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# Worked Examples Moderate the Effect of Math Learning Anxiety on Children's Math Learning and Engagement During the COVID-19 Pandemic

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We investigated whether worked examples could be used to reduce cognitive load on mathematics learners who may have reduced available cognitive resources due to experiencing anxiety or excess stress. Across 2 days, 280 fifth-grade students learned from a difficult lesson on ratio, half of whom reviewed worked examples at key problem-solving opportunities during instruction. We also measured two sources of students' worry during learning: math anxiety and worries about learning during the pandemic. We explored the attentional and affective effects of worked examples and worries in addition to their effects on learning. Results suggest that math anxiety, but not pandemic learning worries, negatively predicted procedural and conceptual learning from the lesson. In line with previous research and cognitive load theory, math anxiety also predicted greater mind wandering during testing and lower situational interest during learning. Critically, reviewing worked examples during learning mitigated these effects on learning and engagement. Pandemic-related learning worries were unrelated to learning outcomes but did predict affective and motivational outcomes. Educational implications are discussed.

***Educational Impact and Implications Statement***

Math lessons that compare different solution strategies are effective but demanding, especially for anxious students who have thoughts and worries that compete for their attention. Reviewing worked examples—which are fully-worked out examples of problem solutions—can promote learning by drawing students' attention directly to the key parts of the compared strategies. In our study, we show that having students review worked examples during a ratio lesson that compared two strategies greatly reduced the negative impacts of math anxiety on their learning and attention.

*Keywords:* worked examples, math anxiety, COVID-19, math learning, mind wandering

*Supplemental materials:* https://doi.org/10.1037/edu0000795.supp

The inclusion of worked examples during instruction has been shown to be an effective tool to promote mathematics learning for students of all ages (see Renkl, 2014), likely by freeing up learners' limited cognitive resources like working memory that are essential to mathematical problem solving (Tuovinen & Sweller, 1999). Affective influences, like math anxiety and context-based stressors, in contrast, have been shown to impair performance and learning by inducing verbally rehearsed worries that tax the same limited working memory resources (see Beilock, 2008; Boals & Banks, 2020; Schmader et al., 2008). Despite the similar underlying mechanisms, no work has yet to explore whether the use of worked examples during instruction may mitigate the negative effects of math anxiety and/or other worry-inducing factors on students' math performance or learning. A secondary unexplored question pertains to students' engagement with and attitudes toward worked examples, which has implications for classroom implementation.

We explored these questions in this study of fifth-grade students' learning from a lesson on ratio during the COVID-19 pandemic, a

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potential source of worry in students' performance and learning contexts. Specifically, we examined two different sources of heightened worry and negative affect—math anxiety and worry about learning during the COVID-19 pandemic—and tested whether worked examples could mitigate the negative effects of these experiences on students' learning, in addition to their attention, affect, and task engagement.

## Worked Examples

Worked examples are an instructional tool in which students study a problem and its solution laid out in a step-by-step manner (Renkl, 2014). Rather than teaching students through problem-solving alone (Booth, Oyer, et al., 2015; Carroll, 1994; Ward & Sweller, 1990) or receiving no worked examples during instruction (Vollman et al., under review), empirical evidence from classroom and laboratory studies reveal that studying worked examples promotes elementary and middle school students' learning of mathematics by making their learning process more efficient, effective, and flexible (see Renkl, 2014; van Gog & Rummel, 2010 for reviews). Therefore, it is recommended that instructors provide opportunities to have students review worked examples (Booth, McGinn, et al., 2015; McGinn et al., 2015).

Comparing different solution strategies to a single instructional problem has also been a recommended pedagogical tool because it is effective in supporting deep, flexible math learning (see National Mathematics Panel, 2008). Worked examples have been tested in teaching contexts of multiple strategy solutions and multiple problems of a single strategy (see Booth, McGinn, et al., 2015). Instructional supports, like embedding opportunities for students to generate self-explanations when reviewing worked examples (Barbieri et al., 2019; Booth, Oyer, et al., 2015) and simultaneous presentation of compared worked examples (Rittle-Johnson et al., 2009; Rittle-Johnson & Star, 2007, 2009), are essential to scaffold students' learning of mathematical procedures and concepts.

## Worked Examples: A Cognitive Load Perspective

Drawing from cognitive load theory (Sweller, 2011), worked examples facilitate more effective and efficient learning by reducing the extraneous load associated with learning and thereby freeing up limited working memory resources (Renkl, 2014; Sweller, 2010). Working memory, a limited cognitive resource, allows one to mentally represent, hold in mind, and manipulate limited amounts of information at a time (Miyake & Shah, 1999). Cognitive resources like working memory capacity are crucial for mathematics performance (Miller-Cotto & Byrnes, 2020; Raghubar et al., 2010), particularly during relational reasoning opportunities such as comparing solutions, making inferences about new problems based on prior examples, or drawing connections between concepts (Begolli et al., 2018). Compromised working memory resources during learning often manifest as mind wandering (McVay & Kane, 2010; Mrazek et al., 2012): Much work across students of all ages shows that mind wandering during instruction is related to lower test scores and learning (Mrazek et al., 2013; Pan et al., 2020; Wammes et al., 2016; see also Smallwood et al., 2007, 2008).

More specific to this study, reviewing worked examples directs learners' limited working memory resources toward understanding the relational concepts underlying the solution strategies (i.e., "why" the strategies achieve the correct answer), rather than using up said resources to attempt to employ a means-end strategy (the "how"; attempting to execute the solution strategies; Rittle-Johnson et al., 2001). When presented with a packet of practice problems, students typically employ novice and potentially incorrect strategy solutions given that they are not yet well understood (Booth, McGinn, et al., 2015). Hyper focus on solving and computation at early learning stages may hinder deeper conceptual learning later (Givvin et al., 2019; see also Skemp, 2006). With more available working memory capacity, learners who review worked examples are able to devote more attention toward building schematic representations across problems (Sweller et al., 1998) and the *why* (i.e., conceptual understanding) behind the solution strategies they are taught (Atkinson et al., 2003; Chi et al., 1989).

## Worry and Children's Math Performance

Many affective factors can consume students' cognitive resources during instruction, meaning that they cannot focus all of their capacity and resources on learning. One such factor, students' worry during learning, is of particular relevance in the mathematics classroom and during stressful and/or uncertain times, such as the COVID-19 pandemic. Below, we outline two sources of worry about math learning that students may have experienced in the classroom during the time of this data collection: math anxiety and worry about the pandemic. We detail the prevailing mechanistic explanations and discuss implications for classroom learning. We conclude by proposing worked examples as a candidate pedagogical tool for mitigating any negative effects of these worries during learning.

### *Math Anxiety*

Math anxiety is commonly defined as the feelings of tension or apprehension one feels when thinking about or working on math (Richardson & Suinn, 1972). Feeling math anxious has considerable implications for math achievement, including lower test performance (see Barroso et al., 2021; Caviola et al., 2022 for recent reviews) and reduced capacity to learn (Vukovic et al., 2013). Moreover, math anxiety is related to affective and engagement outcomes such as lower motivation (e.g., Wang et al., 2015), lower self-concept (Ahmed et al., 2012; Ashcraft, 2002; Goetz et al., 2010; Jameson, 2014), reduced calibration accuracy (Erickson & Heit, 2015), lower perceived competence (Goetz et al., 2013), and reduced persistence in math-related academic programs (Ahmed, 2018). Math anxiety-performance relations are likely cyclical, wherein feelings of math anxiety lead one to perform lower, which, in turn, exacerbates anxiety and disengagement (Carey et al., 2016).

Math anxiety compromises math performance via working memory (Ashcraft & Kirk, 2001; Beilock, 2008; Caviola et al., 2022). Specifically, feeling high math anxiety can generate verbally rehearsed, intrusive thoughts and worries that take up the same limited working memory resources that are needed for task-relevant mathematical thinking and reasoning, resulting in lower performance (Ashcraft & Kirk, 2001). Accordingly, baseline working memory capacity is an important moderator of the negative effects of children's math anxiety on performance (e.g., Trezise & Reeve, 2014; Vukovic et al., 2013). Moreover, evidence from similarly anxiety-inducing performance contexts, like stereotype threat and performing under pressure, further supports the role of working memory, as findings reveal the greatest performance decrements on more working memory-demanding math problems (Beilock &

Carr, 2005; Beilock et al., 2007). Compromised cognitive resources may particularly threaten students' ability to engage in higher-order relational reasoning in math learning contexts (Begolli et al., 2018).

### *Worries About Remote Learning During the COVID-19 Pandemic*

In addition to contending with feelings of math anxiety, children's academic performance may be further challenged due to the psychological effects of the COVID-19 pandemic and novel remote learning contexts. A growing body of evidence suggests that the pandemic has had substantial, negative impacts on children's academic achievement (see Bailey et al., 2021 for a review), with the greatest impacts on mathematics performance specifically (Curriculum Associates, 2020; Engzell et al., 2021; Kuhfeld et al., 2020). Moreover, some work has found changes in children's mathematics self-concept and motivation that correspond with the onset of the pandemic, possibly suggesting motivational and/or affective consequences of the pandemic on mathematics (Rutherford et al., 2022).

Although the effects of the pandemic on mathematics achievement are evident, the mechanisms remain unclear. Some argue that poor access to requisite technologies is a key mechanism underlying pandemic-related changes in performance (Bacher-Hicks et al., 2021), whereas others suggest reduced quality instructional time (Engzell et al., 2021; Kalogeropoulos et al., 2021), increases in distress and worry (Mesghina et al., 2021; see also Boals & Banks, 2020), or the intersection of all of these structural, digital, cultural, and psychological factors (Goudeau et al., 2021) may play a role. Importantly, the level and time scale at which researchers have measured students' achievement during the pandemic may be a confounder, as the effects of each academic obstacle may not become evident, nor influence students' achievement, simultaneously (see Goudeau et al., 2021 for a discussion). We take the approach to focus on the impacts of the pandemic on students' immediate, in-the-moment engagement and learning during one well-controlled, high-quality lesson administered to all students, which allowed us to test specific mechanisms to explain differences in learning and engagement from said lesson.

Like math anxiety, pandemic-related worries may also affect cognition and disrupt students' mathematics performance and learning via intrusive worries that consume working memory resources and manifest as mind wandering. The COVID-19 pandemic is a potentially traumatic and distressing life event for many children (Claypool & Moore de Peralta, 2021), which can lead to increases in worry, anxiety, and other internalizing behaviors (National Child Traumatic Stress Network [NCTSN], 2003; Ridner, 2004). Survey data with U.S. children suggest worry and other internalizing behaviors increased after the onset of the pandemic (Patrick et al., 2020; Rosen et al., 2021). Moreover, these events can negatively impact children's cognitive processing capacities necessary for academic performance (Perfect et al., 2016), including attention deficits and related difficulties focusing (NCTSN, 2003). In their recent review, Boals and Banks (2020) argued that increased stress and worry resulting from the pandemic may likely compromise learning and performance by increasing mind wandering.

Evidence from college students lends further empirical support for the roles of worry, working memory, and mind wandering. Research revealed considerable levels of anxiety and worry among college students in response to the pandemic (e.g., Son et al., 2020), which many students believed compromised their ability to focus on schoolwork (Hoyt et al., 2020). There is empirical evidence for a link between students' pandemic-related worries and difficulties focusing in academic contexts (Kecojevic et al., 2020). In a direct assessment of the impacts of the pandemic on college students' cognition and learning, Mesghina et al. (2021) found that students' self-reported pandemic-related distress predicted lower learning from an asynchronous science lesson via increased mind wandering, again underscoring the potential cognitive mechanisms.

