Bricks or Studs: Exploring Irrelevant Details When Using LEGO® Bricks as Manipulatives

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Abstract

Bricks or Studs: Exploring Irrelevant Details When Using LEGO® Bricks as Manipulatives

Alison Tellos

The present study examined whether the studs on LEGO® bricks act as irrelevant details when solving fraction division problems and whether prior fractions knowledge played a role in children's distraction and accuracy performance. Thirty-eight fifth- and sixth-grade students participated in the study. Participants were asked to complete a Fractions Test to assess their prior conceptual understanding of fractions. A median split was used to create a low prior knowledge group (n = 19) and a high prior knowledge group (n = 19). An instructional intervention showed students how to create fractions with LEGO® bricks and how to solve fraction division problem using measurement division. The results revealed that the studs did not distract the participants from solving fraction division problems with LEGO® bricks, regardless of prior knowledge. However, prior knowledge effects were found in accuracy performance, with low prior knowledge students generating less accurate solutions compared to high prior knowledge students. Participants also used both correct strategies and a variety of incorrect strategies to solve the fraction division problems. Particularly, children made errors in choosing the correct bricks to represent the dividend fractions, which, in part, resulted in having inaccurate solutions. The present study is relevant to teaching professionals as it provides new information about the ways children use LEGO® bricks to solve fraction division problems.

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Chapter 1: Statement of the Problem

The word "LEGO" is an abbreviation of "leg godt," which in Danish means "play well" (The LEGO® Group, 2020). The LEGO® Group (2020) was founded in 1932, and the now-famous LEGO® brick was launched in 1958. The LEGO® brick was made to offer unlimited building possibilities, and to allow individuals to imagine and create ideas through play. Most LEGO® bricks possess one or more studs (i.e., the circular bumps on each brick), which permit the bricks to be locked onto one another. The LEGO® Group (2020) holds a handful of brand values such as imagination, creativity, fun, and learning. More specifically, they maintain that learning expands thinking and doing, and helps develop new insights and skills. The LEGO® Group (2020) also states that through building, un-building, and rebuilding, individuals can create new things and develop novel ways of thinking.

An informal Internet search revealed hundreds of webpages and videos that show how to integrate LEGO® bricks in mathematics instruction. These webpages and videos are mostly targeted to show teachers and parents how to include LEGO® bricks in mathematics to make learning it fun and interesting. They show various ways to use these bricks to teach specific mathematical concepts, including addition, subtraction, fractions, counting, measurement, and fraction division. While several researchers have explored the effects of LEGO® robotics (e.g., Chalmers, 2018; Coxon et al., 2018; Leonard et al., 2016) and LEGO® play (e.g., Nath & Szücs, 2014; Simoncini et al., 2020; Wolfgang et al., 2003) on mathematics achievement, to my knowledge, there are no empirical investigations on the effectiveness of using LEGO® bricks as manipulatives in mathematics teaching. Research in this area is important because although LEGO® bricks may be used as manipulatives to facilitate learning in the classroom, it is possible that these manipulatives have physical features that may hinder learning (Carbonneau & Marley, 2015; Kaminski & Sloutsky, 2013; McNeil & Jarvin, 2007; McNeil et al., 2009; Petersen & McNeil, 2013; Uttal et al., 2013). Therefore, research examining the effects of LEGO® bricks under different instructional conditions is critical for advances to be made in the use of bricks in mathematics teaching.

Teachers have a great influence on the choice of materials they use in the classroom. Because they have significant control over the lessons and the environments that can direct children's motivation, they may use children's interests to make school content more engaging (Hidi & Renninger, 2006). One such way to capitalize on children's interests is to integrate LEGO® bricks in mathematics instruction to make it more interesting or to grab children's attention because they are colorful and attractive (Carbonneau & Marley, 2015; Kaminski & Sloutsky, 2013; McNeil & Jarvin, 2007; McNeil et al., 2009; Petersen & McNeil, 2013). In addition, teachers may include LEGO® bricks in mathematics lessons because they have physical properties (e.g., color and studs) that they believe will positively impact children's learning strategies (Manches & O'Malley, 2016). Although the multitude of videos and webpages indicate a recent surge in popularity in using LEGO® bricks in mathematics teaching, there may conditions under which the bricks are more effective than others for student learning. In other words, teachers may be using LEGO® bricks in ways that could limit or even harm students' mathematical performance. It is the potentially harmful effects of using LEGO® bricks in mathematics lessons that is driving the current study.

Chapter 2: Literature Review

Despite research on manipulatives and their use in mathematical contexts (e.g., Carbonneau et al., 2013; Chan et al., 2017; Manches & O'Malley, 2016; Mix et al., 2019; Osana et al., 2017; Uribe-Flórez & Wilkins, 2017; Uttal et al., 2013), it remains unclear if and how LEGO® bricks support children's mathematics learning. Previous research on the boundary conditions of various representations in mathematics instruction, including manipulatives, is reviewed below. The review will be used to frame the current investigation on the affordances of LEGO® bricks in students' learning about fraction division.

Manipulatives

Manipulatives are concrete objects that teachers use in pedagogical contexts (Manches & O'Malley, 2016; Uribe-Flórez & Wilkins, 2017; Uttal et al., 2013). Teachers use various manipulatives during mathematics instruction so that students can experience mathematics with different representations (Manches & O'Malley, 2016; Uribe-Flórez & Wilkins, 2017; Uttal et al., 2013). For example, base ten blocks can expose students to important concepts about numbers and place value (Chan et al., 2017; Mix et al., 2019; Mix et al., 2017). Cuisenaire® rods include 10 differently-colored rods, each corresponding to a specific length; they allow students to explore addition, patterning, multiplication, division, fractions, and decimals (Baroody & Hume, 1991; Cobb et al., 1992). In sum, there are many types of manipulatives that can support the development of children's learning in mathematics.

Manipulatives have many advantages for students, such as making mathematical ideas tangible (Osana et al., 2017) and improving their mathematics performance (Carbonneau et al., 2013; Uttal et al., 1997). Manipulatives provide visual and tactile information that may influence children's mathematical interpretations (Manches & O'Malley, 2016). Moreover, manipulatives offer students the opportunity to visualize and manipulate mathematical concepts, often through hands-on experiences (Martin & Schwartz, 2005; McNeil & Jarvin, 2007; Moyer, 2001; Uribe-Flórez & Wilkins, 2017; Uttal et al., 1997). Students who learn mathematics using manipulatives as representations of quantities are more likely to learn the target concepts because manipulating objects has been found to improve performance on learning tasks (Carbonneau et al., 2013; Martin & Schwartz, 2005).

