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# Watch Those Studs! How Prior Domain Knowledge and Extraneous Details on LEGO® Bricks Influence Children's Fraction Division

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**Abstract:** The primary aim of the present study was to examine whether extraneous details on LEGO® bricks prompted inappropriate counting strategies and impacted performance accuracy when solving fraction division problems. The secondary aim was to investigate whether prior domain knowledge of fractions concepts influenced the extent to which the extraneous details on the bricks affected children's problem-solving performance. Thirty-eight fifth- and sixth-grade students ($N$ = 38) participated in the study. A fractions test was used to classify students into low ($n$ = 19) and high prior knowledge ($n$ = 19) groups. Then, all participants watched an instructional lesson that showed them how to represent fractions with LEGO bricks and how to solve fraction division problems using measurement division with the bricks. The participants then completed a learning task and a second task designed to assess whether extraneous details on LEGO bricks influenced their problem-solving performance. The results revealed that the extraneous details on LEGO bricks prompted some students to use inappropriate counting strategies, but prior knowledge did not explain the attention to extraneous details. In contrast, prior knowledge accounted for the variance in performance accuracy and the types of errors committed. Specifically, children with low prior knowledge made more errors choosing the correct bricks to represent the dividend fractions, which resulted in a larger number of inaccurate solutions compared to children with high prior knowledge.

**Keywords:** Extraneous details; Fraction division; Prior domain knowledge; Visual representations.
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## Introduction

There are hundreds of online videos (e.g., Kidspot, 2016; TheDadLab, 2019; TheDadLab, 2020; We Are Teachers, 2018) and mathematics lessons (e.g., Brick Math Series, 2024) targeted to teachers and parents on how to use LEGO® bricks to teach mathematics. Specifically, the lessons demonstrate various ways to use LEGO bricks as manipulatives to teach a variety of mathematics concepts, such as arithmetic, fractions concepts, and measurement. Although these videos and lessons make it seem like LEGO bricks are effective for teaching mathematics concepts, there is a dearth of empirical research investigating the impact of using LEGO bricks as visual representations on children's mathematics learning.

In recent years, research on using LEGO bricks in mathematics and science education has revealed benefits for children's spatial skills (McDougal et al., 2023; McDougal et al., 2024), mathematics achievement (Simoncini et al., 2020), and computational thinking (Chalmers, 2018; Leonard et al., 2016). Fewer researchers have investigated the effects on children's learning of using LEGO bricks as visual representations of mathematical concepts. The present study aimed to fill this gap. We examined the use of LEGO bricks as visual representations of quantities in the context of fraction division. In particular, we investigated the extent to which children are derailed by the perceptual features of images of LEGO bricks–in particular, the studs, or the cylindrical bumps on the bricks that serve to connect the physical objects–when solving fraction division problems. Gaining a better understanding of how the perceptual features of LEGO bricks may influence children's mathematics learning has important implications for teachers should they choose to include LEGO bricks in their mathematics instruction.

### Extraneous Details in Visual Representations

Visual representations are frequently used in mathematics instruction (Bolden et al., 2015) because they can support students in making sense of mathematical concepts (Rau, 2017; Schoenherr & Schukajlow, 2024), including those that can be used to solve fraction division problems. A useful way to think about fraction division is by applying measurement concepts: determining how many times a divisor fits into the dividend (Barnett-Clarke et al., 2011; Gregg & Gregg, 2007). In this division context, the divisor is reinterpreted as a unit of measure to determine the size of the dividend. In elementary mathematics instruction, however, fraction division is often taught using the “flip and multiply” algorithm, which hides the underlying division structure (Olanoff et al., 2014). Consequently, researchers have suggested that visual representations (e.g., bar diagrams) can help make the structure of measurement division more apparent (Barnett-Clarke et al., 2011). Physical LEGO bricks, as well as images of bricks, can be used to illustrate the structure of measurement division with fractions (TheDadLab, 2019). They can be used to represent the whole, the dividend fraction, and the divisor fraction in a fraction division problem. Using measurement division, the process involves determining how many times a divisor brick can be stacked onto the dividend brick to find the solution.

Visual representations used in mathematics and science teaching often include details that are not related to the to-be-learned concept (Kaminski & Sloutsky, 2020; Menendez et al., 2020). Such perceptual details have been called “extraneous” (Kaminski & Sloutsky, 2013) and can hinder children’s learning and transfer. In one study, Menendez and colleagues (2020) delivered a science lesson on metamorphosis to undergraduates. One condition received a lesson with bland diagrams (e.g., an outline of a ladybug without spots), while the other condition was exposed to diagrams with extraneous details (e.g., a ladybug with spots). The authors found that participants who viewed bland diagrams were more successful on a transfer task than those who received the same lesson with diagrams that had extraneous details. Because the participants likely did not focus on the information in the diagrams that would support their understanding of metamorphosis, the authors speculated that the extraneous details in the diagrams may have drawn students’ attention away from the target concepts.

Kaminski and Sloutsky (2020) examined the effects of perceptual features in visual representations on children’s fraction-labeling performance. Children were randomly assigned to one of two groups: In one group, children were asked to write a fraction symbol that described the proportion of a generic grey circle, while the other group was asked to write a fraction for a portion of a pizza with extraneous details (e.g., pepperonis, mushrooms). The results showed that children were more likely to write correct fractions when shown portions of generic circles compared to slices of pizza. Additionally, children who were exposed to pizzas with extraneous details tended to focus only on the number of slices present (i.e., the numerator), suggesting that they emphasized counting the slices rather than thinking relationally about fractional quantities.

Other researchers have observed that when extraneous details are in the form of discrete objects, young children tend to count them, even though counting may be unrelated to the solution. Fitzpatrick and Hallett (2019) reported that children are more likely to adopt inappropriate counting strategies when stimuli contain discrete objects than when stimuli represent continuous quantities. Kaminski and Sloutsky (2013), for instance, examined the role of extraneous information in reading bar graphs among kindergarteners, first graders, and second graders. One condition was exposed to graphs with black and grey bars, while the other condition was exposed to graphs with extraneous details in the bars (e.g., flowers, shoes). The results showed that the younger children counted the number of extraneous details when reading the bar graphs instead of correctly using the y-axis to determine the quantities, suggesting that when extraneous details are discrete elements, children may be prompted to count them. Indeed, some have speculated that young children rely on counting strategies because of their prior experiences counting collections in school and at home (Mix et al., 1999).