Yet, little work has examined whether these cognitive mechanisms may explain children's performance and learning declines during the pandemic. Notably, Kalogeropoulos et al. (2021) surveyed Australian elementary students' experience of learning mathematics from home during the pandemic: Approximately half of the students said they found the experience difficult and most of the students' difficulties with remote learning centered on compromised cognitive engagement with the lessons, including increased distractibility and difficulty focusing (Kalogeropoulos et al., 2021). Evidence from youths' social media posts further supports difficulty focusing as a key issue faced during the pandemic (Literat, 2021).

## Present Study

Researchers concerned about the detrimental academic impacts of math anxiety (Hembree, 1990) and situational sources of worry such as the COVID-19 pandemic (Kaffenberger, 2021) argue that implementing high-quality pedagogical interventions in the classroom is a critical way to mitigate the deleterious impacts of negative affect on students' academic performance. We investigated the use of worked examples as one tool to promote students' deep learning from a highly demanding mathematics lesson, particularly for those who were most anxious or worried. It is not the case that worked examples would directly reduce students' experienced worry. Rather, worked examples may help more anxious students redirect their attention away from task-relevant and task-irrelevant intrusive thoughts and worries and instead bring their attention toward the relevant procedural aspects (learning how to execute the strategies) and conceptual aspects (learning when and why to use some strategies over others) of learning from instruction that compares between multiple solution strategies, which, in turn, would promote learning.

We were particularly interested in the effects of worked examples and worry on students' initial learning of new math concepts, rather than performance outcomes (see also Mesghina et al., 2021). Importantly, gaps in initial math learning may compound over time, widening achievement gaps. Moreover, with regard to students' math anxiety, we placed particular emphasis on worry (the cognitive component of math anxiety) and anxiety about math learning as these components of math anxiety have been shown to be most strongly related to math achievement. This is above emotionality (physiological component) and anxiety about math evaluation (see Barroso et al., 2021).

Beyond investigating these primary cognitive resource mechanisms, we also explored how reviewing worked examples could change students' affective and motivational experiences while learning, which would provide key insights for understanding its utilization and efficacy in the classroom. Little research to date has assessed students' attitudes toward, engagement with, or preference for worked examples during instruction—those who have do not find much evidence in support of worked examples. For example, Barbieri and

Booth (2016) found no effect of worked examples on middle school students' sense of belonging to math or their expectations of success over the course of a 2-month intervention in their algebra classes. Other work with middle school students suggests they enjoy business-as-usual problem-solving to example-based learning, at least in a digital math learning platform (Adams et al., 2014). Perhaps seeing worked examples may be overwhelming to students, particularly if the example includes many steps or includes steps that a student has yet to master. At the same time, worked examples could alleviate feelings of confusion and help students feel assured that they can figure out how to solve the problems. Yet, evidence for the influence of worked examples on metacognitive awareness—in particular, one's perceived understanding of newly learned content—is mixed (Adams et al., 2014; Baars et al., 2014; Barbieri & Booth, 2016) and was assessed in the present study.

### *Math Lesson and Worked Examples Manipulation*

Using a pre–post design, we assessed fifth-grade students' learning from a video lesson on ratio wherein an instructor compared two strategies to solve ratio word problems: equivalent fractions and unit ratio. We chose fifth-grade students and ratio to align with prior work finding empirical support for the use of worked examples (Rittle-Johnson & Star, 2007, 2009). Ratio is a key learning objective for students of this age (Common Core State Standards in Mathematics, 2010).

The key manipulation for this study was the presence of worked examples during instruction—half of the students were given access to review fully worked examples at key problem-solving opportunities during the video lesson, half were not. Worked examples have been manipulated in various ways (see Booth, McGinn, et al., 2015; Rittle-Johnson & Star, 2011 for reviews), all of which have shown positive effects on immediate learning and retention. The key distinction between our study design and prior work is that we employed worked examples within a lesson requiring relational reasoning across strategy solutions. The ultimate learning objective for the lesson was for students to engage in structure mapping across the two instructed solution strategies to understand when and why to use one correct strategy over another to solve ratio. To support this higher-order relational understanding, we first administered worked examples to serve students' transfer of knowledge of each solution strategy to novel problems. Afterwards, the lesson culminated in the higher-order comparison across both strategies, where we predicted having reviewed worked examples for each strategy would have then further scaffolded students' capacity to relationally reason across the two correct strategies. Regardless of condition, all students in the present study answered questions during the lesson and 3 days later during the posttest. For both sets of questions, we assessed students' learning by measuring their procedural and conceptual knowledge of ratio following the lesson (Rittle-Johnson et al., 2001; Rittle-Johnson & Star, 2007, 2009).

### *Hypotheses*

Students' self-reported levels of math anxiety and worries regarding the COVID-19 pandemic were also measured and were our predictors of interest. We predicted that worked examples would interact with math anxiety and with COVID-19 worries to promote students' attention toward the lesson and, ultimately, their math learning. Specifically, we anticipated that students who were the most math anxious or worried about learning in the pandemic would see greater gains in learning and fewer instances of mind wandering with the aid of worked examples relative to controls. Throughout the study, we also measured students' affective, motivational, and metacognitive engagement with the lesson—including their situational interest, state worry, and perceived understanding during learning—as these factors have been shown to be predicted by children's math anxiety (e.g., Goetz et al., 2013; Jameson, 2014) and the onset of the pandemic (Rutherford et al., 2022). We hypothesized these two sources of worry would negatively predict math engagement, but we made no predictions regarding the role of worked examples on affect or engagement.

# Method

## Transparency and Openness

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study (Simmons et al., 2012). All data, research materials, and analytic code are available upon request. Data were analyzed using Stata (Version 15.1; StataCorp, 2017) and R (Version 4.1.3; R Core Team, 2022). This study was not pre-registered.

## Participants

Participants were 285 students from 10 fifth-grade classrooms in four schools at two sites across the United States. Our recruitment was constrained due to the pandemic and its demands on teachers and students. Nonetheless, we believe we were sufficiently powered: We conducted a power analysis for a similar study (https://osf.io/2yc5a) that was simultaneously conducted with students of the same age and using a nearly identical video lesson. With a power of 0.80 and alpha of 0.05, the estimated minimum sample size to detect small-to-medium effects of condition on procedural and conceptual learning between two conditions for that study was 192. Two classes were located around the Chicago, Illinois area. The other eight classes were located around the Irvine area in Orange County, California. Students received a $20 gift card after completing the 2-day study. Four students opted out of the study, and one student did not complete any part of the procedures. The final sample included 280 participants (Gender: 46% girls, 34% boys, 20% missing; race/ethnicity: 15% White, 3% Black, 12% Asian American/Pacific Islander; 13% Hispanic/Latinx, 26% Mixed race/other, 31% missing). Students were randomly assigned to either the worked examples condition ($n = 141$) or control ($n = 139$).

## Procedure

The study was conducted over 2 days. All study materials were individually administered to students via Qualtrics. On Day 1 of the study, students provided assent, followed by a measure of their COVID-19 learning worry. Students then answered a pretest question to measure their prior knowledge of ratio and proportional reasoning. Next, students began the lesson on ratio. The 20-min video lesson was divided into nine smaller segments. To actively engage students during the lesson, students answered procedural and conceptual questions between each video segment. The key experimental manipulation was whether students reviewed worked examples at certain problem-solving opportunities during instruction. See below for more details on the conditions. At various points throughout the lesson (but not at pretest), students were also intermittently asked to provide ratings of their state worry and perceived understanding. After the lesson, students reported how frequently they mind wandered during the lesson.

Day 2 occurred 3 days after Day 1. Students first completed a math anxiety questionnaire, followed by a posttest assessing their ratio knowledge. State worry was assessed at various points throughout the posttest as well. Upon the conclusion of the posttest, students again reported their frequency of mind wandering during the test and completed a situational interest survey. The lesson and all assessment items were purposefully designed to avoid evaluative language (e.g., describing the assessment as "math problems") to minimize any additional worry.

## Math Lesson

Researchers collaborated with a teacher and a curriculum designer to create a lesson script introducing ratio and proportional reasoning. The videos are available upon request. The 20-min, teacher-led lesson was recorded as a live, semi-scripted lesson. The teacher taught a class of fifth- and sixth-grade students who were recruited for the recording of the lesson. Recording a live lesson with real students allowed for the natural variability of classroom instruction with students engaging in authentic conversations regarding the solution strategies. This experimental procedure enabled the instructional stimuli to have high ecological validity while maintaining experimental control (see Begolli & Richland, 2017 for more on the merits of this design).

In the lesson, the teacher presented two correct strategies to solve ratio problems: the equivalent fraction strategy and the unit ratio strategy. The main learning objective of the lesson was for students to understand that both strategies could be employed to solve ratio problems, but that certain strategies were more efficient given the numerical properties of the items compared. Instruction was carefully designed and scaffolded so that students could relationally reason between the two equally effective strategies to determine efficiency. See Figure 1 for a screenshot from the culmination of the lesson, in which the teacher compared and contrasted across the two solution strategies using two example word problems.

The lesson was informed by research in conceptual change (Vosniadou, 2013) and mathematical discussion (Kazemi & Hintz, 2014) and was designed using research-backed pedagogical strategies that have been found to best scaffold students' relational reasoning. Specifically, to facilitate structure mapping, the lesson employed two solution strategies, which were simultaneously presented during comparison, and the features of the strategies that were to be compared were spatially aligned (Richland et al., 2007). The same is true for the comparisons made between the two example word problems within each strategy. Moreover, to draw learners' attention to the key comparisons and to orient them to the utility of relational reasoning, the instructor used relational language when describing and comparing across the two strategies (e.g., "8 eggs *is like* 16 apples") and employed linking gestures between shared representations across the compared solution strategies (Alibali et al., 2014; Richland, 2015).

For the purposes of this study, the lesson was segmented into nine brief video clips (approximately 2 min each), which were embedded into the Qualtrics survey platform. Students could pause a video clip, but they could not rewind or fast-forward, nor could they return to a completed video clip. Students were actively engaged with the video lesson: Between video segments, students answered questions to promote their learning. Specifically, the instructor would pose a question to the class; then, the video clip would end and students in our study would see the question written out in Qualtrics with a space for them to solve the problem and provide their answer alongside the instruction in real time. We embedded prompts through the video lesson for students to self-explain key concepts as they learned them, in line with recommended practices (Atkinson et al., 2003; Chi et al., 1989). Once students submitted their answers, they would proceed to the next video clip, where the instructor would explain the correct answer to the question(s) and resume the lesson. There were no response time constraints. The nine video clips in the lesson were organized into four main sections: pretest, equivalent fraction strategy, unit ratio strategy, and comparison. The procedure for each is described in turn. The coding rationale for each section is provided later in the Measures section.

### *Pretest Section*

The students in our study first answered one word problem (the cake problem; see Table 1) using any strategy they liked. This was the pretest item (see the Measures section below for how we coded students' strategy attempts to this problem).

### *Equivalent Fraction Section*

Next, students watched the teacher introduce the equivalent fraction strategy. During this video segment, (a) a student in the virtual classroom described how they solved the pretest problem using the equivalent fraction strategy, (b) the teacher summarized the student's explanation and wrote it out on the board, and (c) the teacher explained the main elements being compared using the equivalent fraction strategy.