Although manipulatives can be beneficial, some manipulatives may hinder mathematics learning (Carbonneau & Marley, 2015; McNeil & Jarvin, 2007; McNeil et al., 2009; Petersen & McNeil, 2013; Uttal et al., 2013). Perceptually rich manipulatives may impede learning because they possess physical features that may draw students' attention away from the relevant information being taught (Carbonneau & Marley, 2015; McNeil et al., 2009; Uttal et al., 2013). For instance, manipulatives that are rich in color and patterns (Uttal et al., 2013) and that are detailed in appearance (e.g., bills and coins) may make it harder for students to focus on the mathematical concepts they are intended to represent (McNeil et al., 2009).

Teachers may want to grab children's attention by using manipulatives that are colorful and attractive, but what they may not realize is that these physical features could hinder mathematics learning (Carbonneau & Marley, 2015; Kaminski & Sloutsky, 2013; McNeil & Jarvin, 2007; McNeil et al., 2009; Petersen & McNeil, 2013; Uttal et al., 2013). For example, manipulatives that possess different colors and patterns may be irrelevant to the learning of certain mathematical concepts (Uttal et al., 1997; Uttal et al., 2013), thus creating large amounts of extraneous processing that is not directed toward achieving instructional goals (Mayer et al., 2008). Mayer et al. (2008) explained that when cognitive processing is used for extraneous processing, the learner has less capacity available to select, organize, and integrate information, which are all cognitive processes that are required for learning. Consequently, children will be less likely to engage in the cognitive processes required for learning (Mayer & Moreno, 2003).

LEGO® Bricks as Manipulatives

According to the literature on the use of manipulatives in mathematics teaching and learning (e.g., Manches & O'Malley, 2016; Uribe-Flórez & Wilkins, 2017; Uttal et al., 2013), LEGO® bricks can be considered manipulatives because they are concrete objects that teachers could use in mathematical contexts. In fact, there are hundreds of online videos that provide examples on how to use LEGO® bricks to teach specific mathematical concepts. For instance, TheDadLab (2020) created multiple videos on YouTube that show children how to use LEGO® bricks to solve addition, multiplication, and basic fractions problems. Another example is the Brick Math Series, a program that teaches students from kindergarten to Grade 6 how to use LEGO® bricks in mathematics learning (Brigantine Media, 2019). The program uses LEGO® bricks to illustrate mathematics concepts such as counting and cardinality, addition, subtraction, multiplication, division, basic fractions, basic measurement, fraction division, fraction multiplication, decimals, and advanced measurement and geometry. The Brick Math Series program uses YouTube videos and teacher-student workbooks designed to support these mathematics concepts with LEGO® bricks.

Children may enjoy working with LEGO® bricks because they have attractive features such as studs and bright colors, but these features may, in fact, distract children from creating connections to mathematical concepts and symbols (Uttal et al., 1997). Although there may be occasions where the studs and color support student learning, these physical features could also hinder mathematics learning by altering children's cognitive processes (Mayer & Moreno, 2003; Mayer et al., 2008). In other words, the details that are irrelevant to the instructional objectives may draw students' attention away from developing an understanding of the target concepts (Park et al., 2011). Consequently, features such as studs and color may create large amounts of extraneous processing that is not directed toward achieving instructional goals (Mayer et al., 2008).

In sum, although there are hundreds of online videos (e.g., TheDadLab) and teacher-student workbooks (e.g., Brick Math Series) that suggest uses for LEGO® bricks in mathematical contexts, there is no empirical evidence on the effectiveness of using LEGO® bricks as manipulatives in mathematics teaching. While research exists to show that irrelevant details affect mathematical learning with a variety of non-concrete and concrete representations (e.g., Kaminski and Sloutsky, 2013; Lehman et al., 2007; McNeil et al., 2009; Uttal et al., 2013), to date there is no research on the impact of the physical features of LEGO® bricks on students' learning.

Irrelevant Details and Learning

Irrelevant details are defined in this study as physical features of mathematics manipulatives that are not relevant to the instructional goal (Magner et al., 2014; Mayer et al., 2008). These details may make mathematics lessons more engaging, but they can also decrease learning, immediate performance, and transfer (Belenky & Schalk, 2014; Harp & Mayer, 1997). Several studies have investigated the effects on student learning of irrelevant details in text and other non-concrete representations. For example, Lehman et al. (2007) examined the effects of seductive details on recall and processing during a lesson on lightning. They described seductive details as sentences in a passage that are highly interesting, but irrelevant to the text's main ideas. Their study included 53 undergraduate students, who were randomly assigned to one of two conditions. The no-seductive details group read a base text that did not include seductive details, whereas the seductive details group read the same base text that included additive sentences with seductive details. The outcome measures were reading time, recall of text ideas, holistic understanding, and total claims. Holistic understanding and total claims were collected by asking participants about cause-and-effect relationships in the text. The results revealed that the participants in the seductive details group spent less time reading the base text sentences and recalled less information about the formation of lightning compared to the participants in the no-seductive details group. In addition, participants who read the text with seductive details provided fewer legitimate claims and had more difficulty integrating important aspects of how lightning is formed compared to the participants who read the text without seductive details. In sum, the seductive details interfered with the participants' comprehension and processing by drawing their attention away from the main ideas being presented.

In another study, Kaminski and Sloutsky (2013) examined irrelevant details in non-concrete representations on student learning in a mathematics context. The authors investigated whether irrelevant details affected children's performance when learning how to read bar graphs. Their study included a total of 122 participants from kindergarten to Grade 2. They were randomly assigned to one of two conditions: no extraneous details or extraneous details. In the no extraneous details condition, the bar graphs were monochromatic (i.e., bars of a single color). In the extraneous details condition, the bars were filled with pictures of the objects that represented the quantities in the task (e.g., images of shoes or flowers). For each of the bar graphs, the experimenter read a scenario, and then asked the participants to state the quantity represented by the bar in the graph. The authors found that the extraneous details (i.e., the images in each bar) interfered with learning. More specifically, the presence of the images in the bars encouraged participants to count the objects instead of reading the graphs using the y-axis. In contrast, all the participants in the no-extraneous details condition accurately read the bar graphs. In other words, the presence of the images in the bars distracted the children from using the appropriate strategy for reading bar graphs.