In another study, Jeong and colleagues (2007) compared the impact of visual representations that showed either discrete or continuous quantities on the proportional reasoning of children aged 6 to 10 years. All children were presented with two circular spinners with blue and red regions that represented different proportions of the whole spinner. The children were asked to select the spinner that had a higher probability of landing on a red region. In the continuous condition, children were presented with circular spinners that contained continuous (i.e., undivided) red and blue regions. In the discrete condition, children were presented with spinners with the same red and blue regions, but each region was divided into equal discrete partitions that, if counted, would result in incorrect responses. Results revealed that all children performed better when the spinners involved continuous quantities than discrete quantities. The findings also revealed that 8-year-old children were more likely to inappropriately count the discrete partitions compared to the 10-year-old children, suggesting that age may play a role in children's attention to extraneous details. Similarly, Boyer and colleagues (2008) found that children struggled to reason proportionally when diagrams contained discrete quantities because they relied on counting them rather than attending to the ratios needed for solution. Together, these studies suggest that when extraneous details come in the form of discrete quantities, children are prompted to count them even if they are not related to the target mathematical concepts.

**Prior Domain Knowledge**

Prior domain knowledge has been characterized as previously learned information that is related to key principles in a domain (Brod, 2021; Simonsmeier et al., 2022). Learners' prior knowledge of key concepts can influence the extent to which they attend to extraneous details when solving problems by enabling them to prioritize relevant information when interpreting visual representations (Chi et al., 1981; Cook, 2006). In a review of research in science education, Cook (2006) found that learners pay attention to relevant information in visual representations more effectively when they possess sufficient domain knowledge, which allows them to identify and interpret the underlying conceptual structure (Chi et al., 1981; Larkin, 1983).

There also exists empirical support for the benefits of prior knowledge in interpreting visual representations when solving mathematics problems. Magner and colleagues (2014), for example, investigated the relationship between secondary students' prior knowledge of angles and their problem-solving performance following a geometry lesson.

The lesson either included extraneous information, such as an image of a person riding a bicycle or had no extraneous information. The authors found that students with low prior domain knowledge performed significantly worse on a near transfer task when they were exposed to extraneous information compared to students with high prior domain knowledge. In another study, Cooper and colleagues (2018) examined the role of participants' standardized mathematics test scores in their performance on trigonometry problems. The problems were accompanied by visual representations that contained relevant diagrams and accompanying illustrations with either extraneous real-world information or no extraneous details. The results revealed that students with low prior knowledge were less accurate on problems with illustrations that contained extraneous information than students with high prior knowledge. The authors speculated that children with lower prior knowledge may have had difficulty recognizing the relevant mathematical information in the representations because they were overwhelmed by the extraneous details and could not rely on their prior knowledge to ignore them.

In sum, the research reviewed above focused on the relation between prior knowledge and the presence or absence of images that as a whole were irrelevant to the mathematical task (e.g., images of helicopters and bicycles). Fewer studies have investigated how prior knowledge influences learners' responses to the *specific details* in the images. Further, researchers have reported developmental trends in children's tendency to apply inappropriate counting strategies when the extraneous details are discrete and countable, with younger children being more likely to count than older children (Boyer et al., 2008; Jeong et al., 2007; Kaminski & Sloutsky, 2013). There is an apparent gap in the literature, however, on whether prior knowledge plays a role in such counting strategies. To the extent that age effects can be explained by an accumulation of domain-specific knowledge as children progress through school, we hypothesize that prior knowledge influences the way children interact with extraneous details. Specifically, we aimed to examine whether prior knowledge plays a role in children's counting of the studs on LEGO bricks when studs are irrelevant to solving fraction division problems.

## Present Study

The current study had two overarching objectives. The first was to examine the extent to which children use inappropriate counting strategies when solving fraction division problems with LEGO bricks that contained extraneous details. The second objective was to investigate whether prior knowledge of fractions concepts played a role in children's use of inappropriate counting strategies and performance accuracy when solving fraction division problems with LEGO bricks.

The study was conducted with fifth- and sixth-grade students in a single session using an online conferencing platform. All participants received online instruction on how to represent fractions presented symbolically using images of LEGO bricks and how to use LEGO bricks to solve fraction division problems using a measurement division procedure. The bricks used during the instruction did not contain any extraneous details–that is, there were no superfluous studs on any of the LEGO bricks. After the instruction, the participants first completed a task using the same bricks as those used in the instruction to assess their learning of the measurement division procedure. Then, they completed a second task that was designed to test whether superfluous studs on the bricks that were not needed for the solution (i.e., the additional studs were extraneous) would prompt the participants to use inappropriate counting strategies to solve a series of fraction division problems. Using a test of fractions concepts, we placed the participants into low and high prior knowledge groups and examined group differences on the frequency of inappropriate counting strategies and accuracy. We addressed the following research questions:

1. To what extent do extraneous details (i.e., extra studs) on images of LEGO bricks prompt children to use inappropriate counting strategies (Research question 1A)? Is there a relation between prior fractions knowledge and the use of inappropriate counting strategies when extraneous details are present on the bricks (Research question 1B)?
2. Is children's accuracy on fractions division problems lower when LEGO bricks contain extraneous details than when they do not (Research question 2A)? Does prior fractions knowledge moderate the effect of extraneous details on problem-solving accuracy (Research question 2B)?

Finally, an exploratory error analysis was conducted to better understand how extraneous details on LEGO bricks and children's prior fractions knowledge impacted performance on the fraction division problems.