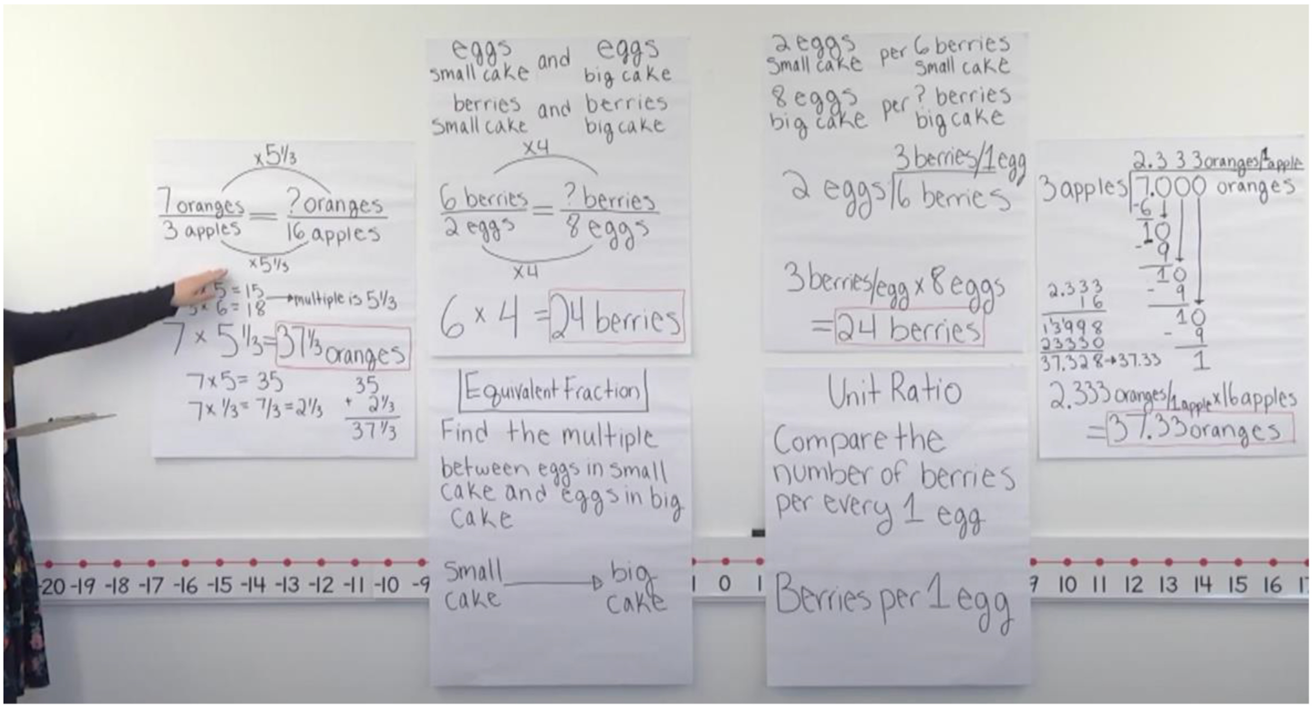
To consolidate learning of the new strategy, the teacher next posed a new word problem to the class (the juice problem; see Table 1), and asked students to solve the juice problem using the equivalent fraction strategy they just learned. Here was the first instance of the experimental manipulation: Students assigned to the worked examples condition solved this new problem while also seeing a screenshot of the teacher's fully worked example of the pretest (cake) problem. Those in the control did not see the screenshot of the worked example. After students submitted their answer, they saw the next video clip, where the teacher explained how to solve the new juice word problem using the equivalent fraction strategy. Then, the student was shown the equivalent fraction solution strategies for both the cake and juice problems, and they were asked to independently draw connections between the two solution strategies using an analogy-type question. Finally, the teacher concluded this section by comparing the cake and juice solutions using the equivalent fraction strategy, particularly emphasizing that the equivalent fraction strategy was harder for the juice question because the multiple was not a whole number.

### *Unit Ratio Section*

After concluding the Equivalent Fraction section, students repeated the same series of steps with the same cake and juice word problems, but this time using the unit ratio strategy. Again, students in the worked examples condition saw a screenshot of the teacher's worked example from the cake problem when they

**Figure 1**

*A Screenshot From the Comparison Section of the Video Lesson, Where the Teacher Compared the Equivalent Fraction and Unit Ratio Solutions for the Cake Problem and the Juice Problem*




*Note.* See the online article for the color version of this figure.

attempted to solve the juice problem using the unit ratio strategy on their own.

### *Comparison Section*

The teacher concluded the lesson by comparing and contrasting the procedures and providing a conceptual overview of the two strategies (equivalent fraction and unit ratio) and two problems (cake and juice problem; see Figure 1). With all four solution strategies on the board, the teacher highlighted the similarities and differences between the features of the word problems being compared and the numbers that were obtained. In particular, the teacher again underscored that the efficiency of each strategy was determined by the numerical properties of the word problem.

**Table 1**

*The Two Word Problems Presented During Instruction to All Students*

| Problem | Word Problem | Presented when? |
|---|---|---|
| **Cake Problem**  | Alex is making a strawberry cake. To make a small cake, the recipe calls for 2 eggs and 6 strawberries. Alex wants to make a big cake, so he uses 8 eggs. **How many strawberries will Alex need in order to make a big cake?** | At pretest |
| **Juice Problem**  | Maria is making fruit juice. To make a small pitcher of juice, the recipe calls for 3 apples and 7 oranges. Maria wants to make a big pitcher of juice, so she uses 16 apples. **How many oranges will Maria need in order to make a big pitcher of juice?** | While introducing equivalent fraction and unit ratio strategies during lesson. |

*Note.* See the online article for the color version of this table.

Finally, students completed four problems. The first two were near-transfer word problems in which they were asked to use the equivalent fraction strategy and then the unit ratio strategy to solve the problem. Those assigned to the worked examples condition again saw a screenshot of the teacher's equivalent fraction and unit ratio worked examples alongside the corresponding word problem. The second two questions were multiple-choice items that asked students to identify the most efficient way to solve a posed word problem.

## Worked Examples Manipulation

We manipulated the presence of worked examples during the problem-solving sections of the lesson. Students in the worked examples condition were provided with fully worked examples at four times during the lesson: (a) when attempting the juice problem using the equivalent fraction strategy, (b) when attempting the juice problem using the unit ratio strategy, and (c) twice when solving the two near-transfer problems during the comparison section. These worked examples were screenshots of what the teacher wrote on the board when explaining the equivalent fraction strategy and unit ratio strategy to solve the cake problem (see Figure 2). Students received either the equivalent fraction or unit ratio worked example depending on the word problem. This worked example was provided alongside the word problem so students could refer to it while problem-solving.

The goal of these worked examples was to support structure mapping by scaffolding students' understanding and transfer of each strategy to a new problem context. This was instrumental within the context of this ratio lesson, for which the ultimate learning objective was the higher-order relational reasoning and structure mapping across the two solution strategies (see Figure 1). Specifically, worked examples were used to support students' learning and transfer within the lower order relations (cake problem solution : juice problem solution; for both equivalent fraction and unit ratio strategies) in order to foster the higher-order relation (Cake [EF] : Juice [EF] :: Cake [UR] : Juice [UR]). Such scaffolding of relational reasoning is critical for higher-order thinking and learning, particularly in mathematics (see Richland & Simms, 2015 for a discussion).

Conversely, students in the control condition did not see any worked examples while completing these word problems during instruction. Critically, besides the presence of these four worked examples, students in the worked examples and control conditions viewed identical, high-quality relational instruction and completed the same posttest items.

## Measures

### *Pretest Item*

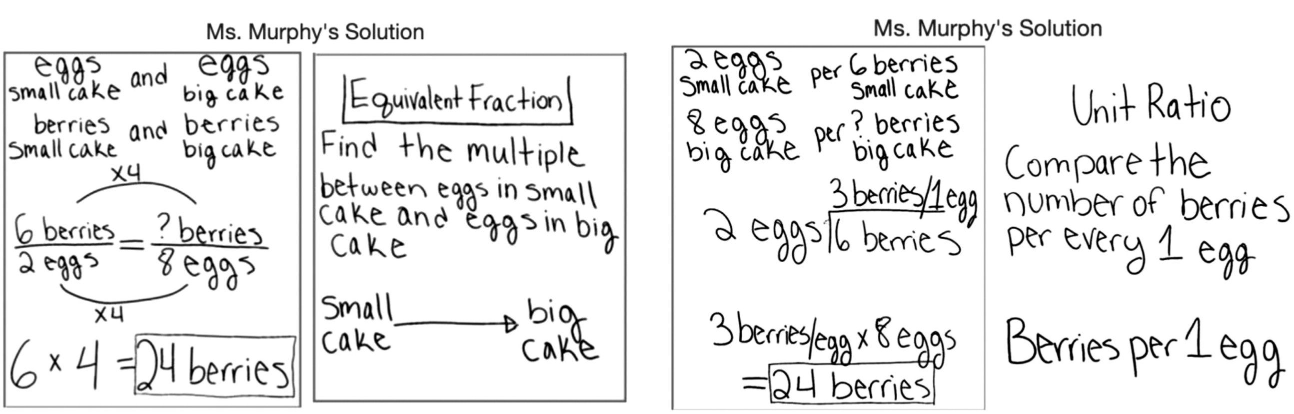
The one-item pretest was administered at Day 1 immediately prior to watching the lesson (see Table 1). The pretest was short due to time constraints: Students were asked to solve one ratio word problem (the cake problem) using any strategy they knew. Students provided their answer and were also asked to write out all their problem-solving steps: Our aim was to determine if students were inclined to use proportional strategies at baseline. Two trained research assistants coded pretest performance by reviewing students' problem-solving steps. Initially, six categories of problem-solving strategies were coded: use of an equivalent fraction strategy, a unit ratio strategy, another proportional strategy, a non-proportional strategy (e.g., subtraction), blank responses, or guesses without corresponding work. Interrater reliability was high (Krippendorf's $\alpha = .86$; Hayes & Krippendorff, 2007). Expectedly, due to the fact that ratio word problems had not been introduced in the curriculum at the start time of this study, there were only a small number of students who used the instructed proportional strategies. Thus, we simplified the six categories into one binary pretest measure: If students attempted any type of proportional strategy on the pretest item (regardless of if they achieved the correct answer), they received a 1. Otherwise, they received a 0.

### *Math Learning From the Lesson*

We assessed students' gains in ratio understanding at two time points throughout the 2-day study: during the lesson (Day 1) and on a posttest 3 days later (Day 2). Whereas the pretest item assessed whether students could employ *any* type of proportional strategy without instruction, the lesson and posttest items assessed students' capacity to adopt, employ, and compare across the two *instructed* proportional strategies. Specifically, we coded students' procedural and conceptual understanding using their answers to multiple-choice questions and free-response word problems. Most multiple-choice items were coded as correct (1) or incorrect (0); however, students could receive partial credit (0.5) for some multiple-choice items.

**Figure 2**

*Worked Examples for Equivalent Fraction (Left) and Unit Ratio (Right) Strategies*



Trained research assistants coded all students' open-ended responses to the word problems on the pretest and posttests as correct (1) if they achieved the correct answer (or nearly the correct answer, e.g., rounding error) and incorrect (0) otherwise. See the online supplemental material for complete items and scoring guide across all assessments.

In accordance with prior work (Rittle-Johnson & Star, 2007), we calculated three math learning outcomes based on students' performance during the lesson (Day 1) and during the posttest (Day 2): overall accuracy, procedural understanding, and conceptual understanding. Below, each is described in turn, and psychometric data are provided.

**Overall Accuracy.** Two overall accuracy scores were calculated: the proportion correct across all 12 items during the lesson (Day 1 overall accuracy) and across all 15 items on the posttest (Day 2 overall accuracy). Reliability for overall accuracy was high (Cronbach's $\alpha = .86$; pooled across both assessment timepoints).