Other studies have tested the effect of irrelevant details in concrete objects on students' mathematical problem solving. For instance, McNeil et al. (2009) investigated the effects of perceptually rich concrete objects that resembled realistic bills and coins on students' performance on word problems involving money. The authors described perceptually rich objects as possessing features that may draw students' attention away from the mathematical concepts the objects intend to represent. Their study included 85 fifth-grade students who were randomly assigned to one of three conditions. In the perceptually rich condition, participants were given realistic bills and coins to help solve the word problems. In the bland condition, participants were given black-on-white bills and coins with only the value indicated. In the control condition, participants solved problems without the presence of any manipulatives. The results revealed that students in the perceptually rich condition solved fewer problems correctly compared to students in the bland and control conditions. Interestingly, there was no difference in the number of problems solved correctly by students in the bland and control conditions. In other words, the presence of concrete objects did not hinder students' performance, but the authors speculated that the perceptually rich bills and coins possessed features that hindered problem-solving performance.

A study by Uttal et al. (2013) examined irrelevant details on blocks and student learning. The authors investigated the effects of what they called "distinctive" manipulatives on children's learning of two-digit subtraction. The authors described the distinctive manipulatives as physically attractive objects that may lead children to focus more on the manipulatives themselves instead of the mathematical concepts they represent. Their study included 19 children between the ages of 6 and 8. Nine of these children were assigned to work with standard Digi-Block manipulatives (i.e., all blocks were one color), and 10 were assigned to use distinctive Digi-Block manipulatives. In their study, non-toxic permanent markers were used to add different colors (e.g., blue or red) and patterns (e.g., swirls or polka dots) on the distinctive manipulatives. In other words, the only difference between the standard and the distinctive manipulatives were the added colors and patterns on the blocks. Uttal et al. (2013) asked each child to complete a paper-and-pencil test that included 28 double-digit subtraction problems at pre- and posttest.

Next, the authors provided instruction to children in both groups on double-digit subtraction with either standard manipulatives or distinctive manipulatives. The results revealed that the children who used standard manipulatives scored higher than children who used distinctive manipulatives at posttest. Seven of the 10 participants in the distinctive manipulatives group used the blocks in non-mathematical ways (e.g., building towers or sorting the blocks by color) in both the pre- and posttests, compared to only one participant in the standard manipulatives group. The authors speculated that the colors and patterns on the distinctive manipulatives distracted children from solving the mathematics problems in appropriate ways, making it difficult for them to create connections between the objects and their written representations.

Prior Knowledge and Transfer

Prior knowledge plays an important role in mathematics learning because it allows students to connect previously learned information to new information (Kalyuga, 2007; Sweller, 2010). Prior knowledge helps learners decide what information to select, how to organize new information, and how to integrate mental representations in long-term memory (Magner et al., 2014). Differences in prior knowledge can also determine the development of strategy flexibility, which is the ability to select the most appropriate strategy for a given problem (Star et al., 2009). Specifically, Star et al. (2009) found that students with high prior knowledge possessed greater strategy flexibility during computational estimation tasks compared to students with low prior knowledge. Rittle-Johnson et al. (2001) found that high prior conceptual knowledge of decimal fractions predicted performance on transfer of procedures to novel problems. The authors speculated that prior conceptual knowledge can guide children's choices among alternative procedures. In turn, children may use their conceptual knowledge to evaluate the relevance of known procedures to novel problems. Other studies on mathematics learning also found the same patterns of results on the effects of prior knowledge and student performance (e.g., Harp & Mayer, 1998).

Prior knowledge has also been found to be a critical factor in determining whether irrelevant details affect children's learning performance (Magner et al., 2014; Sweller, 2010). For low prior knowledge learners, irrelevant information may cause a heavy working memory load (Kalyuga, 2007; Magner et al., 2014; Maloy et al., 2019; Park et al., 2011; Sweller, 2010). Consequently, low-prior knowledge learners may not have the cognitive capacity to store meaningful chunks of incoming information. Students with low prior knowledge may direct their attention to the irrelevant details that "prime the activation of inappropriate prior knowledge," which hinders learning and performance (Harp & Mayer, 1998, p. 415). With little to no external guidance, students with low prior knowledge are forced to search for answers by using ineffective procedures (Kalyuga, 2007). In contrast, high prior knowledge learners may not be similarly affected by irrelevant information because their working memory has enough space to chunk new information and to overcome the additional cognitive load created by irrelevant details. These students may be able to ignore irrelevant details by relying on their available long-term memory knowledge structures (Magner et al., 2014). Therefore, prior knowledge plays a role in learning when irrelevant details are present in instructional representations.

Magner et al. (2014) examined the effects of prior knowledge and decorative illustrations on immediate learning assessed by geometry problems. The authors described decorative illustrations as images of real-life situations of students or objects (e.g., an image of a person on a bicycle) that have no relation to the geometry problems. In other words, the illustrations were considered to be irrelevant because they were designed to draw participants' attention away from the learning objective. Magner et al. (2014) recruited 52 participants with an average age of 13 who worked on geometry problems in a computer-based learning environment. The students were assigned to two conditions: the decorative illustrations condition (e.g., illustrations that did not support the comprehension of the geometry problems), and the no-decorative illustrations condition (e.g., illustrations that supported the comprehension of the geometry problems). A pretest was used to assess the participants' prior knowledge of geometry principles (e.g., linear pair, complementary angle, vertical angle, or angle addition), and a posttest was used to assess their immediate learning.

The results revealed that the participants with low prior knowledge learned significantly more without the decorative illustrations compared to the low-prior knowledge participants in the decorative illustrations condition. In contrast, participants with high prior knowledge learned more in the decorative illustrations condition compared to the no-decorative illustrations condition. The authors speculated that students who have high prior knowledge may have enough working memory capacity available to manage any cognitive overload caused by irrelevant details.

Wang and Adesope (2016) examined the relationship between prior knowledge and seductive details on students' problem-solving performance on knowledge about the earth. The authors defined seductive details as irrelevant pieces of information that may cause distraction or an extraneous cognitive load. The study included 209 students between the ages of 12 and 14, who were randomly assigned to one of three conditions. The participants in the seductive-details-before condition read a text with seductive details at the beginning of the passage. The participants in the seductive-details-after condition read a text with seductive details at the end of the passage. The participants in the no-seductive details condition read a passage about the earth without irrelevant details. In addition, the participants' prior knowledge was assessed with a prior-knowledge test on the earth.

The authors found that the high-prior knowledge participants in the seductive-details conditions outperformed low-prior knowledge participants in the seductive-details conditions. Low-prior knowledge participants in the no-seductive details condition scored significantly higher on problem-solving performance compared to all participants in the seductive-details conditions. Interestingly, high-prior knowledge participants in the no-seductive details condition and in the seductive-details conditions performed at the same level. In sum, Wang and Adesope (2016) speculated that seductive details do not impact the performance of high-prior knowledge students, whereas seductive details may interfere with low-prior knowledge students' learning by overloading their working memory (Kalyuga, 2007; Magner et al., 2014; Maloy et al., 2019; Park et al., 2011; Sweller, 2010). Therefore, prior knowledge plays a critical role in students' performance, especially if seductive details are included in the instructional materials used.