## Method

### Participants

The participants were 39 fifth- and sixth-grade students from one French-speaking private suburban school in eastern Canada. One participant was excluded from the sample because the parent indicated that the child was diagnosed with a mathematics learning disability, attention deficit disorder, and a learning disorder in reading or spelling. For the sake of inclusion, the child was tested, but the data were not included in the analyses. Therefore, the final sample included 38 fifth- ($n$ = 18) and sixth- ($n$ = 20) grade students ($M_{age}$ = 11.6 years, $SD_{\text{age}}$ = .59) from two fifth-grade classrooms and two sixth-grade classrooms.

### Design

A two-group design (i.e., low prior knowledge, high prior knowledge) was used to assess the relation between prior knowledge and participants' problem-solving performance. Once the participants completed the test of fractions knowledge, all participants received the same instruction on the procedure for solving fraction division problems with LEGO bricks. After the instruction, the participants completed two tasks: a task designed to assess their learning of the measurement division procedure when solving fraction division problems with LEGO bricks and a task designed to assess whether the studs on the divisor bricks prompted an inappropriate counting strategy to solve the problems. Two outcome measures were used to assess participants' performance: (a) the proportion of inappropriate counting strategies used, and (b) accuracy.

### Instruction

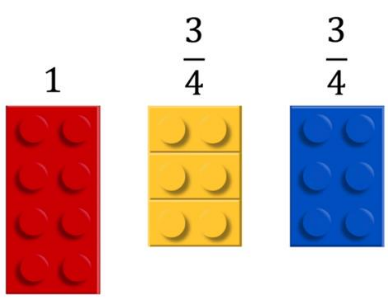
The instruction was delivered individually to all participants using a pre-recorded video and consisted of two phases. Phase 1 included a lesson that illustrated how to represent fractions using LEGO bricks, and Phase 2 featured a lesson on how to use the bricks to solve fraction division problems using measurement division.

#### *Phase 1: Introduction to Fractions*

The instruction began with a lesson that demonstrated how to represent fractions with images of LEGO bricks. Figure 1 shows an example of how fractions were represented with the bricks. Two different bricks were used to represent the whole or “1.” A 2 × 4 brick was used to represent the whole to show how to represent five fractions (1/2, 1/4, 1/8, 2/4, and 3/4), and a 2 × 6 brick was used to represent the whole to show how to represent four fractions (1/2, 1/3, 1/12, 2/3). In each case, the whole brick was positioned on the left side of the screen, marked with a “1” to indicate its value. The target brick then appeared on the whole brick, and through animation, it was placed on the whole brick as many times as possible to show what fraction of the whole the target brick represented. Next, the target brick was placed to the right of the whole and the fraction in symbolic form would appear on top of it. Additional brick configurations were always used to show that various types and combinations of bricks could represent the same fraction. As shown in Figure 1, three yellow 1 × 2 bricks together represented 3/4 of the whole, while one blue 2 × 3 brick represented the same fraction.

**Figure 1**

*Sample Fractions from the Introduction to Fractions Lesson*



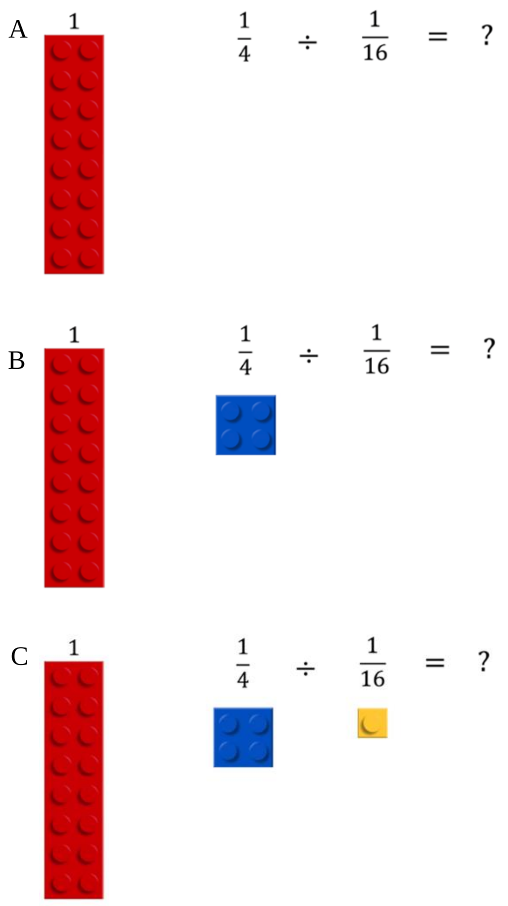

#### *Phase 2: Fraction Division*

Phase 2 consisted of a short lesson that demonstrated how to use LEGO bricks to solve fraction division problems where both the dividend and divisor were fractions. The lesson illustrated how to solve three fraction division problems (1/4 ÷ 1/16 =, 5/6 ÷ 1/12 =, and 3/4 ÷ 1/8 =) using three different bricks (2 × 8, 2 × 6, and 2 × 4, respectively) as the whole. Through video animation, the narrator placed the divisor bricks onto the dividend bricks and then pointed to each divisor brick to find the solution. All demonstrations in the instructional video involved a one-stud divisor to solve the problems, but in general cases with divisors represented by bricks with more than one stud, the solution would require counting the number of bricks and not the number of studs.

The video began with a fraction division problem (i.e., 1/4 ÷ 1/16 =) appearing at the top of the screen, after which a brick (i.e., 2 × 8) representing the whole appeared on the left side of the screen (see Figure 2, Panel A). Using the whole brick as the referent, a brick representing the dividend fraction appeared on top of the whole brick. Through animation, the single dividend brick moved onto the whole brick four times, showing that it covers a quarter of the whole one at a time. The target brick then moved under "1/4" in the problem (see Figure 2, Panel B). Next, a 1 × 1 brick (i.e., a brick with one stud) representing the divisor appeared on the whole brick. It moved onto the whole brick 16 times to show that it represents 1/16 of the whole, after which the target divisor brick slid under "1/16" in the problem (see Figure 2, Panel C).