**Procedural Understanding.** Procedural understanding entailed students' "ability to execute action sequences to solve problems" using one of the instructed ratio strategies (Rittle-Johnson et al., 2001, p. 346). We assessed procedural understanding with 15 items throughout the lesson and posttest using a mix of multiple-choice items and word problems ($\alpha = .81$). For multiple-choice items, students were shown a word problem and had to select the correct proportional solution strategies to solve problems. For word problems, we scored students' responses as correct if they worked out the problem and achieved the correct answer. Day 1 procedural understanding was calculated as the proportion correct of the four items during the lesson, and Day 2 was the proportion correct of the 11 items on the posttest.

**Conceptual Understanding.** Whereas procedural understanding is anchored to the problem context, conceptual understanding is a more transferrable knowledge (Rittle-Johnson et al., 2001). Conceptual understanding is students' "implicit or explicit understanding of the principles that govern a domain and of the interrelations between units of knowledge in a domain" (Rittle-Johnson et al., 2001, p. 346). Applied to this study, conceptual understanding entailed students' higher-order, generalized understanding of the ratio strategies, including the relations between them (Rittle-Johnson & Star, 2007). Again, conceptual understanding was assessed via a mix of multiple-choice items, word problems, and free-response items ($\alpha = .73$). For each multiple-choice item, students were shown a new word problem and asked to identify the solution strategy that was fastest or most efficient. Another set of multiple-choice items were presented after students solved a word problem using an instructed strategy; then, students were asked to select all the ways they could have solved the word problem. For word problems, we selected two word problems (coded under procedural understanding) that specifically asked students to solve using the most efficient strategy; conceptual understanding was evidenced by attempting the problem using the appropriately efficient strategy, regardless of whether they obtained the correct answer (i.e., independent of procedural accuracy). Lastly, there were also two analogy-style free-response items that asked students to find relations among compared solution strategies. Day 1 conceptual understanding was calculated as the proportion correct of the eight items during the lesson, and Day 2 was the proportion correct of the six items on the posttest.

### *Math Learning Anxiety*

We measured students' math anxiety using the five-item learning subscale of the Modified Abbreviated Math Anxiety Scale (Carey et al., 2017), which has been validated for use in elementary and middle school-aged mathematics students. We focused on the learning subscale to remain consistent with this study's focus on learning concerns, and because math learning anxiety is a greater predictor of math achievement than math evaluation anxiety (see Barroso et al., 2021). Students were provided a list of five "things that happen a lot during math class" and were asked to report how they would feel in the event that the things occurred (e.g., "Starting a new topic in math"). We used the same five-point Likert scale as Carey et al. (2017), except we changed "anxiety" to "stress" because not all students in prior pilot tests understood the word anxiety (1 = *low stress* to 5 = *high stress*). The scale was administered at the beginning of Day 2. We summed across the items ($\alpha = .79$) to generate a continuous measure of math anxiety.

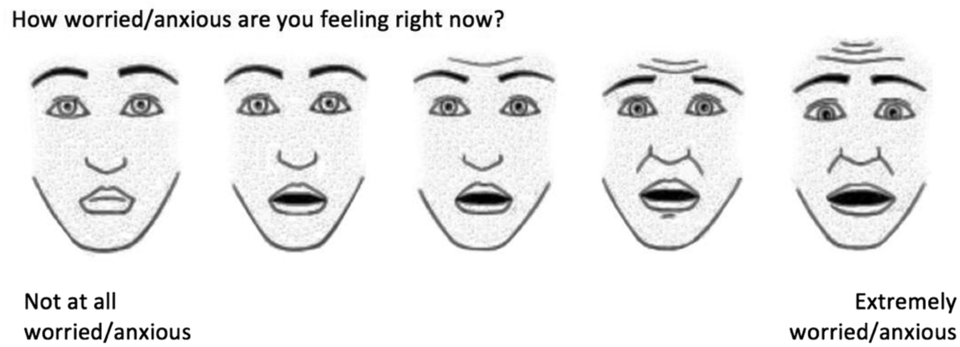
### *COVID-19 Learning Worries*

We measured students' worries about the effects of the pandemic on learning using a self-designed scale. In line with this study's focus on math learning anxiety, and with prior work assessing pandemic-related impacts on immediate STEM learning (Mesghina et al., 2021), we modified these items to specifically address students' worries about pandemic-related impacts on their learning (e.g., "Does online learning make you more nervous than learning in the classroom?"). First, students read a prompt stating that the researchers "want to know how you are feeling about learning at home during this pandemic." Then, for each statement, students were asked to use a five-point Likert scale (0 = *not at all* to 4 = *often*) to indicate how much they had felt each feeling in the past 7 days. We summed across their responses to the five items to obtain a measure of COVID-19 learning worries ($\alpha = .71$). The items have also shown good internal consistency in two other pilot studies in which we administered this scale during the pandemic (Spring 2020, $n = 186$, $\alpha = .76$; Spring 2021, $n = 145$, $\alpha = .80$). Moreover, the COVID-19 learning worries measure correlated moderately with students' math learning anxiety, $r(278) = .42$, $p < .001$, and state worry—see below; Day 1: $r(278) = .36$, $p < .001$; Day 2: $r(278) = .30$, $p < .001$—during the study in theoretically predicted ways. The complete items and instructions for the COVID-19 worries scale are provided in the online supplemental material.

### *State Worry*

We asked students to report how worried they felt at nine time points throughout the entire lesson (Day 1, except for pretest) and posttest (Day 2). Students used a five-point visual analog scale (1 = *not at all worried* to 5 = *extremely worried*; see Figure 3) with corresponding facial representations of neutral to extreme worry. Similar "faces" scales have been reliably used to assess state worry during math performance for children of a similar age (Punaro & Reeve, 2012; Trezise & Reeve, 2014). Students were prompted to report their worry at the beginning and end of each day, immediately after the COVID-19 worries scale, during key instructional moments during the lesson (see below), and at the midpoint of the posttest. We averaged students' six responses on Day 1 and their three responses on

**Figure 3**
*State Worry Visual Analog Scale*






Day 2 to obtain measures of state worry during learning ($\alpha = .88$) and during testing ($\alpha = .84$), respectively.

### *Perceived Understanding*

At seven times throughout the lesson, students were asked to use a continuous sliding scale (0–100) to respond to the following prompt: "I completely understand __% of the stuff I just watched in the video." We inserted these perceived understanding prompts at key instructional points in the lesson: after each strategy was introduced, after students tried each strategy independently, after students identified similarities across the two strategies, and, lastly, after the two strategies were compared. Perceived understanding was the average across the seven items ($\alpha = .92$).

### *Mind Wandering*

Students' mind wandering was assessed twice during the study using the same five-item Mind Wandering Questionnaire (Mrazek et al., 2013), which has been validated for use with elementary and middle school-aged students. The questionnaire was completed using a six-point Likert scale (1 = *never* to 6 = *always*). At the end of Day 1, students completed the questionnaire with the instructions to reflect on how they were feeling while they were watching the math lesson ($\alpha = .83$). We summed across these items to obtain our measure of mind wandering during learning. We obtained a measure of mind wandering during testing immediately after students completed the posttest on Day 2. Here, students again completed the questionnaire, this time with instructions that referenced their experience during the posttest ($\alpha = .86$).

### *Situational Interest*

We assessed students' situational interest in the lesson at the end of Day 2 using Linnenbrink-Garcia et al.' (2010) Situational Interest Scale. This 14-item scale uses a five-point Likert scale (1 = *strongly disagree* to 5 = *strongly agree*) to measure affective and motivational components of interest in both the instructional content and presentation of a lesson. Importantly, the scale has been validated on middle school students in mathematics lessons and can be modified to assess interest in a specific lesson as we did (e.g., "I am excited about what I learned in the math lesson"; $\alpha = .94$). We summed across the items to obtain a measure of situational interest.

## Analytic Plan

We investigated whether the presence of worked examples during instruction could support students' learning from and engagement during a mathematics lesson. In line with cognitive load theory, we were particularly interested in whether worked examples may promote learning and engagement for those students who were most worried about learning during the pandemic and/or those who were most math anxious. To examine this, we first used chi-squared tests and *t* tests to ensure that pretest performance and baseline measures were balanced across the two conditions. Then, we provided descriptive statistics and correlations among the math learning and engagement measures.

Next, we conducted our main analyses of interest using three-step linear regression analyses to examine the effects of COVID-19 worries, math anxiety, and worked examples condition, first on students' math learning outcomes for Day 1 and Day 2 (overall accuracy, procedural accuracy, and conceptual accuracy), then on their Day 1 and Day 2 engagement outcomes (mind wandering during learning and testing, state worry during learning and testing, perceived understanding, and situational interest). For each three-step regression analysis, we first tested the independent effects of math anxiety and COVID-19 worry. We believed it important to assess the independent effects of these affective factors first, as the influence of either has not been assessed in the context of relational mathematics instruction that utilizes worked examples. We included site as a covariate given performance and engagement differences at baseline. In analyses of learning specifically, we controlled for pretest performance. In the second step, we included the main effect of condition. Then, we tested whether math anxiety and COVID-19 worries interacted with condition in the third step.[1] Standardized beta coefficients (β) and standard errors are reported for all regression outputs. Where applicable,

[1] It is possible that COVID-19 learning worries may have compounded effects of math anxiety on learning and engagement. Thus, one analytical possibility was to test the three-way interaction between COVID-19 learning worry, math anxiety, and condition on learning and affect/engagement outcomes. We re-ran all our regression models with a fourth step that included the three-way interaction between worked examples condition, COVID-19 learning worries, and math anxiety. This three-way interaction did not predict any learning or affect/engagement outcomes. The one exception was a small effect of the three-way interaction on students' mind wandering during learning ($\beta = -0.27, p = .008$). However, we were quite underpowered to conduct such an analysis, so the results are not discussed further.

unstandardized coefficients (*b*) are reported for post hoc simple slope analyses.

We used multiple imputation to account for missing data in students' responses using the MICE package in R). Forty students completed Day 1 but did not participate in Day 2. Independent of this, we also had some incomplete data: Nine students did not finish all activities on Day 1, and 12 students on Day 2. Missingness was not related to students' school site, Chicago or Irvine: $\chi^2(1) = 0.43$, $p = .51$, nor their condition, $\chi^2(1) = 1.16$, $p = .28$—the variables for which we had data for all recruited participants. All variables were used to specify the imputation model. In the Results section, all descriptive statistics are shown using available raw data. All inferential analyses reported use imputed data, though we note that all results hold using pairwise deletion as well. All data, code, and materials are available upon request.

# Results

## Balance Checks

Descriptive statistics for all outcomes are provided in Table 2. Sixty-two percent of students attempted the pretest question with a strategy indicative of proportional thinking, regardless of execution accuracy. Those in Chicago were less likely to correctly attempt the pretest question compared to those in Irvine, $\chi^2(1) = 5.36$, $p = .02$. The Chicago participants also had significantly lower accuracy and learning throughout Day 1 and Day 2 (see Tables 3 and 4). Moreover, on average, Chicago participants had lower COVID-19 worry, $t(115.30) = 2.97$, $p = .004$,[2] were more interested in the lesson, $t(278) = -3.91$, $p < .001$, and had lower perceived understanding during the lesson, $t(278) = 3.04$, $p = .003$. Thus, we included site as a covariate in all subsequent regression analyses of performance, engagement, and affect.

