-of-year gender ability beliefs

<table>
<thead>
<tr>
<th></th>
<th>Girls (n = 65)</th>
<th></th>
<th></th>
<th>Boys (n = 52)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model 1</td>
<td>Model 3</td>
<td>Model 4</td>
<td>Model 1</td>
<td>Model 3</td>
<td>Model 4</td>
</tr>
<tr>
<td>Intercept</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept, $\gamma_{00}$</td>
<td>0.06, 0.09</td>
<td></td>
<td></td>
<td>0.07, 0.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher math anxiety, $\gamma_{01}$</td>
<td>0.27*, 0.12</td>
<td></td>
<td></td>
<td>0.08, 0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher math knowledge, $\gamma_{02}$</td>
<td>0.01, 0.02</td>
<td></td>
<td></td>
<td>$-0.00, 0.02$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Numbers in parentheses are SEs. Teacher math knowledge and teacher math anxiety are centered at their mean values.

*P < 0.05.

Other Supporting Information Files

Appendix (PDF)
Appendix A

1. Imagine that you are working with your class on multiplying large numbers. Among your students’ papers, you notice that some have displayed their work in the following ways:

<table>
<thead>
<tr>
<th>Student A</th>
<th>Student B</th>
<th>Student C</th>
</tr>
</thead>
</table>
| 35  
  x 25  
  125  
  +75  
  875   | 35  
  x25  
  175  
  +700  
  875   | 35  
  x25  
  25   
  150  
  100  
  +600  
  875   |

Which of these students would you judge to be using a method that could be used to multiply any two whole numbers?

<table>
<thead>
<tr>
<th>Method</th>
<th>Method would work for all whole numbers</th>
<th>Method would NOT work for all whole numbers</th>
<th>I’m not sure</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Method A</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>b) Method B</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>c) Method C</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
2. Mrs. Johnson thinks it is important to vary the whole when she teaches fractions. For example, she might use five dollars to be the whole, or ten students, or a single rectangle. On one particular day, she uses as the whole a picture of two pizzas. What fraction of the two pizzas is she illustrating below? (Mark ONE answer.)

![Diagram of two pizzas with shaded parts]

a) $\frac{5}{4}$  
b) $\frac{5}{3}$  
c) $\frac{5}{8}$  
d) $\frac{1}{4}$

3. Which of the following story problems could be used to illustrate $1 \frac{1}{4}$ divided by $\frac{1}{2}$? (Mark YES, NO, or I’M NOT SURE for each possibility.)

<table>
<thead>
<tr>
<th>Story Problem</th>
<th>Yes</th>
<th>No</th>
<th>I’m not sure</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) You want to split $1 \frac{1}{4}$ pies evenly between two families. How much should each family get?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>b) You have $1.25 and may soon double your money. How much money would you end up with?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>c) You are making some homemade taffy and the recipe calls for $1 \frac{1}{4}$ cups of butter. How many sticks of butter (each stick = $\frac{1}{2}$ cup) will you need?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
Appendix B

Math story

This is a story about a student who is really good at math. This student is always the first to finish every math problem, no matter how hard. And this student also really likes doing math. If there is a math problem to be done, this student is the one to do it. This student is a really great mathematician. Can you draw a picture of this student?

Reading story

This is a story about a student who is really good at reading. This student is always the first to finish reading a story, no matter how hard. And this student also really likes to read. If there is a story to be read, this student is the one to do it. This student is a really great reader. Can you draw a picture of this student?