The studs on LEGO® bricks might hinder mathematics learning if they are irrelevant to the understanding of specific mathematical concepts (Mayer et al., 2008). Consequently, the studs may create extraneous processing that is not directed toward achieving instructional goals. However, children's prior knowledge may affect the way children process the studs on the LEGO® bricks (Magner et al., 2014; Sweller, 2010). For instance, it is possible that children with high prior knowledge are able to ignore the studs on the LEGO® bricks because they have enough working memory capacity to process the concepts targeted by the bricks despite the presence of irrelevant details (Magner et al., 2014). In other words, the studs on the LEGO® bricks may hinder learning among students with low prior knowledge because irrelevant details may surcharge their cognitive load, thus hindering their learning (Kalyuga, 2007; Magner et al., 2014; Maloy et al., 2019; Park et al., 2011; Sweller, 2010).

Fraction Division with LEGO® Bricks

Division problems involve quantities that are grouped or partitioned into equivalent groups (Carpenter et al., 2014). The problems involve three quantities: the number of groups, the amount in each group, and the total. In a problem, any one of the three quantities can be unknown. For instance, in measurement division, the number of groups is unknown, whereas the total number of groups and the amount in each group are given. Therefore, measurement division involves children constructing sets, each with specified number of objects and counting the number of sets constructed. In other words, students use the number of objects in each group to measure the total number of objects.

An example of a measurement division problem involving fractions is: "John has to water his plants, and he has ½ a cup of water. Each plant needs ¼ cup of water. How many plants can John water before he needs to get more water?" The solution equation here is $\frac{1}{2} \div \frac{1}{4} =$ and the answer is 2. The number that is being partitioned (e.g., ½) is the total quantity, and ¼ is the size of each group. The answer to the problem, 2, refers to the number of groups of ¼ cup in ½ cup. Lastly, each number in an equation also has a specific term. For example, in the number problem $\frac{1}{2} \div \frac{1}{4} = 2$, ½ is the dividend, ¼ is the divisor, and 2 is the quotient.

Chapter 3: The Present Study

The primary purpose of the present study was to test whether the studs on the LEGO® bricks act as irrelevant details in students' learning of fraction division in an instructional context. An additional objective was to examine the role of prior knowledge on the extent to which the students are distracted by the studs on the LEGO® bricks. One group of 39 fifth- and sixth-grade students from a private French school participated in the study.

The study included a Fractions Test, an instructional intervention, and two outcome measures (i.e., Accuracy Score and Distraction Score), assessed through a Learning and a Transfer Task. I tested the participants' prior knowledge of basic fractions concepts with a fractions test based on Saxe et al. (2001). The purpose of these data was to examine the role of prior knowledge in students' performance on the outcome measures.

The intervention was presented individually to all participants, which included two phases: (a) an introductory lesson on fractions with LEGO® bricks, and (b) demonstrations on how to solve fractions division problems using LEGO® bricks. The objective of the two phases was to demonstrate how to represent fractions with various LEGO® bricks and to provide instruction on how to use the bricks to solve measurement division problems with fractions as both the dividend and divisor. All three demonstrations on how to use LEGO® bricks to solve measurement division problems involved a yellow 1 x 1 LEGO® brick (i.e., with one stud) as the divisor. The researcher used these 1 x 1 bricks to solve the problems by placing these bricks onto the dividend bricks. The researcher then used a finger icon to count the number of 1 x 1 bricks that were placed on the dividend to find the solution. Therefore, the counting of the 1 x 1 bricks resulted in the same actions as counting the studs. Note that in the general cases, to find the correct answer, one must count the number of groups indicated by the divisor, which may be represented by bricks with more than one stud.

Immediately after the intervention, the Learning Task and the Transfer Task were administered to the participants. The Learning Task items required the use of a 1 x 1 divisor brick on each item and the Transfer Task items required a divisor brick that has more than one stud. Both the Learning Task and the Transfer Task required counting the bricks to arrive to the correct answer, but counting the studs instead of the bricks on the Transfer Task would provide evidence that the studs acted as irrelevant details.

The research questions guiding this study were: (a) Are children distracted by the number of studs in divisors as assessed by the Transfer Task?, (b) Will high prior fractions knowledge compensate for the negative effects of the irrelevant details on the Transfer Task?, (c) Is prior knowledge and task type (i.e., learning, transfer) related to solution accuracy when solving fraction division problems with LEGO® bricks?, and (d) What strategies did children use to solve the fraction division problems with LEGO® bricks?

With respect to the first two research questions, I predict that participants with low prior knowledge will obtain a lower score on the Distraction measure (i.e., they will get more distracted) compared to participants with high prior knowledge because the studs on the divisor bricks will serve as an irrelevant detail on the Transfer Task (Kalyuga, 2007; Magner et al., 2014; Maloy et al., 2019; Park et al., 2011; Sweller, 2010). On the other hand, I predict that the participants with high prior knowledge will receive a higher Distraction Score (i.e., they will get less distracted) relative to the low prior knowledge participants (Harp & Mayer, 1998; Magner et al., 2014; Star et al., 2009; Wang & Adesope, 2016) because their higher prior fractions knowledge will allow them to overcome the irrelevant details during the intervention.

I predict that all participants, regardless of their prior knowledge, will be more accurate on the Learning Task compared to the Transfer Task because the former assesses performance on the same type of problems presented during the intervention (Kalyuga, 2007; Magner et al., 2014; Sweller, 2010). Another reason I predict participants will obtain a higher Accuracy Score on the Learning Task compared to the Transfer Task is there is more room to make errors on the Transfer Task. That is, it is possible to count the studs instead of the bricks on the Transfer Task, whereas it is not possible on the Learning Task. Moreover, I predict that there will be differences in children's accuracy when taking into account their prior knowledge level (e.g., low, high) (Star et al., 2009; Sweller, 2010) and that there will be an interaction between prior knowledge and the task type on Accuracy Scores.

Chapter 4: Method

Participants

A group of 39 fifth- and sixth-grade students from a private French school participated in the study. They attended a private French school in a large urban center in Canada. A participant was excluded from the sample because her parent questionnaire indicated that she was diagnosed with a mathematics learning disability, attention deficit disorder, and a learning disorder in reading or spelling. Therefore, the final sample size was 38 participants.

The participants' parents completed a questionnaire (see Appendix F) to gather information on their child's age, gender, family income, mathematics difficulty level, colorblindness, disabilities, and languages spoken at home. The exclusion criteria for participants were the following: participants who did not speak or understand French.