No differences by condition emerged at pretest or on any baseline affective or engagement outcomes. Key to our research questions, there were no differences between conditions in their reported COVID-19 worry, $t(278) = 0.84$, $p = .40$, or math anxiety, $t(278) = 0.77$, $p = .44$. The only main effect of condition emerged on mind wandering during Day 2, where those in the worked examples condition reported significantly less mind wandering than controls, $t(253.18) = -2.72$, $p = .007$.[2]

## Relations Between Math Performance and Math Affect/Engagement

Correlations among all study measures are provided in Table 5. For the most part, all math affect/engagement outcomes were related to learning outcomes in theoretically predicted ways. Students who were more math anxious and who reported higher COVID-19 worry also reported lower situational interest, lower perceived understanding, and greater mind wandering and state worry during learning and testing. However, there were a few notable exceptions to these predicted patterns. First, while learning on Day 1, students' state worry did not predict their procedural, conceptual, or overall accuracy, nor did their frequency of mind wandering predict any of those Day 1 learning outcomes. Conversely, on Day 2, students' state worry and frequency of mind wandering during testing did negatively predict their procedural, conceptual, and overall accuracy on the posttest. Second, students' situational interest in the lesson did not relate to their performance on either day. Situational interest did correlate with other indices of affect and engagement across both days. Lastly, and congruent with prior research, math anxiety was negatively related to all three learning outcomes on both Day 1 and Day 2. However, the correlations between COVID-19 worries and our measures of learning were smaller in magnitude and statistically insignificant compared to math anxiety. Importantly, though COVID-19 worries may not have predicted students' learning, it was a consistent predictor of all other math engagement and affect measures.

## Math Performance

### Day 1

Full results from the three-step regression analyses of students' math performance on Day 1 are provided in Table 3. For all math learning outcomes, site and pretest remained significant predictors of students' performance: Those in Irvine and those who correctly attempted the pretest question with a proportional strategy[3] had higher scores on all three measures of math performance.

First, we analyzed overall accuracy during instruction on Day 1. The negative effect of math anxiety on students' overall accuracy was small but statistically insignificant ($\beta = -0.11$, $p = .06$). COVID-19 worries did not predict performance. Condition was added to the model in Step 2: Again, a small but insignificant effect suggested that those with worked examples had lower overall accuracy relative to controls ($\beta = -0.21$, $p = .06$). Condition did not interact with math anxiety or COVID-19 worry to predict performance.

We next considered whether the effects of math anxiety, COVID-19 worry, and condition differed depending on whether the math items assessed procedural understanding or conceptual understanding. For conceptual items, we found a small main effect of condition, whereby students in the control performed better on the conceptual items than students who reviewed worked examples ($\beta = -0.23$, $p = .04$). Neither COVID-19 worry, math anxiety, condition, nor their interactions predicted procedural understanding.

In sum, while students were viewing the lesson on Day 1, we found weak, inconsistent, and largely statistically insignificant effects of math anxiety and condition on students' learning. Notably, reviewing worked examples during instruction was related to relatively lower accuracy on conceptual items as compared to controls.

### Day 2

Next, we analyzed math performance outcomes for Day 2, when students completed the posttest (see Table 4). Again, analyses controlled for pretest performance and site, both of which remained significant predictors of all Day 2 math outcomes. As for overall accuracy at Day 2, we found a significant main effect of math anxiety

[2] Degrees of freedom were adjusted due to unequal variances between conditions.

[3] Despite the brevity of the one-item pretest, whether students attempted a proportional strategy on the pretest item remained a medium-to-large predictor of all learning outcomes, explaining between 5% to 12% of the variance in procedural and conceptual learning across Day 1 and Day 2. Still, capacity to employ proportional strategies likely does not capture all the variation in students' baseline understanding of ratio.

**Table 2**
*Descriptive Statistics for All Performance and Affective/Engagement Measures, by Condition and Site*

| Measure | By condition | | By site | | Overall |
|---|---|---|---|---|---|
| | Worked examples | Control | Chicago | Irvine | |
| Performance and learning | | | | | |
| Pretest (0 or 1) | 0.66 (0.47) | 0.58 (0.50) | 0.49 (0.50) | 0.66 (0.48) | 0.62 (0.49) |
| Day 1 overall (% correct out of 12) | 0.49 (0.22) | 0.52 (0.22) | 0.38 (0.19) | 0.54 (0.22) | 0.50 (0.22) |
| Day 1 procedural (% correct out of 4) | 0.40 (0.28) | 0.40 (0.30) | 0.26 (0.23) | 0.44 (0.29) | 0.40 (0.29) |
| Day 1 conceptual (% correct out of 8) | 0.53 (0.26) | 0.58 (0.26) | 0.44 (0.25) | 0.59 (0.25) | 0.56 (0.26) |
| Day 2 overall (% correct out of 15) | 0.63 (0.21) | 0.61 (0.25) | 0.44 (0.21) | 0.67 (0.21) | 0.62 (0.23) |
| Day 2 procedural (% correct out of 11) | 0.65 (0.24) | 0.64 (0.27) | 0.44 (0.25) | 0.71 (0.22) | 0.65 (0.25) |
| Day 2 conceptual (% correct out of 6) | 0.50 (0.24) | 0.48 (0.28) | 0.42 (0.25) | 0.51 (0.26) | 0.49 (0.26) |
| Affect and engagement | | | | | |
| Day 1 state worry (0–4) | 0.84 (0.89) | 0.90 (0.88) | 0.93 (0.95) | 0.86 (0.87) | 0.87 (0.88) |
| Day 2 state worry (0–4) | 0.58 (0.92) | 0.73 (0.91) | 0.80 (1.08) | 0.61 (0.86) | 0.65 (0.92) |
| Perceived understanding (0–100) | 79.59 (20.95) | 74.19 (25.15) | 68.97 (25.77) | 79.11 (22.05) | 76.93 (23.23) |
| Day 1 mind wandering (5–30) | 10.83 (4.95) | 11.43 (5.08) | 11.73 (5.61) | 10.94 (4.83) | 11.12 (5.01) |
| Day 2 mind wandering (5–30) | 8.57 (3.88) | 10.25 (5.78) | 9.90 (5.04) | 9.24 (4.94) | 9.39 (4.95) |
| Situational interest (12–60) | 43.38 (10.88) | 40.73 (11.33) | 46.92 (10.10) | 40.71 (11.08) | 42.09 (11.16) |
| Math anxiety (5–25) | 9.72 (3.97) | 9.94 (4.13) | 9.43 (4.20) | 9.94 (4.00) | 9.83 (4.04) |
| COVID-19 learning worry (0–15) | 5.87 (3.29) | 6.24 (3.73) | 5.02 (2.81) | 6.33 (3.64) | 6.05 (3.51) |

*Note.* Raw, non-imputed means and standard deviations are reported. The possible range of scores is provided for each measure.



in the predicted direction ($\beta = -0.18$, $p < .001$), with higher math anxiety predicting lower performance. Importantly, we also found that math anxiety interacted with condition to predict performance ($\beta = 0.38$, $p = .001$; Table 4). We used simple slope analyses to follow-up on the interaction,[4] finding that the benefits of worked examples were greatest for those who were most anxious. For the control group, we found a negative relationship between math anxiety and overall performance ($b = -0.02$, $p < .001$). However, for those assigned to worked examples, there was no significant relationship between their math anxiety levels and overall performance ($b = 0.0001$, $p = .99$).

Split by question type, the interaction between math anxiety and condition remained a significant predictor of procedural accuracy ($\beta = 0.29$, $p = .009$) and conceptual accuracy ($\beta = 0.44$, $p = .001$; see Table 4). Whereas higher math anxiety was related to lower procedural accuracy ($b = -0.02$, $p < .001$) and lower conceptual accuracy ($b = -0.03$, $p < .001$) for those in the control, worked examples blunted the effects of math anxiety on performance, as evidenced by relatively flatter slopes (procedural: $b = -0.0003$, $p = .94$; conceptual: $b = -0.002$, $p = .68$; see Figures 4 and 5).

## Math Affect and Engagement

### *Day 1*

We used identical three-step regression analyses controlling for site to test the effects of math anxiety, COVID-19 worry, condition, and their interactions on students' affect and engagement during the lesson. See Table 6 for full regression results. Students with higher math anxiety and students with higher COVID-19 worry tended to report greater state worry while learning (Math anxiety: $\beta = 0.29$, $p < .001$; COVID-19 worry: $\beta = 0.25$, $p < .001$) and mind wandered more frequently while learning during Day 1 (Math anxiety: $\beta = 0.26$, $p < .001$; COVID-19 worry: $\beta = 0.28$, $p < .001$). Additionally, math anxiety levels ($\beta = -0.18$, $p = .006$) and, to a lesser extent, COVID-19 worries ($\beta = -0.12$, $p = .06$) were negatively related to students' perceived understanding during the lesson. Interestingly, condition did not predict any affective or engagement outcomes at Day 1, nor did condition interact with math anxiety or COVID-19 worry.

### *Day 2*

Effects of condition on students' affect and engagement emerged during testing on Day 2 (see Table 7). Condition interacted with math anxiety to predict mind wandering at Day 2 ($\beta = -0.25$, $p = .01$), conditional on Day 1 mind wandering. Post hoc analyses revealed a positive relation between math anxiety and mind wandering for those in the control ($b = 0.30$, $p = .001$), but math anxiety did not predict mind wandering for those assigned to worked examples ($b = -0.01$, $p = .90$; see Figure 6). Math anxiety and condition similarly interacted to predict students' situational interest in the lesson ($\beta = 0.40$, $p = .001$). Again, higher math anxiety was related to lower interest for those in controls ($b = -1.35$, $p < .001$) but not those in the worked examples condition ($b = -0.24$, $p = .30$; see Figure 7). Conditional on Day 1 state worry, we also found a small, negative effect of worked examples on state worry during Day 2 ($\beta = -0.15$, $p = .04$), wherein those who reviewed worked examples had lower state worry during testing than controls. In sum, and consistent with students' Day 2 math performance outcomes, worked examples seemed to buffer against the deleterious

[4] To complement the line graphs, we also visually decomposed the math anxiety-by-condition interaction using bar graphs. We tested the local effects of condition for students who were high (1 *SD* above the mean) and low (1 *SD* below the mean) in math anxiety. Interpretations are similar to those reported in the main text and further illustrate the particular benefit of worked examples for those most anxious. See the online supplemental material for this alternate illustration for each outcome that was significantly predicted by the interaction.