**Figure 2**

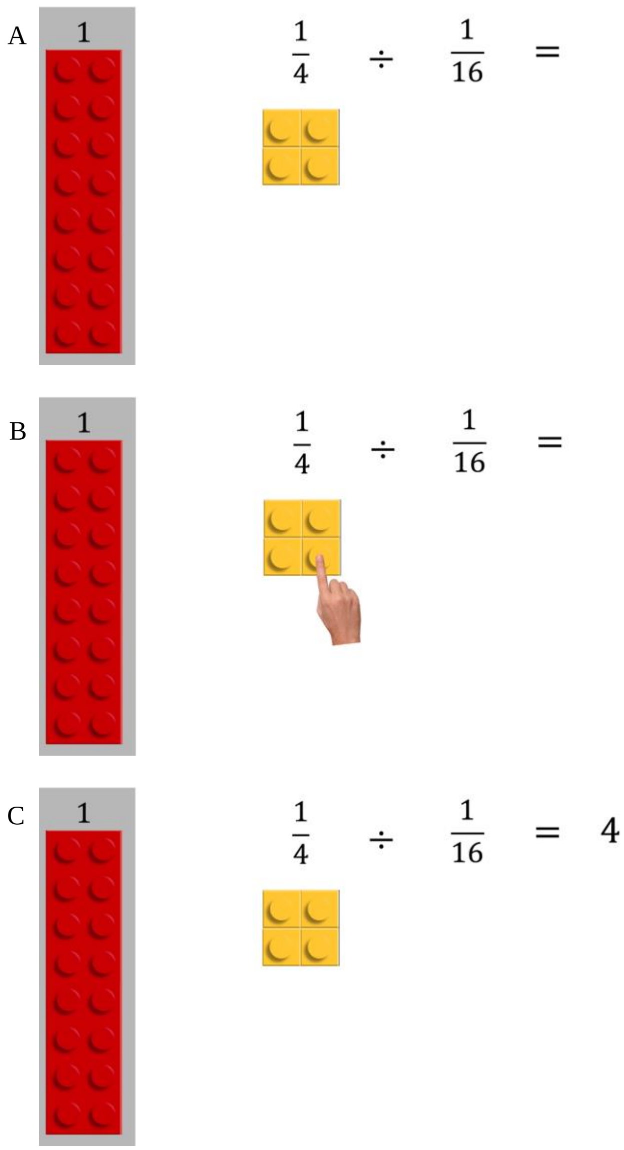
*Sample Fraction Division Problem from the Fraction Division Lesson*




At this point in the lesson, a demonstration began to show how to solve the fraction division problem using the LEGO bricks. The narrator explained the steps involved in measurement division: "We need to find how many one-sixteenths are in one-quarter." Next, the 1 × 1 divisor brick moved onto the dividend brick, followed by three additional 1 × 1 bricks appearing on the dividend brick (see Figure 3, Panel A). Next, the narrator reminded the participants that they needed to find how many 1/16s are in 1/4, which was followed by a finger that pointed to each 1 × 1 brick on the dividend brick (see Figure 3, Panel B). When all bricks were pointed out, the answer (i.e., “4”) appeared next to the equal sign to complete the equation (see Figure 3, Panel C).

**Figure 3**

*Using Measurement Division to a Solve Fraction Division Problem from the Fraction Division Lesson*




Following the demonstration of the procedure for solving the fraction division problem, the video showed how to solve two more problems (5/6 ÷ 1/12 = and 3/4 ÷ 1/8 =) using the same procedure. All three problems used a 1 × 1 divisor brick.

## Measures

### *Fractions Test*

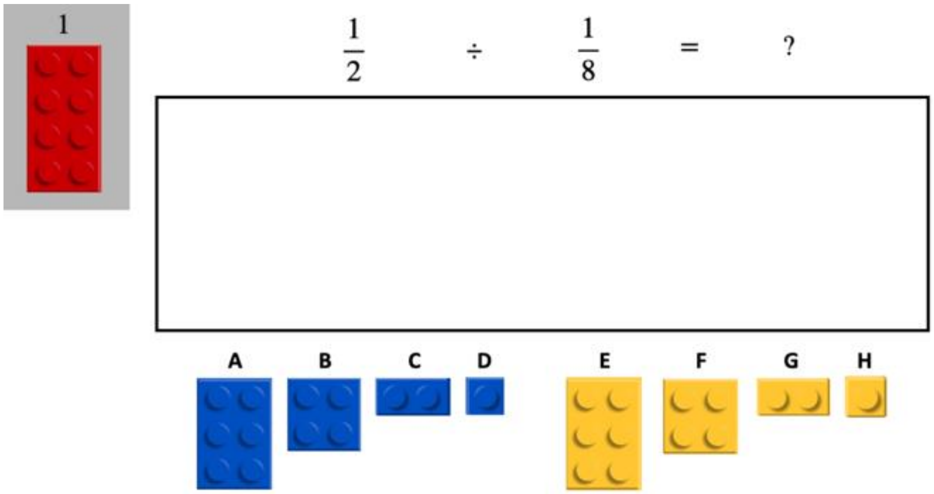
The Fractions test was a paper-and-pencil test based on Saxe et al. (2001) that assessed conceptual and procedural knowledge of fractions. For the purposes of the present study, only the conceptual subscale was used. The test consisted of eight items: (a) three items that required writing a fraction that corresponded to a shaded amount in an area model; (b) two estimation items that required circling a fraction from a choice of three that best represented the unpartitioned shaded region in a circle; (c) two fair-sharing items, requiring partitioning area models evenly among a given number of people; and (d) one item that required drawings to compute 2/5 + 3/5. The fractions score was the proportion of correct responses, with a minimum score of 0 and a maximum score of 1.

### *Learning Task*

The Learning task consisted of five items and was designed to assess children's learning of the measurement division procedure when solving fraction division problems with LEGO bricks. On each of the five items, the participants directed the researcher to select specific bricks from among those at the bottom of the screen by naming the letters assigned to each brick (see Figure 4) and to move them around in ways that would lead to a solution.