The sample included 14 (36.84%) girls and 24 (63.16%) boys, with 18 (47.37%) fifth-grade students and 20 (52.63%) sixth-grade students. The minimum age was 10.5 years and the maximum age was 12.9 years (M = 11.6, SD = .59). Additionally, 35 participants (92.11%) reported no mathematics difficulty, while three participants (7.89%) had some mathematics difficulty. No participant had color-blindness. Lastly, none of the 33 participants (85.84%) had a diagnosis of any type of disorder, whereas four participants (10.53%) were medicated for attention deficit disorder, and one participant (3.63%) had attention deficit disorder, but was not receiving medication. Table 1 shows the proportion of participants in the sample according to language spoken in the home and family income.

Table 1

Language Spoken in the Home and Family Income (N = 38)

Characteristic	Participants

	n	%
Language spoken at home		
French	6	15.79
English	6	15.79
French and English	10	26.32
French and other	2	5.26
English and other	4	10.53
French and English and other	4	10.53
Other	6	15.79
Family income		
< 20,000	0	0
20,000 – 40,000	1	2.63
40,000 – 60,000	0	0
60,000 – 80,000	1	2.63
80,000 – 100,000	4	10.53
> 100,000	19	50
Prefer not to answer	13	34.21

Note. Percent represent the proportion of participants in the sample.

Design

A two-group design (low prior knowledge, high prior knowledge) was used to assess the relation between prior knowledge and performance. Two outcome measures were used to assess children's performance: (a) Accuracy Score, as measured on the Learning and Transfer Tasks, and (b) Distraction Score, as measured by the Transfer Task only. A median split on the Fractions Test was used to create the two prior knowledge groups.

Instructional Intervention

The instructional intervention included two phases designed to show participants how to use LEGO® bricks to solve fractions problems. Phase 1 was a video that showed participants how to represent fractions with LEGO® bricks, and Phase 2 was a video that demonstrated to participants how to solve fractions division problems with LEGO® bricks.

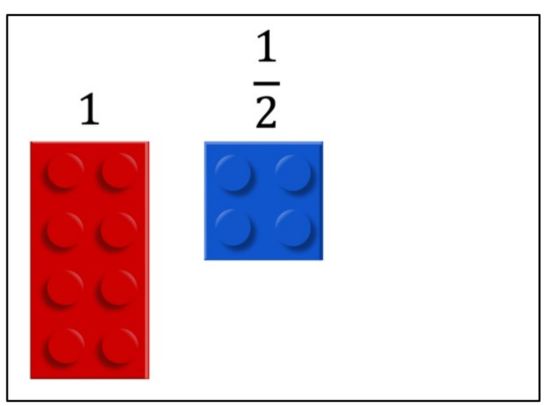
Phase 1: Introduction to Fractions

The Introduction to Fractions video was a two-minute lesson that showed participants how to represent fractions with different LEGO® bricks. The video demonstrated how to represent eight fractions with LEGO® bricks using two different wholes: five fractions with a red 4 x 2 LEGO® brick as the whole, and the remaining three fractions with a red 6 x 2 LEGO® brick as the whole. In each demonstration, the whole appeared on the left side of the screen, with a "1" placed on top of the brick to indicate the whole (see Figure 1). Using the red brick as a reference, the video showed how to use LEGO® bricks to represent various fractions, how to represent some of these same fractions with different LEGO® bricks, and how to represent all the fractions using written symbols. This was important because to learn from manipulatives, children must first understand how the manipulative represents a concept or a written symbol (Uttal et al., 1997).

Figure 1

Examples Taken from the Introduction to Fractions Video

A



B

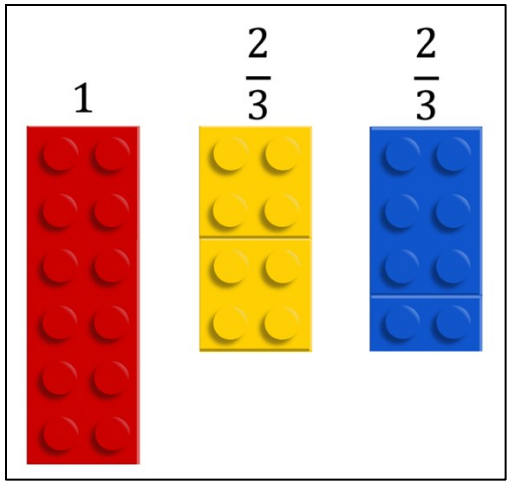
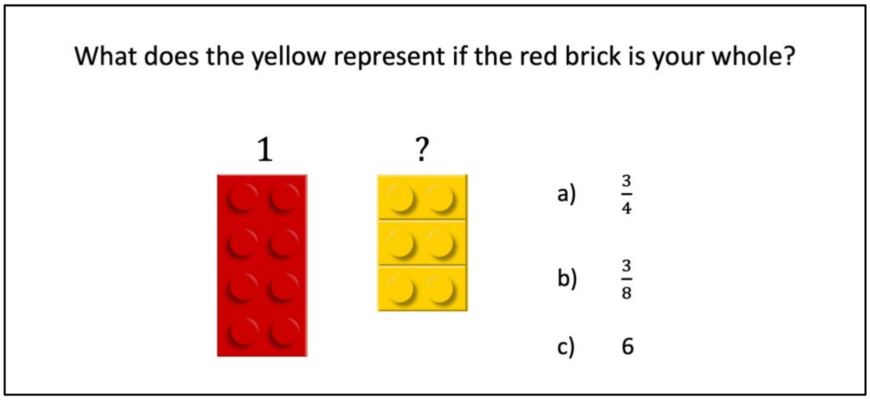


Figure 1 (Panels A and B) shows two examples taken from the Introduction to Fractions video. For the demonstrations using the 4 x 2 LEGO® brick as the whole, the video began by showing how to represent $\frac{1}{2}$ with one LEGO® representation (see Figure 1, Panel A), which was followed by representations of $\frac{1}{4}$, $\frac{1}{8}$, $\frac{2}{4}$ and $\frac{3}{4}$ using the same whole, After these five demonstrations, the participants were shown three additional demonstrations, each showing how to represent previously-introduced fractions (specifically, $\frac{1}{4}$, $\frac{2}{4}$, and $\frac{3}{4}$) using different LEGO® bricks. Appendix A presents all examples presented in Phase 1, in order of appearance. The video was narrated to highlight the steps involved in representing fractions with LEGO® bricks and to provide the conceptual rationale for constructing fractions with bricks.

The LEGO® Representation Task was administered after the Introduction to Fractions video. Participants solved six multiple-choice practice problems, each on one Keynote slide. The objective of these problems was to provide the participants the opportunity to review the concepts presented in the video. Figure 2 shows a sample item taken from the LEGO® Representation Task. Each question involved showing the participants either an 8 x 2, 6 x 2, or 4 x 2 red LEGO® brick, representing the whole, and one or more yellow or blue bricks next to the red brick (see Figure 2).