**Table 3**
*Results From the Three-Step Regression Analyses of Learning From the Math Lesson at Day 1*

| Step | Predictor | β (*SE*) | *t* | *p* |
|---|---|---|---|---|
| | Day 1 overall accuracy | | | |
| Step 1 | Math anxiety | −0.11 (0.06) | −1.89 | .06 |
| | COVID-19 worry | −0.01 (0.06) | −0.19 | .85 |
| | Chicago | −0.63 (0.14) | −4.64 | <.001 |
| | Pretest | 0.59 (0.11) | 5.23 | <.001 |
| Step 2 | Math anxiety | −0.12 (0.06) | −1.95 | .05 |
| | COVID-19 worry | −0.02 (0.06) | −0.26 | .80 |
| | Chicago | −0.64 (0.14) | −4.71 | <.001 |
| | Pretest | 0.61 (0.12) | 5.37 | <.001 |
| | Worked examples | −0.21 (0.11) | −1.92 | .06 |
| Step 3 | Math anxiety | −0.19 (0.09) | −2.23 | .03 |
| | COVID-19 worry | −0.02 (0.08) | −0.22 | .83 |
| | Chicago | −0.65 (0.14) | −4.76 | <.001 |
| | Pretest | 0.61 (0.11) | 5.33 | <.001 |
| | Worked examples | −0.21 (0.11) | −1.99 | .05 |
| | Math Anxiety × Worked Examples | 0.15 (0.12) | 1.24 | .22 |
| | COVID-19 Worry × Worked Examples | 0.02 (0.12) | 0.14 | .89 |
| | Day 1 procedural accuracy | | | |
| Step 1 | Math anxiety | −0.11 (0.06) | −1.81 | .07 |
| | COVID-19 worry | −0.11 (0.06) | −1.72 | .09 |
| | Chicago | −0.58 (0.14) | −4.14 | <.001 |
| | Pretest | 0.42 (0.10) | 3.62 | <.001 |
| Step 2 | Math anxiety | −0.11 (0.06) | −1.83 | .07 |
| | COVID-19 worry | −0.11 (0.06) | −1.74 | .08 |
| | Chicago | −0.59 (0.14) | −4.16 | <.001 |
| | Pretest | 0.43 (0.12) | 3.66 | <.001 |
| | Worked examples | −0.08 (0.11) | −0.73 | .46 |
| Step 3 | Math anxiety | −0.17 (0.09) | −1.90 | .06 |
| | COVID-19 worry | −0.17 (0.08) | −1.99 | .05 |
| | Chicago | −0.59 (0.14) | −4.21 | <.001 |
| | Pretest | 0.44 (0.12) | 3.73 | <.001 |
| | Worked examples | −0.08 (0.11) | −1.92 | .06 |
| | Math Anxiety × Worked Examples | 0.11 (0.12) | 0.91 | .36 |
| | COVID-19 Worry × Worked Examples | 0.14 (0.12) | 1.15 | .25 |
| | Day 1 conceptual accuracy | | | |
| Step 1 | Math anxiety | −0.07 (0.06) | −1.17 | .24 |
| | COVID-19 worry | 0.05 (0.06) | 0.76 | .45 |
| | Chicago | −0.50 (0.14) | −3.50 | .001 |
| | Pretest | 0.51 (0.12) | 4.31 | <.001 |
| Step 2 | Math anxiety | −0.08 (0.06) | −1.23 | .22 |
| | COVID-19 worry | 0.04 (0.06) | 0.70 | .49 |
| | Chicago | −0.50 (0.14) | −3.57 | <.001 |
| | Pretest | 0.53 (0.12) | 4.48 | <.001 |
| | Worked examples | −0.23 (0.11) | −2.08 | .04 |
| Step 3 | Math anxiety | −0.13 (0.09) | −1.49 | .14 |
| | COVID-19 worry | 0.08 (0.09) | 0.91 | .37 |
| | Chicago | −0.51 (0.14) | −3.60 | <.001 |
| | Pretest | 0.52 (0.12) | 4.38 | <.001 |
| | Worked examples | −0.23 (0.11) | −1.24 | .22 |
| | Math Anxiety × Worked Examples | 0.11 (0.12) | 0.88 | .38 |
| | COVID-19 Worry × Worked Examples | −0.10 (0.11) | −0.54 | .59 |

*Note.* Standardized coefficients and standard errors are reported.



effects of math anxiety on their engagement with and interest in the lesson while testing during Day 2.

## Discussion

Researchers interested in ameliorating the effects of worries on children's achievement have typically targeted the emotion response itself, using emotion regulation and mindset interventions for mathematics performance (e.g., Ganley et al., 2021; Mesghina & Richland, 2020; Ramirez et al., 2018) and for STEM achievement during the pandemic more specifically (Mesghina et al., 2021), with mixed success. Instead, this study explored whether intervening at the level of instruction may support all students' learning, despite varying levels of worry about the performance domain (math anxiety) or performance context (COVID-19 worries) that students may possess during learning (see Hembree, 1990; Kaffenberger, 2021). We found that one instructional modification—worked examples—moderated the relation between worry due to math anxiety and

**Table 4**

*Results From the Three-Step Regression Analyses of Learning From the Math Lesson at Day 2*

| Step | Predictor | β (*SE*) | *t* | *p* |
|---|---|---|---|---|
| | Day 2 overall accuracy | | | |
| Step 1 | Math anxiety | −0.18 (0.06) | −3.22 | .001 |
| | COVID-19 worry | 0.006 (0.06) | 0.11 | .92 |
| | Chicago | −0.84 (0.13) | −6.49 | <.001 |
| | Pretest | 0.59 (0.11) | 5.47 | <.001 |
| Step 2 | Math anxiety | −0.18 (0.06) | −3.19 | .002 |
| | COVID-19 worry | 0.008 (0.06) | 0.14 | .89 |
| | Chicago | −0.84 (0.13) | −6.46 | <.001 |
| | Pretest | 0.59 (0.11) | 5.39 | <.001 |
| | Worked examples | 0.09 (0.10) | 0.87 | .39 |
| Step 3 | Math anxiety | −0.38 (0.08) | −4.64 | <.001 |
| | COVID-19 worry | 0.06 (0.08) | 0.80 | .43 |
| | Chicago | −0.86 (0.13) | −6.70 | <.001 |
| | Pretest | 0.57 (0.11) | 5.31 | <.001 |
| | Worked examples | 0.09 (0.10) | −2.45 | .02 |
| | Math Anxiety × Worked Examples | 0.38 (0.11) | 3.33 | .001 |
| | COVID-19 Worry × Worked Examples | −0.09 (0.11) | −0.80 | .42 |
| | Day 2 procedural accuracy | | | |
| Step 1 | Math anxiety | −0.15 (0.06) | −2.64 | .009 |
| | COVID-19 worry | 0.03 (0.06) | 0.50 | .62 |
| | Chicago | −0.91 (0.13) | −7.12 | <.001 |
| | Pretest | 0.66 (0.11) | 6.20 | <.001 |
| Step 2 | Math anxiety | −0.15 (0.06) | −2.62 | .009 |
| | COVID-19 worry | 0.03 (0.06) | 0.52 | .61 |
| | Chicago | −0.90 (0.13) | −7.10 | <.001 |
| | Pretest | 0.65 (0.11) | 6.13 | <.001 |
| | Worked examples | 0.06 (0.10) | 0.60 | .55 |
| Step 3 | Math anxiety | −0.30 (0.08) | −3.71 | <.001 |
| | COVID-19 worry | 0.05 (0.08) | 0.65 | .52 |
| | Chicago | −0.92 (0.13) | −7.28 | <.001 |
| | Pretest | 0.65 (0.11) | 6.09 | <.001 |
| | Worked examples | 0.06 (0.10) | −2.25 | .03 |
| | Math Anxiety × Worked Examples | 0.29 (0.11) | 2.62 | .009 |
| | COVID-19 Worry × Worked Examples | −0.02 (0.11) | −0.20 | .85 |
| | Day 2 conceptual accuracy | | | |
| Step 1 | Math anxiety | −0.24 (0.06) | −3.76 | <.001 |
| | COVID-19 worry | −0.01 (0.06) | −0.20 | .84 |
| | Chicago | −0.32 (0.14) | −2.24 | .03 |
| | Pretest | 0.18 (0.12) | 1.52 | .13 |
| Step 2 | Math anxiety | −0.24 (0.06) | −3.74 | <.001 |
| | COVID-19 worry | −0.01 (0.06) | −0.18 | .86 |
| | Chicago | −0.32 (0.15) | −2.22 | .03 |
| | Pretest | 0.18 (0.12) | 1.47 | .14 |
| | Worked examples | 0.08 (0.12) | 0.64 | .53 |
| Step 3 | Math anxiety | −0.45 (0.09) | −5.05 | <.001 |
| | COVID-19 worry | 0.05 (0.08) | 1.11 | .27 |
| | Chicago | −0.32 (0.14) | −2.39 | .02 |
| | Pretest | 0.19 (0.12) | 1.27 | .05 |
| | Worked examples | 0.001 (0.12) | −1.99 | .008 |
| | Math Anxiety × Worked Examples | 0.44 (1.12) | 3.35 | .001 |
| | COVID-19 Worry × Worked Examples | −0.13 (0.13) | −1.64 | .10 |

*Note.* Standardized coefficients and standard errors are reported.

students' learning from the lesson, in addition to their mind wandering during and interest toward the lesson.

## Worked Examples

Worked examples are theorized to promote deep mathematical learning by reducing students' cognitive load during instruction (Cooper & Sweller, 1987) and helping redirect limited cognitive resources toward understanding key conceptual features of problem-solving strategies (Skemp, 2006; see also Booth, McGinn, et al., 2015). This allows for more advanced reasoning and schema formation during learning (Atkinson et al., 2003; Chi et al., 1989; Sweller et al., 1998). We specifically focused our analyses of worked examples during a lesson on ratio, as it is a particularly complex concept but is foundational for higher level mathematics. Additionally, ratio provides a rich, but cognitively demanding, learning environment

**Table 5**
*Correlation Matrix of All Math Performance and Affective/Engagement Outcomes*

| Measure | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Day 1 total | — | | | | | | | | | | | | | |
| 2. Day 1 proc | .68* | — | | | | | | | | | | | | |
| 3. Day 1 con | .90* | .30* | — | | | | | | | | | | | |
| 4. Day 2 total | .51* | .47* | .39* | — | | | | | | | | | | |
| 5. Day 2 proc | .52* | .48* | .39* | .97* | — | | | | | | | | | |
| 6. Day 2 con | .34* | .30* | .27* | .73* | .56* | — | | | | | | | | |
| 7. Day 1 worry | −.11 | −.05 | −.11 | −.16** | −.15* | −.13*** | — | | | | | | | |
| 8. Day 2 worry | −.17** | −.11 | −.14*** | −.29* | −.27* | −.23* | .79* | — | | | | | | |
| 9. Understand | .23* | .12*** | .21* | .28* | .27* | .20* | −.34* | −.35* | — | | | | | |
| 10. Day 1 MW | −.10 | −.06 | −.08 | −.16** | −.13*** | −.21* | .26* | .28* | −.39* | — | | | | |
| 11. Day 2 MW | −.15*** | −.03 | −.16** | −.21*** | −.18** | −.21* | .34* | .39* | −.43* | .64* | — | | | |
| 12. Sit interest | .01 | .003 | −.004 | .10 | .05 | .23* | −.13*** | −.23* | .30* | −.31* | −.24* | — | | |
| 13. Math anxiety | −.12*** | −.15*** | −.05 | −.18** | −.13*** | −.24* | .39* | .41* | −.22* | .37* | .36* | −.30* | — | |
| 14. COVID-19 | −.04 | −.13*** | .03 | −.04 | −.001 | −.10 | .36* | .30* | −.17** | .38* | .34* | −.16** | .42* | — |

*Note.* MW refers to mind wandering. Proc and Con refer to students' accuracy on the math items assessing procedural understanding and conceptual understanding, respectively.
* $p < .001$. ** $p < .01$. *** $p < .05$.

for comparison across multiple novel strategy solutions (Begolli et al., 2018).

Findings from this study showed interesting interaction effects that suggest that in addition to these theorized benefits, worked examples can provide intervention support for anxiety. The most math anxious students tended to report a greater frequency of mind wandering during testing, unless they reviewed worked examples during instruction, in which case there was no relation between math anxiety and mind wandering during testing. This reveals that reviewing worked examples during instruction changed the students' experience, and the mechanism may have been that it freed up limited cognitive resources for task-directed reasoning and more focused attention (Cooper & Sweller, 1987), leading to improved learning as measured 3 days later.