**Figure 4**

*Sample Item on the Learning Task*




The five fraction division problems were: 2/3 ÷ 1/12 =, 1/2 ÷ 1/16 =, 1/2 ÷ 1/8 =, 1/6 ÷ 1/12 =, and 3/4 ÷ 1/16 =. All five items required using a one-stud divisor to solve the problems. If any of the participants showed signs that they did not remember how to use the measurement division procedure with the bricks to solve the problems (e.g., did not say anything, said they do not know what to do), the researcher repeated explanations from the Fraction Division lesson: "Remember, we need to find how many one-eighths are in one-half." Reminders stopped once the participants were able to successfully use the procedure on one of the five items on their own, with no help from the researcher. No corrective feedback was provided. The accuracy score was the proportion of correct responses, with a minimum score of 0 and a maximum score of 1.

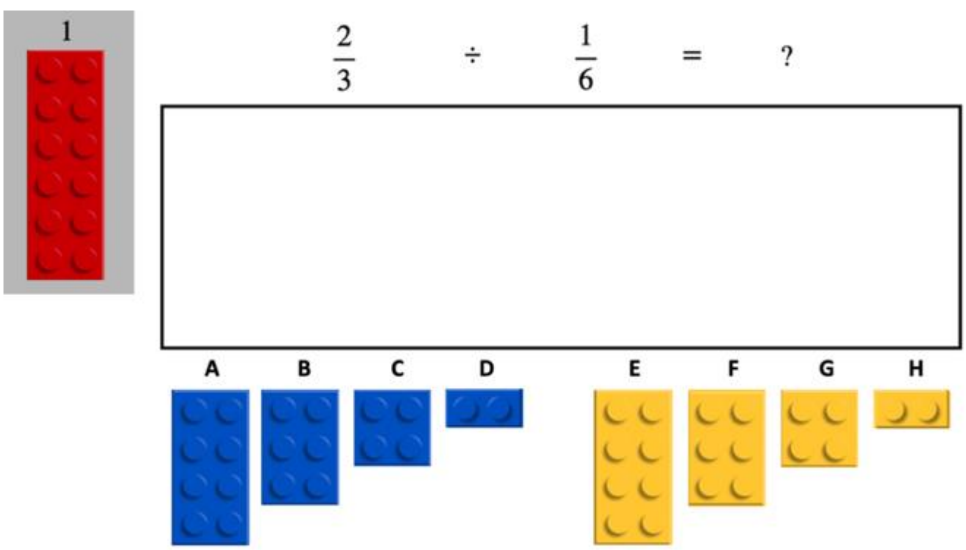
***Extraneous Details Task***

The Extraneous Details task consisted of five items and was designed to detect whether participants used an inappropriate counting strategy when using the divisor bricks to solve the problems. The five fraction division problems were: 2/3 ÷ 1/6 =, 3/4 ÷ 1/8 =, 1/2 ÷ 1/4 =, 1/2 ÷ 1/6 =, and 1/4 ÷ 1/8 =. The items on the Extraneous Details task were presented in the same way as those on the Learning task: On each of the five items, the participants directed the researcher to select specific bricks from among those at the bottom of the screen and to move them around in ways that would lead to a solution. No reminders or corrective feedback was provided.

In contrast to the Learning task, which always involved one-stud divisors, all five items on the Extraneous Details task involved divisor bricks with two studs. Counting studs would be considered an inappropriate strategy because it would show that the children were attending to extraneous details (i.e., the studs) that were irrelevant to the solution. Counting the bricks, in contrast, would indicate a conceptual understanding of the unit required to solve the fraction division problems. As such, the bricks at the bottom of the screen did not offer the choice of a one-stud brick to solve the problems (see Figure 5).

**Figure 5**

*Sample Item on the Extraneous Details Task*




The participants' performance on the Extraneous Details task was assessed using two outcome measures: (a) the extraneous score, which was the proportion of items on the task on which an inappropriate counting strategy was used, and (b) the accuracy score, which was the proportion of correct responses, with a minimum score of 0 and a maximum score of 1.

### Procedure

All parents gave consent for their child to participate and completed a demographic questionnaire about their child. Parents were asked to contact the first author to schedule a time for the online session. At most two weeks before the online session took place, the first author delivered envelopes to the participants' school. The envelopes were labeled with a sticker that read, "Do not open until the day of the [online] meeting," and they contained the paper-and-pencil Fractions test, a pencil and eraser, and a return stamped envelope. The staff in the front office delivered the envelopes to the participants. The online meetings were conducted by the first author and were recorded using the software's recording feature. The researcher's screen was always shared with the participant to facilitate the administration of the instruction and measures. Each session began by obtaining assent from the participant, which was followed by the administration of the Fractions test.

After the Fractions test was completed, the researcher began the instruction, which was presented via Keynote® using a laptop that ran on MacOS. After the instruction, the Learning task and the Extraneous Details task were conducted by sharing Keynote slides. During the administration of each task, the researcher read the symbolic equation out loud to the participant and manipulated the bricks on the screen, as directed by the participant. The participant was asked to provide an answer to the problem before moving on to the next problem and all responses were recorded on a scoring sheet.

The researcher read each item out loud to the participant and provided graduated prompts ranging from general encouragement to restating the instructions, if needed. The researcher asked the participant to indicate when they had completed each item before proceeding to the next. If participants asked questions related to content, the researcher restated the instructions and told them to try their best. If they still did not know how to answer a question, the researcher encouraged them to move on to the next item. Once the meeting ended, the researcher sent the parents an email of thanks and a participation certificate with their child's name on it. The parents could either return the Fractions test booklet by mail (with the return stamped envelope that was provided) or return it to the child's teacher.

## Results

In the first part of this section, we report the proportion of items on the Extraneous Details task on which an inappropriate counting strategy was used (i.e., counting the studs on the divisor brick instead of counting the entire brick) and whether prior domain knowledge was related to this measure. In the second part, we report whether accuracy was lower on the Extraneous Details task than on the Learning task. We also examined whether prior domain knowledge influenced the extent to which the extraneous studs affected their problem-solving accuracy.

Lastly, we report an exploratory analysis of the errors children made when solving fraction division problems using LEGO bricks on the Learning and Extraneous Details tasks to gain a deeper understanding of how prior domain knowledge was related to their problem-solving performance.