Figure 2

Sample of an Item on the LEGO® Representation Task

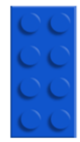


On each item, the red brick had a "1" labeled on top of it, and the yellow or blue brick had a "?" labeled on top of it. The researcher asked each participant, "What does the yellow [or blue] represent if the red brick is your whole?" This question was asked live (on Zoom) for each of the six items, and it also appeared in text on each Keynote slide. On the right side of the Keynote slide, three options were displayed. For all items, the options included a number in symbolic form representing: (a) the correct answer, (b) the number of yellow or blue bricks as the numerator and the number of studs in the red brick as the denominator, and (c) the number of studs in the yellow or blue brick. The order of the options was randomized on each item. Because of the constraints of online data collection, the researcher did not provide feedback.

Figure 3 shows all the multiple-choice items in the LEGO® Representation Task. Appendix B presents all the multiple-choice representations in order of appearance.

Figure 3

All Items on the LEGO® Representation Task

Item Number	Brick Representing Whole	Fractional Quantity	Correct Answer
1	6 x 2		$\frac{1}{6}$
2	8 x 2		$\frac{1}{2}$
3	4 x 2		$\frac{3}{4}$
4	8 x 2		$\frac{1}{4}$
5	6 x 2		$\frac{5}{6}$
6	4 x 2		$\frac{3}{8}$

Phase 2: Fractions Division

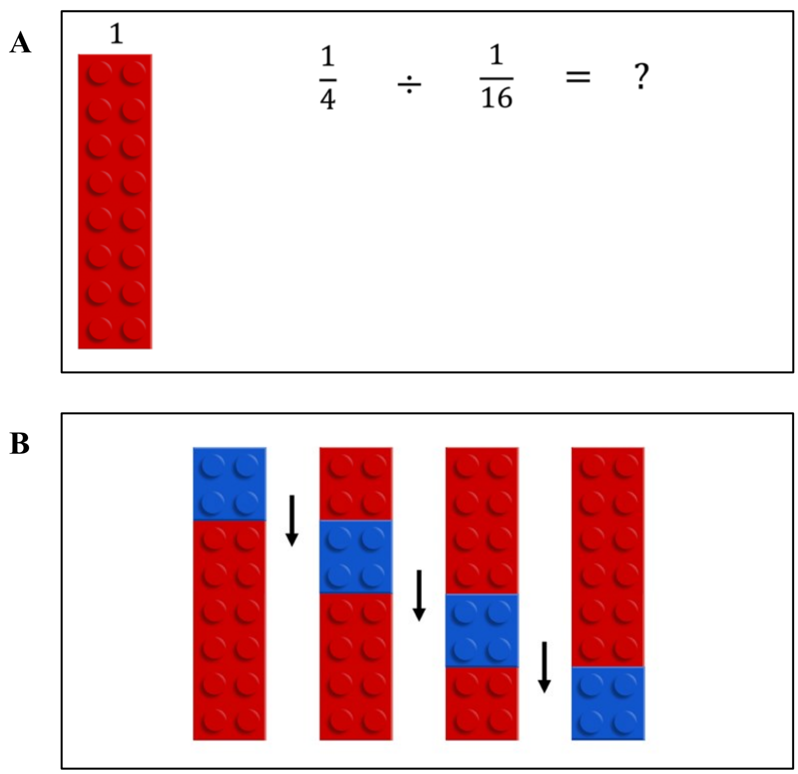
The Fractions Divisions video consisted of showing the participants a three-minute video, with the goal to show them how to solve fractions division problems using LEGO® bricks. This video consisted of three demonstrations on how to use the bricks to solve the problems using a measurement division model. The procedure for solving the problems was inspired by a video created by TheDadLab (2019). In all demonstration problems, the fraction's whole was represented by a red brick, the dividend was represented by a blue brick, and the divisor was represented by a yellow brick.

The video was narrated to highlight the steps involved in the procedure for solving the division problems. It was based on the video in TheDadLab (2019), but with modifications based on multimedia instructional principles outlined by Mayer and Moreno (2003). For example, the steps in the video were narrated to reduce the processing demands on the visual channel so that the participant would be better able to select important aspects of the video's animation for further processing. Moreover, the video did not include background music to reduce the use of superfluous cognitive resources, leaving more cognitive capacity for essential processing. The words that were included in the narration were not presented on the screen to maximize cognitive capacity for the processing relevant to the task.

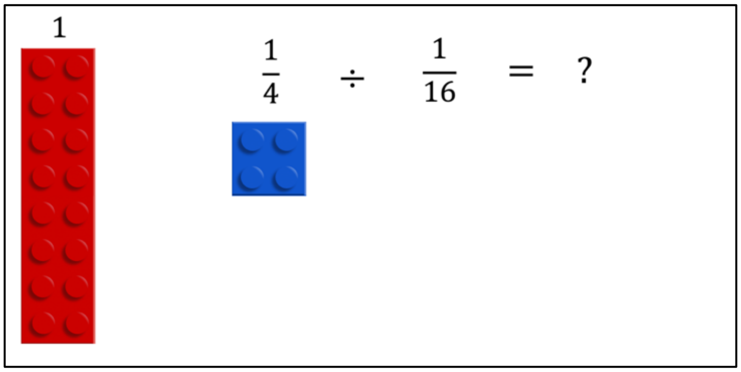
Figure 4 shows how the dividend in the fractions division video is introduced and represented in all three fraction division problems.