Beyond cognitive mechanisms, worked examples could have influenced performance and learning via affective and motivational advantages to students while learning. Worked examples blunted the negative effects of math anxiety on situational interest experienced by students in the control condition. Moreover, there was a small but significant main effect of condition on state worry during testing, where students who reviewed worked examples were less worried than controls on average, which was related to learning. Worked examples did not necessarily make students feel more confident about their learning in the moment. Still, perhaps students who reviewed worked examples felt more supported and/or had greater self-efficacy during learning, with iterative effects on engagement and performance throughout the rest of the lesson (Ahmed et al., 2012). This would be particularly beneficial for the most math anxious students, who tend to have lower mathematical self-concept and self-efficacy (e.g., Ahmed et al., 2012; Jameson, 2014) and are more likely to disengage from or opt out of difficult math performance contexts (Martin et al., 2012; Pizzie & Kraemer, 2017). With few exceptions (Adams et al., 2014; Baars et al., 2014; Barbieri & Booth, 2016; Greensfeld & Nevo, 2017), little work has assessed students' subjective experience using worked examples, or empirically examined the influence of worked examples on students' affective or motivational experiences in math performance and learning contexts. This poses an important theoretical question because

**Figure 4**
*Predicted Performance on the Procedural Items by Condition During Testing at Day 2*

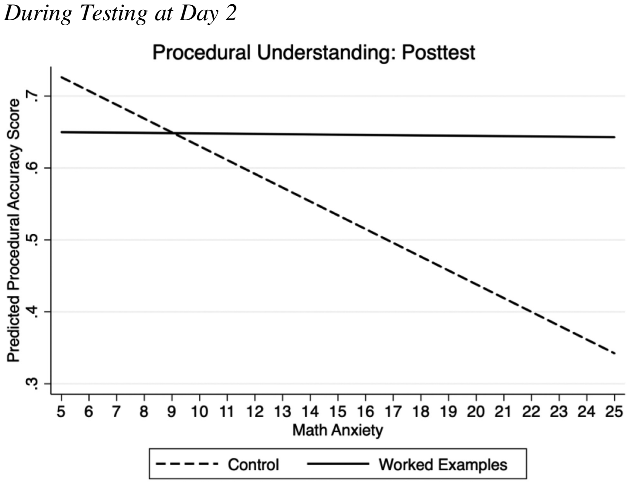



**Figure 5**
*Predicted Performance on the Conceptual Items by Condition During Testing at Day 2*

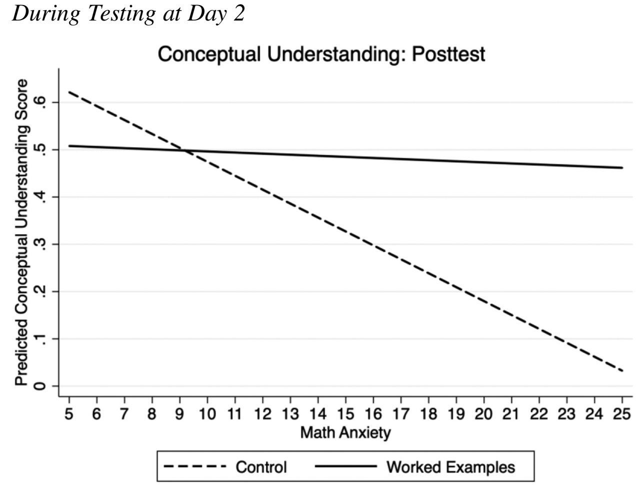


**Table 6**

*Results From the Three-Step Regression Analyses of Affect and Engagement Measures at Day 1*

| Step | Predictor | β (*SE*) | *t* | *p* |
|---|---|---|---|---|
| | Day 1 State worry | | | |
| Step 1 | Math anxiety | 0.29 (0.06) | 4.83 | <.001 |
| | COVID-19 worry | 0.25 (0.06) | 4.25 | <.001 |
| | Chicago | 0.22 (0.13) | 1.63 | .11 |
| Step 2 | Math anxiety | 0.29 (0.06) | 4.82 | <.001 |
| | COVID-19 worry | 0.25 (0.06) | 4.24 | <.001 |
| | Chicago | 0.22 (0.13) | 1.62 | .11 |
| | Worked examples | −0.01 (0.11) | −0.05 | .96 |
| Step 3 | Math anxiety | 0.37 (0.09) | 4.31 | <.001 |
| | COVID-19 worry | 0.22 (0.08) | 2.72 | .007 |
| | Chicago | 0.22 (0.13) | 1.66 | .12 |
| | Worked examples | −0.01 (0.11) | 0.99 | .31 |
| | Math Anxiety × Worked Examples | −0.16 (0.12) | −1.34 | .19 |
| | COVID-19 Worry × Condition | 0.06 (0.12) | 0.48 | .78 |
| | Day 1 perceived understanding | | | |
| Step 1 | Math anxiety | −0.18 (0.06) | −2.79 | .006 |
| | COVID-19 worry | −0.13 (0.06) | −1.96 | .05 |
| | Chicago | −0.51 (0.14) | −3.61 | <.001 |
| Step 2 | Math anxiety | −0.17 (0.06) | −2.76 | .006 |
| | COVID-19 worry | −0.12 (0.06) | −1.90 | .06 |
| | Chicago | −0.50 (0.14) | −3.56 | <.001 |
| | Worked examples | 0.20 (0.11) | 1.71 | .09 |
| Step 3 | Math anxiety | −0.24 (0.09) | −2.65 | .009 |
| | COVID-19 worry | −0.14 (0.09) | −1.66 | .10 |
| | Chicago | −0.51 (0.14) | −3.60 | <.001 |
| | Worked examples | 0.20 (0.11) | −0.76 | .45 |
| | Math Anxiety × Worked Examples | 0.13 (0.13) | 1.05 | .30 |
| | COVID-19 Worry × Worked Examples | 0.06 (0.13) | 0.49 | .63 |
| | Day 1 mind wandering | | | |
| Step 1 | Math anxiety | 0.26 (0.06) | 4.38 | <.001 |
| | COVID-19 worry | 0.28 (0.06) | 4.75 | <.001 |
| | Chicago | 0.24 (0.13) | 1.84 | .07 |
| Step 2 | Math anxiety | 0.26 (0.06) | 4.35 | <.001 |
| | COVID-19 worry | 0.28 (0.06) | 4.71 | <.001 |
| | Chicago | 0.24 (0.13) | 1.80 | .07 |
| | Worked examples | −0.12 (0.11) | −1.09 | .28 |
| Step 3 | Math anxiety | 0.31 (0.09) | 3.69 | <.001 |
| | COVID-19 worry | 0.28 (0.08) | 3.50 | .001 |
| | Chicago | 0.25 (0.13) | 1.84 | .07 |
| | Worked examples | −0.12 (0.11) | 0.66 | .51 |
| | Math Anxiety × Worked Examples | −0.11 (0.12) | −0.95 | .34 |
| | COVID-19 Worry × Worked Examples | −0.02 (0.12) | −0.15 | .88 |

*Note.* Standardized coefficients and standard errors are reported.

coupling cognitive support with increased affective support (e.g., fostering motivation and interest) during learning is theorized to predict greater gains in understanding (see Huk & Ludwigs, 2009). Thus, the availability of cognitive resources alone may be a necessary but insufficient mechanism to explain worked examples learning gains.

## Variation in the Worked Example Effect

Our findings differ in two key ways from the broader worked examples literature that we wish to describe here. First, where much work finds main effects of worked examples on math learning and performance (see Booth, McGinn, et al., 2015), we did not find any main effects. Rather, in this study, worked examples operated by interacting with student math anxiety levels. Little work has examined student-level moderators of the worked examples effect, like individual differences in math anxiety, that might be obscured by overall main effects and thus should be examined further (though see Booth, Oyer, et al., 2015; Rittle-Johnson et al., 2009 for discussions on the moderating role of students' prior knowledge).

Second, we did not find any immediate effects of worked examples on students' learning or engagement during instruction on Day 1; main effects and interactive effects of the experimental manipulation occurred only after a few days' delay. Prior work has found that worked examples manipulations only improve student learning when measured 1 week after instruction (Adams et al., 2014; van Gog et al., 2011; van Gog & Kester, 2012), likely because reviewing worked examples affords opportunities for students to engage in novel, deeper reasoning practices during learning, which may

**Table 7**

*Results From the Three-Step Regression Analyses of Affect and Engagement Measures at Day 2*

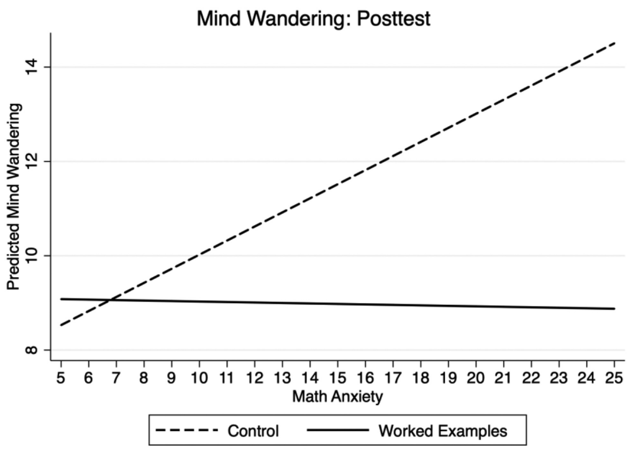
| Step | Predictor | β (*SE*) | *t* | *p* |
|---|---|---|---|---|
| | Day 2 State worry | | | |
| Step 1 | Math anxiety | 0.13 (0.04) | 3.24 | .001 |
| | COVID-19 worry | −0.02 (0.04) | −0.45 | .66 |
| | Chicago | 0.11 (0.09) | 1.24 | .22 |
| | Day 1 state worry | 0.75 (0.04) | 18.38 | <.001 |
| Step 2 | Math anxiety | 0.13 (0.04) | 3.21 | .001 |
| | COVID-19 worry | −0.02 (0.04) | −0.52 | .60 |
| | Chicago | 0.10 (0.09) | 1.17 | .24 |
| | Day 1 state worry | 0.75 (0.04) | 18.48 | <.001 |
| | Worked examples | −0.15 (0.07) | −2.03 | .04 |
| Step 3 | Math anxiety | 0.19 (0.06) | 3.18 | .002 |
| | COVID-19 worry | 0.02 (0.05) | 0.40 | .69 |
| | Chicago | 0.11 (0.09) | 1.26 | .21 |
| | Day 1 state worry | 0.74 (0.04) | 18.43 | <.001 |
| | Worked examples | −0.15 (0.07) | 1.46 | .15 |
| | Math Anxiety × Worked Examples | −0.10 (0.08) | −1.32 | .19 |
| | COVID-19 Worry × Worked Examples | −0.10 (0.08) | −1.31 | .19 |
| | Day 2 mind wandering | | | |
| Step 1 | Math anxiety | 0.12 (0.05) | 2.23 | .03 |
| | COVID-19 worry | 0.09 (0.05) | 1.77 | .08 |
| | Chicago | 0.16 (0.11) | 1.38 | .17 |
| | Day 1 mind wandering | 0.56 (0.05) | 11.05 | <.001 |
| Step 2 | Math anxiety | 0.11 (0.05) | 2.22 | .03 |
| | COVID-19 worry | 0.09 (0.05) | 1.74 | .08 |
| | Chicago | 0.15 (0.11) | 1.32 | .19 |
| | Day 1 mind wandering | 0.55 (0.05) | 10.96 | <.001 |
| | Worked examples | −0.20 (0.09) | −2.25 | .03 |
| Step 3 | Math anxiety | 0.25 (0.07) | 3.42 | .001 |
| | COVID-19 worry | 0.13 (0.07) | 1.85 | .07 |
| | Chicago | 0.16 (0.11) | 1.49 | .14 |
| | Day 1 mind wandering | 0.54 (0.05) | 10.90 | <.001 |
| | Worked examples | −0.20 (0.09) | 2.41 | .02 |
| | Math Anxiety × Worked Examples | −0.25 (0.10) | −2.60 | .01 |
| | COVID-19 Worry × Worked Examples | −0.09 (0.10) | −0.96 | .34 |
| | Day 1 situational interest | | | |
| Step 1 | Math anxiety | −0.28 (0.06) | −4.60 | <.001 |
| | COVID-19 worry | −0.01 (0.06) | −0.19 | .86 |
| | Chicago | 0.51 (0.14) | 3.70 | <.001 |
| Step 2 | Math anxiety | −0.28 (0.06) | −4.56 | <.001 |
| | COVID-19 worry | −0.01 (0.06) | −0.11 | .91 |
| | Chicago | 0.52 (0.14) | 3.78 | <.001 |
| | Worked examples | 0.21 (0.11) | 1.84 | .07 |
| Step 3 | Math anxiety | −0.49 (0.09) | −5.61 | <.001 |
| | COVID-19 worry | 0.10 (0.08) | 1.23 | .22 |
| | Chicago | 0.51 (0.14) | 3.75 | <.001 |
| | Worked examples | 0.21 (0.11) | −1.47 | .14 |
| | Math Anxiety × Worked Examples | 0.40 (0.12) | 3.32 | .001 |
| | COVID-19 Worry × Worked Examples | −0.21 (0.08) | −1.74 | .08 |

*Note.* Standardized coefficients and standard errors are reported. Day 1 values are used as a covariates for analyses of Day 2 state worry and Day 2 mind wandering.

challenge the learner in the short term (see also Soderstrom & Bjork, 2015). We did find that students in the worked examples condition had somewhat lower conceptual understanding scores during learning, though we exercise caution in interpreting this small effect.