## Grade Effects

A median split on the Fractions test was used to classify participants into low ($n = 19$) and high prior knowledge ($n = 19$) groups. An independent samples *t*-test indicated a significant difference in Fractions test scores between grade levels, $t(36) = -3.79$, $p = .001$. Sixth graders' scores were higher ($M = .73$, $SD = .16$) than fifth graders' ($M = .50$, $SD = .20$). Fourteen fifth-grade participants (77.8%) and five sixth-grade participants (25.0%) were placed in the low prior knowledge group, and four fifth-grade participants (22.2%) and 15 sixth-grade participants (75.0%) were placed in the high prior knowledge group. The participants in the fifth grade used inappropriate counting strategies on the Extraneous Details task to the same extent as the participants in the sixth grade (fifth grade: $M = .89$, $SD = .29$; sixth-grade $M = .89$, $SD = .31$). A 2(grade: Grade 5, Grade 6) × 2(task: Learning, Extraneous Details) mixed ANOVA using accuracy as the dependent variable revealed no main effect of grade (fifth grade, $M = .75$, $SD = .05$; sixth grade, $M = .83$, $SD = .05$) nor a grade by task interaction, all $ps > .05$. These results minimize confounding effects of grade in the analyses that follow.

## Research Question 1: Inappropriate Counting Strategies

On the Extraneous Details task, participants across both prior knowledge groups counted the studs on 12% of the items, on average. Thirty-one participants (81.6% of the sample) never counted the studs on any of the items–instead, they counted the bricks, which was the correct procedure for solving the fraction division problems. In addition, three participants (7.9%) counted the studs once across all five items, one participant (2.6%) counted the studs four times, and three participants (7.9%) counted the studs on all five items. In total, 7 of the 38 participants (18.4% of the sample) counted the studs on the LEGO bricks at least once, suggesting that the extraneous studs prompted them to use an inappropriate counting strategy on the task. Finally, prior knowledge did not have an effect on the extent to which the participants used inappropriate counting strategies: Those with low prior knowledge counted the studs instead of the bricks to the same extent as those with high prior knowledge (low prior knowledge: $M = .88$, $SD = .31$; high prior knowledge: $M = .88$, $SD = .29$).

## Research Question 2: Accuracy

Table 1 shows the means and the standard deviations of the accuracy scores on the Learning and Extraneous Details tasks as a function of prior knowledge.

**Table 1**

*Means and Standard Deviations of Accuracy Scores on the Learning and Extraneous Details Tasks by Prior Knowledge Group*

| Measure | **Learning** | | | **Extraneous Details** | | |
|---|---|---|---|---|---|---|
| | *n* | *M* | *SD* | *n* | *M* | *SD* |
| Low prior knowledge | 19 | .67 | .25 | 19 | .74 | .31 |
| High prior knowledge | 19 | .90 | .14 | 19 | .84 | .29 |

A 2(prior knowledge: low, high) × 2(task: Learning, Extraneous Details) mixed ANOVA was conducted, with prior knowledge as the between-groups factor, task as the within-groups factor, and accuracy as the dependent variable. The analysis revealed a significant main effect of prior knowledge, $F(1, 36) = 5.53$, $p = .02$, with participants in the high prior knowledge group ($M = .87$, $SD = .20$) outperforming those in the low prior knowledge group ($M = .71$, $SD = .23$). No main effect of task type or interaction between prior knowledge and task type was observed. These findings suggest that participants with high prior domain knowledge in fractions concepts produced more accurate solutions compared to participants with low prior domain knowledge, regardless of whether extraneous details were present.

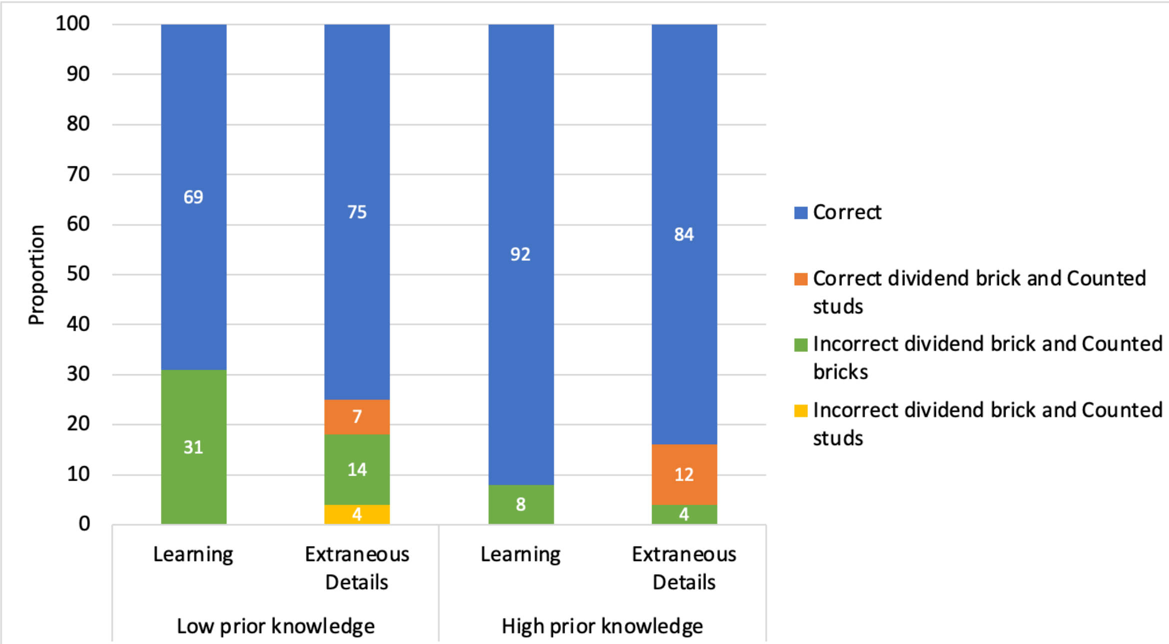
**Error Analysis**

The online recordings were used to document the errors participants made when they solved the fraction division problems on the Learning and Extraneous Details tasks. Although over 80% of the participants counted the bricks instead of the studs to solve the problems, their answers were not always accurate. To better understand how prior knowledge accounted for the variance in accuracy, we conducted a descriptive analysis of their errors on each task within the low and high prior knowledge groups.