Figure 4

Introduction and Representation of the Dividend in the Fractions Division Video



C

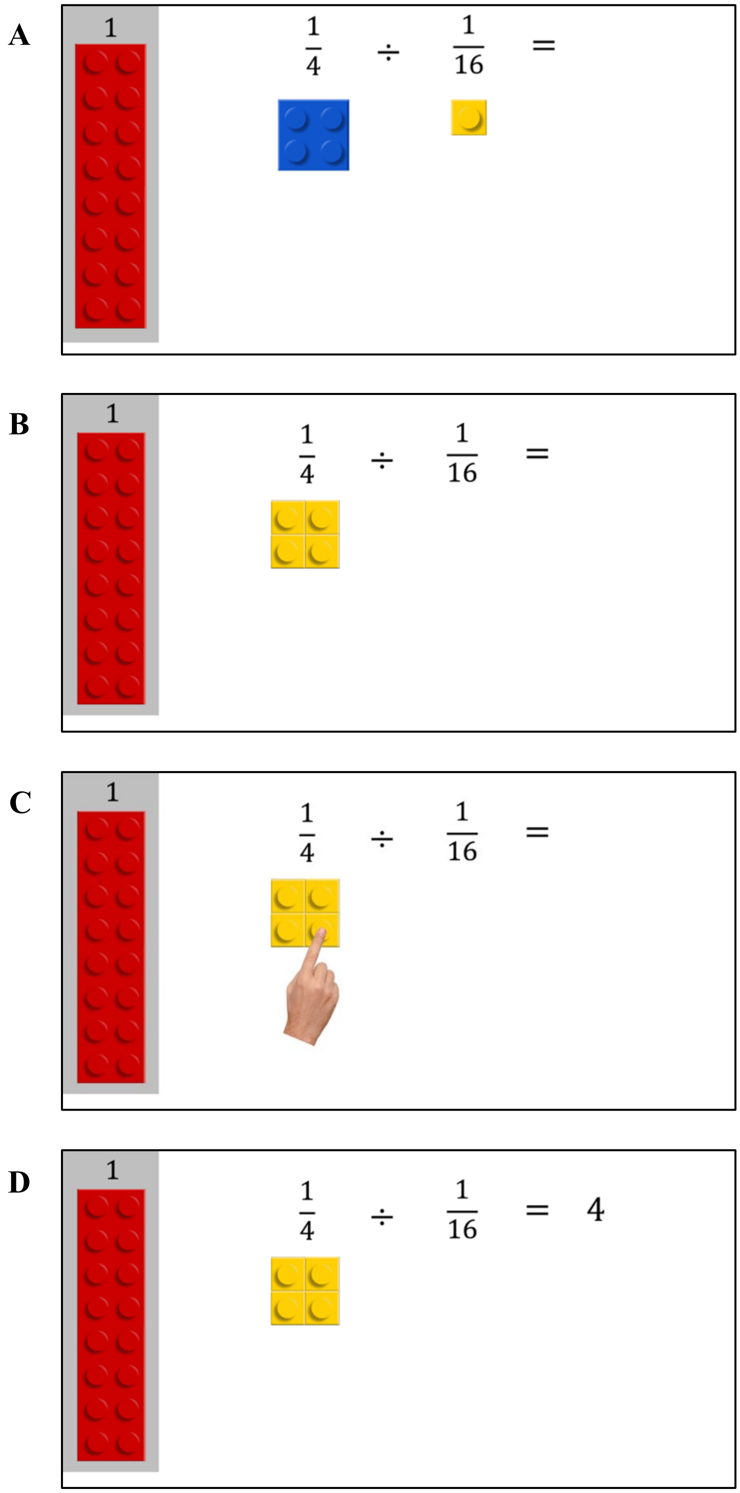


The first demonstration began with a fractions division problem (e.g., $\frac{1}{4} \div \frac{1}{16} = ?$) placed at the top of the screen. A red LEGO® brick representing the whole appeared on the left side of the screen (see Figure 4, Panel A). In this first example, the whole was represented by a red 8 x 2 brick and a "1" placed on top of the brick. Using the red brick as a reference, the video demonstrated how to find $\frac{1}{4}$ of the whole by stacking a blue 2 x 2 brick four times on top of the whole (see Figure 4, Panel B). The blue 2 x 2 brick then moved, through Keynote animation, under the "$\frac{1}{4}$" in the displayed problem (see Figure 4, Panel C).

Figure 5 shows the procedure used to solve fraction division problems with LEGO® bricks. Figure 5 specifically demonstrates how to use the bricks to solve the problem $\frac{1}{4} \div \frac{1}{16} =$. For the divisor, a yellow 1 x 1 brick appeared on top of the red 8 x 2 brick, showing that $\frac{1}{16}$ fits into the whole 16 times. Similar to the demonstration of the dividend, one yellow brick then moved under the "$\frac{1}{16}$" in the problem.

Figure 5

Procedure to Solve 1/4 ÷ 1/16 = in the Fractions Division Video



Once the symbols in the number sentence (i.e., $\frac{1}{4}$ and $\frac{1}{16}$ in Figure 5, Panel A) were represented with the appropriate LEGO® bricks, a demonstration of the solution procedure began. A grey background appeared behind the red LEGO® brick (i.e., the whole) to minimize distraction when solving the problem, but to keep it in view for reference (see Figure 5, Panel A). The narrator then said, "now we are ready to solve the problem," and the question mark in the problem disappeared. Next, the narrator stated that the goal was to find out how many $\frac{1}{16}$s are in $\frac{1}{4}$. The video then showed the number of yellow 1 x 1 bricks (i.e., the number of $\frac{1}{16}$s) that fit on the dividend brick (i.e., $\frac{1}{4}$, represented with one blue 2 x 2 brick). The yellow 1 x 1 brick, which was initially placed under the divisor in the number sentence, moved, through Keynote animation, onto the blue 2 x 2 brick. Then, three additional yellow 1 x 1 bricks were placed on the blue 2 x 2 brick until no other bricks could fit onto it (see Figure 5, Panel B). Once the four 1 x 1 yellow bricks were placed onto the blue 2 x 2 brick, the narrator reminded the participants that they needed to find how many $\frac{1}{16}$s there are in $\frac{1}{4}$. The video showed a finger pointing to each of the yellow bricks that were placed on the blue 2 x 2 brick (see Figure 5, Panel C) as the narrator counted them out loud. In this example, when all four yellow bricks were counted, the answer (i.e., "4") appeared to the right of the "=" sign (see Figure 5, Panel D).

The video then showed how to solve two additional demonstration problems, using the same steps with LEGO® bricks. The second fractions division problem was $\frac{5}{6} \div \frac{1}{12} = ?$ and the third problem was $\frac{3}{4} \div \frac{1}{8} = ?$. It is important to note that the second and third demonstration problems illustrated how to solve fractions division problems also using a divisor that was represented by a yellow 1 x 1 LEGO® brick. The colors of the bricks for the whole, dividend, and divisor in the second and third demonstration problems were the same as the colors used in the first demonstration.

The video was created with PowerPoint and iMovie on a MacBook Pro. Each action was animated by the researcher on PowerPoint using the screen recording feature to create the video. The materials included in the video were computerized images of LEGO® bricks by SlidesMania (2020). These bricks were used to represent the whole, the dividend, and the divisor for each problem. The brick representing the whole was red, the brick representing the dividend was blue, and the brick representing the divisor was yellow. The dividend was always smaller than the whole so that the red brick was never used to represent both the whole and the dividend. The divisor was always represented with a 1 x 1 brick so that the counting of the bricks resulted in the same actions as counting the studs.