On the other hand, the lack of an effect of worked examples on Day 1 may be an artifact of the math lesson's design: A unique contribution of the present study is that the manipulation of worked examples occurred within an already highly supported, relational lesson, meaning the control group also received high-quality instruction. We had carefully designed the instructional content, whiteboard writing, cameras, and the teacher's script and movements to incorporate research-backed pedagogical strategies shown to facilitate students' higher-order relational reasoning through simultaneous presentation and spatial alignment of solution strategies to be compared, linking gestures, and relational language (Alibali et al., 2014; Begolli & Richland, 2017;Richland, 2015; Richland et al., 2007). Thus, we believe the lesson was highly supportive such that all students—including those in the control condition—were able to follow along and solve the

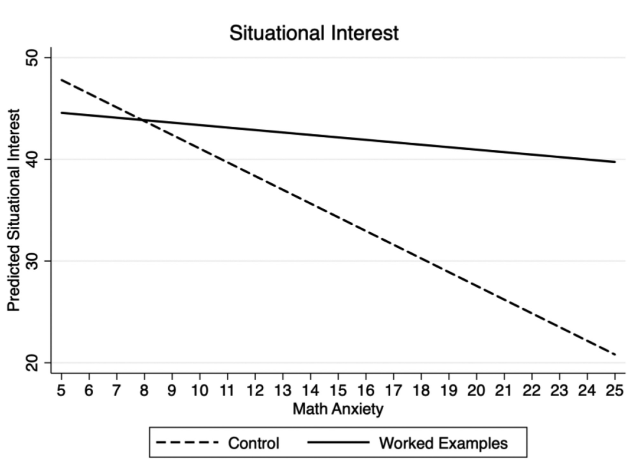
**Figure 6**
*Predicted Mind Wandering by Condition During Testing at Day 2*




problems sufficiently during Day 1, even if contending with demands on cognitive load. This could explain why mind wandering was not correlated to performance outcomes on Day 1.

Worked examples were employed as a tool to further support relational reasoning on top of the enhanced instruction. Specifically, worked examples were embedded at key moments during instruction to support students' reasoning across lower order relations in the service of achieving the higher-order relational understanding, which is highly demanding of cognitive resources (see Richland & Begolli, 2016; Richland & Simms, 2015). The Day 2 results do suggest that reviewing the worked examples was able to change initial learning processes in a meaningful way, even if no differences in Day 1 performance measures emerged. For example, worked examples may aid learners by improving their initial encoding of conceptual aspects of problems (Booth et al., 2013; see also Renkl, 2014). Benefits of worked examples may continue to manifest at later stages of learning: For instance, by facilitating learners' capacity to automatize, or "chunk," procedural steps—therefore relying less on working memory and more on direct retrieval from memory while problem-solving, which could preserve cognitive resources for more flexible problem-solving across various contexts (i.e., greater conceptual understanding; Renkl, 2014). Some evidence from our findings in support of this comes from between-day correlations: Day 1 mind wandering and state worry did not predict learning at Day 1, but did predict Day 2 learning outcomes. Again, that all effects were greatest for the most math anxious individuals still aligns with the proposed working memory pathway.

**Figure 7**
*Predicted Situational Interest by Condition During Testing at Day 2*




In sum, worked examples may not have changed the efficacy of students' learning at the initial moment on Day 1, but it perhaps did change the *efficiency* by which they learned, with implications for retrieval and retention as measured after a delay. Our focus on students' posttest accuracy may have obscured differences in these other markers of success following worked examples, including students' speed in achieving understanding (Cooper & Sweller, 1987). We may not wholly understand the benefits of worked examples during initial learning.

Lastly, the affective and engagement effects of worked examples also did not manifest until after a delay and was unexpected, which warrants future research. We theorize that perhaps students simply needed some time to reflect on their experiences with the math lesson and questions (i.e., math anxiety and COVID-19 worries, but also perhaps unpredicted feelings, e.g., dread and frustration). Thus, worked examples would be effective in reducing cognitive load only insofar as one's affective state was salient. However, we are limited as our manipulation varied somewhat from typical worked examples manipulations. This remains an important area of investigation for future research.

## Worries About Learning and Their Relation to Learning

### *Math Anxiety*

We found that math learning anxiety, but not worries about pandemic learning, negatively predicted learning from the lesson as measured during instruction and at a posttest 3 days later. Of note is the relation between the learning construct of math anxiety and students' actual learning outcomes, which has not received much attention as compared to the evaluative component of math anxiety but has been shown to be a more robust predictor of math achievement (Barroso et al., 2021). Mapping onto the broader math anxiety and related literatures, we showed that math learning anxiety was related to students' immediate performance and retention (Barroso et al., 2021; Caviola et al., 2022; Vukovic et al., 2013), engagement (Martin et al., 2012), worry during learning (Trezise & Reeve, 2014), situational interest (Lyons et al., 2017), perceived competence (Goetz et al., 2013), and task-directed attention (Brunyé et al., 2013; Mrazek et al., 2013; Pizzie & Kraemer, 2017; see also Ashcraft & Kirk, 2001) in theoretically predicted ways.

We chose this measure of math learning anxiety as it measures relatively stable and context-independent individual differences in trait math anxiety (see Carey et al., 2017). To ensure that students' math anxiety would not be influenced by how much they recalled from instruction, we measured their math anxiety on Day 2, before the posttest but after worked examples were manipulated. Though our randomization checks showed no differences between conditions in their reported math anxiety, we acknowledge that it is still possible that students' feelings of math anxiety may have been affected by seeing worked examples.

### *Pandemic-Related Worries*

Though a comparably smaller corpus of research, recent work has also found pandemic-related decreases in children's engagement and motivation toward math instructional content (Rutherford et al., 2022) and increased distraction (Hoyt et al., 2020; Kalogeropoulos et al., 2021; see also Boals & Banks, 2020; Mesghina et al., 2021). We specifically measured students' worries about how the pandemic-induced changes influenced their own learning experiences. We chose to focus on worries related to learning for two reasons: first, to align with our focus on math learning and math learning anxiety, and second, to narrow in on the precise mechanisms explaining the impacts of the pandemic on children's mathematics achievement gaps, which are evident (Bailey et al., 2021), yet remain unexplained (though see Mesghina et al., 2021 for evidence with adults). This is an important step toward designing targeted interventions to improve mathematics achievement during the ongoing public health crisis or other drastic shifts in learning contexts.

COVID-19 learning worries did not predict students' actual learning from the lesson. Still, it consistently predicted state worry, situational interest, perceived understanding, and mind wandering, all of which, in turn, predicted students' learning, suggesting potential indirect effects. Alternatively, it could be the case that even the most worried students in our sample may not have been excessively worried about the pandemic: On average, students' scores corresponded to selecting *Rarely* for each item on the COVID-19 worries scale, and three quarters of students had a score below the midpoint of the summed items. Moderate levels of anxiety in math performance domains have been shown to be most optimal for learning (e.g., Keeley et al., 2008; see also Sapolsky, 2015), where moderately anxious students can still possess high math motivation (e.g., Wang et al., 2015, 2018) and put forth increased effort (see Eysenck et al., 2007), despite increased worries. Thus, perhaps students on average possessed an amount of worry about pandemic learning that was optimal for learning, particularly throughout the novel, highly conceptual lesson and test that spanned 2 days. Nonetheless, we note that we are limited in the generalizability of this scale, particularly in terms of understanding the effects of the pandemic on student well-being more generally.

### Practical Implications

Based on these data, interventions that aim to improve student achievement via instructional changes, like worked examples, are highly recommended, whether they be designed to alleviate the impacts of math anxiety (Hembree, 1990), maintain student attention (Szpunar, 2017), or mitigate the long-term impacts of pandemic school closures (Kaffenberger, 2021). Importantly, our worked examples intervention was quite minimal: Students were provided with screenshots of the teacher's solution strategy from the lesson only two times during key problem-solving opportunities. For implementation purposes, this manipulation poses little if any additional burden or preparation on behalf of the teacher. Again, the ultimate higher-order relation in the lesson was not explicitly supported with these worked examples: That the effects of this small intervention extended to differences in attention, interest, and procedural and conceptual understanding for the more math anxious students 3 days later is remarkable. Worked examples may be particularly instrumental in the teaching of ratio, which has been a difficult concept for students to learn (Harel & Confrey, 1994) and for instructors to teach (Sowder, 2007), yet is foundational to future math learning (Common Core State Standards in Mathematics, 2010).

Another strength of this study is the design and remote administration of the lesson: The video can be spliced so as to maintain student attention and affords opportunities for interactivity and self-explanation despite being completed individually. Students on average showed considerable learning gains after instruction, regardless of condition and despite this being their formal introduction to ratio. The merits of this type of experimental design have been discussed previously (Begolli & Richland, 2017) and may have greater utility during the COVID-19 pandemic given the ease in which the high-quality lesson can be remotely administered and independently completed. Moreover, recorded, interactive, and scaffolded instruction of this type may circumvent sociocultural obstacles to remote learning—for instance, upper-class parents' capacity to monitor and elaborate on their children's instruction—that can persist even with equal access to requisite technologies (Goudeau et al., 2021).

## Conclusion

We examined whether reviewing worked examples during instruction could mitigate the negative effects of students' worries about learning on their engagement and learning from a high-quality, conceptually demanding math lesson on ratio. We specifically focused on two types of worries - math learning anxiety and their worries about pandemic-related impacts on learning. We found that both types of worries predicted fifth-grade students' affective and cognitive engagement during instruction and testing, but only math anxiety predicted their learning from the lesson. Critically, reviewing worked examples during instruction mitigated the negative impacts of math anxiety on students' procedural and conceptual understanding, as well as their situational interest in the lesson and their mind wandering during testing. Our work suggests that the use of worked examples during remote and in-person instruction is a low-cost, easy-to-administer pedagogical intervention with the potential to promote at-risk students' attention, interest, and learning in difficult math contexts.

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