On the Learning task, a single error type was observed: selecting an incorrect brick to represent the dividend fraction in the problem. On the Extraneous Details task, three types of errors were identified: (a) selecting the incorrect dividend brick and counting the bricks as divisor, (b) selecting the correct dividend brick and counting the studs on the divisor, and (c) selecting the incorrect dividend brick and counting the studs. The proportion of each error type produced on the Learning and Extraneous Details tasks are presented in Figure 6 by prior knowledge group, using item as the unit of analysis. Proportions were calculated by dividing the frequency of each error type by the total number of items on each task (i.e., 95 items on the Learning task and 95 items on the Extraneous Details task) within each prior knowledge group.

**Figure 6**

*Proportion of Error Types on the Learning and Extraneous Details Tasks by Prior Knowledge Group (N = 190)*




In line with the statistical analyses on accuracy, the correct procedure was used 87.9% of the time in the high prior knowledge group across both tasks compared to 72.1% of the time in the low prior knowledge group. The errors produced within the Learning and Extraneous Details tasks revealed potential explanations for the prior knowledge effects. On the Learning task, a greater proportion of errors that entailed choosing the incorrect dividend brick was revealed in the low prior knowledge group (i.e., 30.5%) compared to the high knowledge group, where this error was produced in only 8.4% of all responses. Error rates on the Extraneous Details task revealed a similar pattern: The incorrect dividend brick was chosen on 17.9% of all items in the low prior knowledge group regardless of whether they counted the bricks or the studs, whereas the same error was chosen only 4.2% of the time in the high prior knowledge group. Across both tasks, the incorrect dividend brick was selected on 22.1% of all 190 items in the low prior knowledge group, whereas the same error was found 6.3% of the time in the high prior knowledge group.

Recall that counting the studs was not possible on the Learning task because there were no extraneous studs to count. On the Extraneous Details task, however, the proportion of responses that entailed counting the extraneous studs was the same in both knowledge groups (11.6%). These findings are in line with the statistical analyses showing no effect of prior knowledge on the extent to which the participants were prompted to count the extraneous studs.

## Discussion

Teachers often use visual representations because they can illustrate abstract mathematical concepts and principles that appear in the curriculum. The conceptual underpinnings of fraction division are an example of how visual representations can show how the standard flip-and-multiply algorithm works. Several representations have been recommended to teachers (e.g., Barnett-Clarke et al., 2011; Reys et al., 2015) to explain how to solve fraction division problems, including at least one using LEGO bricks (e.g., TheDadLab, 2019). Although using LEGO bricks in the mathematics classroom may be appealing to students, not much research evidence exists to show that using the bricks as representations of quantity can support children's mathematics learning.

The overall objective of the current study was to explore how the perceptual features of LEGO bricks–in particular, the studs on the bricks–influence students' learning about fraction division. We first investigated whether extraneous studs on divisor bricks would prompt the students to count them rather than count how many times the entire divisor brick could fit onto the dividend brick. The data revealed that almost a fifth of the sample was prompted to count the studs on at least one problem. Although the observed rate was considerably lower than we had anticipated, we nevertheless argue that future research is needed to test the robustness of this finding.

Contrary to our expectations and the observations reported in previous research (e.g., Magner et al., 2014), prior knowledge did not explain the tendency for some students to count the studs instead of the bricks. This finding must be nuanced, however, by the accuracy data and the error analysis. We expected that the extraneous details on LEGO bricks would impact accuracy on fraction division problems and that prior domain knowledge would moderate the effect. The statistical analyses revealed that, although performance across tasks and prior knowledge groups was high, prior knowledge nevertheless explained the variance in accuracy regardless of extraneous details. Aligned with the literature on the impact of prior knowledge in mathematics more generally (Cooper et al., 2018; Magner et al., 2014), the students with higher fractions knowledge produced fewer errors on average across all fraction division problems, whether or not they contained extraneous details. The error analysis revealed that when accuracy was compromised for the students with lower prior knowledge, this occurred primarily because they used the incorrect brick to represent the dividend and less so because they counted the studs. This finding suggests that children with low prior knowledge had difficulties representing fractional quantities with visual representations relative to their high prior-knowledge peers.

We speculate that we may have failed to find a direct link between prior knowledge and students' inappropriate counting strategies because the rate of counting the studs was unexpectedly low in the present study. Nevertheless, we argue that the findings suggest an avenue for future research into whether there may be a mediating effect of the ability to represent fractions with LEGO bricks on the tendency to count irrelevant studs. More specifically, students with low prior knowledge struggled to represent fractional quantities with the bricks more so than students with high prior knowledge, presumably because they chose the wrong dividend more often on the fraction division problems. Difficulty representing fractions with the bricks may, at least in part, account for their lack of attention to the entire brick as the appropriate unit in the measurement division context. Thus, greater conceptual knowledge of fractions may reduce children's tendency to be distracted by extraneous details not directly, but rather through the mediating factor of fraction representation. Despite being only a speculation, possible mediating factors that can help explain the impact of prior knowledge on inappropriate counting strategies are worthy of future investigation.

Prior knowledge may in fact have no effect on students' responses to extraneous details in solving fractions problems with LEGO bricks. In this scenario, an avenue for future research would be to investigate the role of executive function in children's engagement with visual representations. Executive functions, such as inhibitory control and shifting, are cognitive processes that have been found to predict mathematics performance (e.g., Gilmore & Cragg, 2018). Most germane to the present study, our task required students to inhibit the studs on the divisor brick to correctly identify the whole brick as the unit to measure the dividend. It is possible that, in line with previous research (Fuhs & McNeil, 2013; Mix, 2008; Wege et al., 2023), executive functioning may play a role in children's problem solving when using LEGO bricks as visual supports.

**Contributions**

The current study expands existing research on the use of LEGO bricks for mathematics instruction by being the first to directly examine their role as representations of quantities on children's learning. Our findings also contribute to the literature by showing that some students can get distracted by the studs on LEGO bricks when using them as representations of fractional quantities and point to potential drawbacks of using LEGO bricks in fractions lessons. Although our data do not suggest that all activities with LEGO bricks would prompt inappropriate strategies nor that most students would be drawn to counting the studs, the data nevertheless revealed that almost one fifth of the sample were prompted to do so on at least one problem. Replications of this research are clearly needed to determine whether our data reveal a true effect, but a significant contribution is that the finding serves as an existence proof of the phenomenon. Further, showing that inappropriate counting of studs is possible when students use LEGO bricks may suggest that under different conditions or in different mathematical contexts (e.g., proportional reasoning, Jeong et al., 2007), similar counting actions may occur to greater extents.

Finally, our expectation that prior knowledge was related to the accuracy in students' fraction division was supported by the data and contributes to the literature by replicating the prior knowledge effect in the context of problem solving with LEGO bricks. Theoretical accounts of the benefits of prior domain knowledge may suggest that the students' prior fractions knowledge guided their attention to the instructional intervention (Yu et al., 2012) and facilitated the encoding of related concepts, such as measurement division (Brod et al., 2013, van Kesteren et al., 2014). Such attention to and encoding of relevant concepts may have resulted in chunking the new information in ways that made it easier for problem solving (Gobet et al., 2001). Because we have no data to directly support this speculation, further investigation is needed.

### Strengths and Weaknesses

A strength of the present study is the direct assessment of students' mathematics learning with LEGO bricks as representations of quantity, which is, to our knowledge, an unexplored area of research. One weakness of the present study is that, because of COVID restrictions, we designed it so that it could be delivered entirely online. The online delivery of the intervention and data collection procedures limit the conclusions to *visual representations of LEGO bricks* in the teaching of fraction division. Therefore, given that learning appears to be contingent on the actions that are afforded by the materials used (Manches et al., 2010; Pouw et al., 2014), our conclusions cannot be generalized to the use of physical bricks to teach fraction division.

Because of the use of digital images of LEGO bricks in the present study, our conclusions may be vastly different from those generated from a similar study with physical LEGO bricks. Physical and virtual manipulatives differ not only in their perceptual features, but also in the strategies they afford (Martin & Schwartz, 2005; Pouw et al., 2014). For instance, physical manipulatives provide sensorimotor experiences that can help students grasp abstract concepts by turning them into concrete actions (Abrahamson et al., 2020; Martin, 2009; Pouw et al., 2014), shaping how they understand and interpret mathematical concepts (Manches & O'Malley, 2016). Physical manipulatives afford motor-based strategies, such as physically aligning, rotating, or grouping objects, which can foster embodied engagement with mathematical ideas (Pouw et al., 2014). In contrast, virtual manipulatives, such as those similar to the ones used in the present study, have been found to encourage more visually-guided strategies, leading learners to focus more on relevant perceptual cues and visual patterns (Pouw et al., 2014). In our study, attention to relevant perceptual cues in the LEGO representations may have directed the students to identify the correct unit more effectively than had they used physical bricks. In sum, there are important differences in the way learners interact with physical and virtual manipulatives, which can differentially influence the way they process and represent mathematical relationships (Manches & O'Malley, 2016; Martin & Schwartz, 2005; Pouw et al., 2014).

Another limitation is that the online delivery introduced several challenges to the monitoring and control of the data collection environment. Because the study was conducted at a distance, it was difficult to adequately monitor students' progress and the extent to which they followed the instructions on the pencil-and-paper task. Additionally, the remote format made it challenging for us to ensure that all students were paying sufficient attention to the instructional video, which may have compromised the extent to which they understood or absorbed the presented information on fraction division.

### Educational Implications

Understanding how visual representations influence children's mathematical thinking can help educators select instructional materials that best support learning. Although a lower rate than we had expected, our data nevertheless revealed that some students inappropriately counted the studs on the LEGO bricks during fraction division problem solving (see Boyer et al., 2008). If educators choose to use LEGO bricks in fraction division instruction, they may need to provide explicit guidance to their students to ensure that they focus on the entire brick as the relevant unit rather than counting individual studs. In addition, incorporating discussions about how LEGO bricks can represent different fractional quantities could enhance their students' problem-solving performance.

It should be noted that because we did not compare the use of LEGO bricks to other approaches to teaching fraction division, we are unable to recommend or discourage the use of LEGO bricks in the mathematics classroom. Using visual representations to teach fraction division has been suggested by teacher educators (e.g., Barnett-Clarke et al., 2011; Reys et al., 2015). In line with this recommendation, our objective was to use images of LEGO bricks as a possible visual representation that teachers could consider to teach the conceptual foundations of fraction division. When children are introduced to new ideas in mathematics, visual representations can help them connect new concepts to what they already know (Rau, 2017). These connections are especially strong when children possess accurate prior knowledge of the domain (Brod, 2021). For instance, learners who have accurate prior knowledge are more likely to select relevant information and are better able to understand the core elements in visual representations (Cook, 2006). We speculate that the LEGO bricks used by the students in our study to solve fraction division problems generated similar processes. Although we have no direct data to recommend specific teacher practices, attending to students' prior knowledge of fractions when introducing the conceptual underpinnings of fraction division with visual representations may result in improved problem solving.

## Conclusion

The present study explored how the perceptual features of LEGO bricks, particularly the studs on the bricks, can influence children's strategies and accuracy in fraction division. Contrary to our expectations, only a few students attended to the extraneous details in visual representations of divisor quantities. Prior knowledge of fractions concepts was not related to the tendency of these students to engage in inappropriate counting strategies, but it did play an important role in problem-solving accuracy. Students with high prior knowledge made fewer errors regardless of the presence of extraneous studs, perhaps because their knowledge facilitated their understanding of which elements in the representation (i.e., bricks or studs) matched the divisor fraction in the problem. Together, these findings suggest that teachers may be better able to modify their instruction when they are aware of how children interpret visual representations when learning mathematics.

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