Measures

Fractions Test

The Fractions Test was a paper-and-pencil test based on Saxe et al. (2001) that was provided in a booklet printed on light blue paper. It was designed to measure the participants' performance on eight items that assessed conceptual understanding of fractions concepts (see Appendix C). In other words, the items were designed so that the participants could not readily solve them by routine algorithmic procedures. The test consisted of: (a) three items that showed a whole (i.e., a square) with shaded parts, where students were asked to write a fraction that represented the shaded amount, (b) two items that asked the participants to circle a fraction (from a choice of three) that best represented the shaded region in a circle, (c) two fair sharing items, and (d) one item that required the students to use drawings to show the solution to $\frac{2}{5}+\frac{3}{5}=$. They were given 10 minutes to complete the test.

The participants were asked to solve the problems in the order that they are presented on the test. To measure accuracy, a total of eight points was possible, with 1 point awarded for each correct answer and 0 for each incorrect answer. Each participant's score was the mean number of correct responses on all attempted items.

LEGO® Representation Task

The LEGO® Representation Task included six multiple-choice practice problems, each on one Keynote slide. The objective of these problems was to provide the participants the opportunity to review the concepts presented in the Introduction to Fractions video.

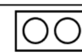
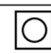
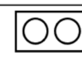
The participants were asked to provide an answer from the list of multiple-choice items to each of the six problems. A total of six points was possible, with 1 point awarded for each correct answer and 0 for each incorrect answer. Each participant’s score was the mean number of correct responses on all attempted items.

Outcome Measures

After the instructional intervention, the Learning Task was used to assess participants’ Accuracy Score on the fraction division problems. The Learning Task was also used as a manipulation check for children’s procedures to solve the fraction division problems with LEGO® bricks. This manipulation check was important, because participants needed to practice the procedure learned in the Fractions Division video in order for the researcher to observe whether they count the bricks or the studs on the Transfer Task. In addition, the Transfer Task was also used to assess participants’ Accuracy Score, but also their Distraction Score. Each Learning and Transfer item was presented on one Keynote slide. Figure 6 presents all Learning and Transfer items, in order of presentation.

Figure 6

Learning and Transfer Items in Order of Presentation

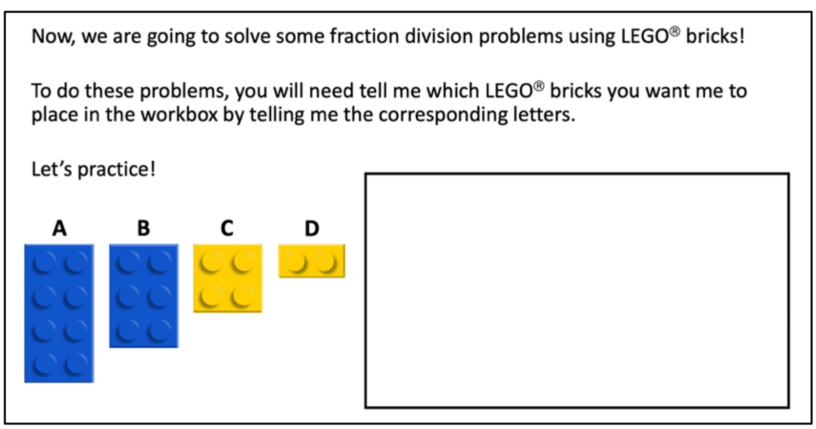
Item Number	Brick Representing Whole	Learning Task	Brick Used for Divisor	Transfer Task	Brick Used for Divisor
1	6 x 2	$\frac{2}{3} \div \frac{1}{12} = ?$		$\frac{2}{3} \div \frac{1}{6} = ?$	
2	8 x 2	$\frac{1}{2} \div \frac{1}{16} = ?$		$\frac{3}{4} \div \frac{1}{8} = ?$	
3	4 x 2	$\frac{1}{2} \div \frac{1}{8} = ?$		$\frac{1}{2} \div \frac{1}{4} = ?$	
4	6 x 2	$\frac{1}{6} \div \frac{1}{12} = ?$		$\frac{1}{2} \div \frac{1}{6} = ?$	
5	8 x 2	$\frac{3}{4} \div \frac{1}{16} = ?$		$\frac{1}{4} \div \frac{1}{8} = ?$	

Every Learning item required a 1 x 1 LEGO® brick as the divisor for the correct solution, and every Transfer item required a LEGO® brick that had two studs as the divisor.

Figure 7 shows the instructions that were provided before administering the Learning and Transfer Tasks.

Figure 7

Instructions Before Administering the Learning and Transfer Tasks

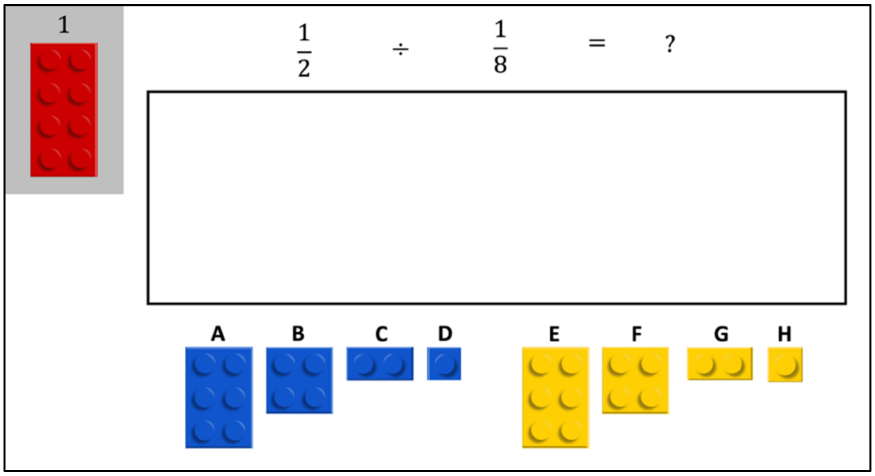


The researcher showed a Keynote slide with the problem task instructions, and the researcher told the students that the video that they just viewed (i.e., the Fractions Division video) will help them solve the upcoming problems. Figure 7 also shows that the researcher practiced placing bricks with the participant in the workbox before administering the Learning and Transfer Tasks.

Learning Task. Figure 8 shows a sample Learning item.

Figure 8

Sample Learning Item



The items on the Learning Task were configured (i.e., placement of the problem and the whole) in the same way as the examples in the instructional video. A red LEGO® brick representing the whole was always present in the upper left corner of each slide. The colors of the bricks were the same as the demonstration problems in the intervention and remained consistent across all items. The reason for the color consistency was to activate the procedure used in the instructional intervention. A rectangular box was placed in the middle of the Keynote slide for the solution workspace, and 8 or 10 LEGO® bricks, depending on the item, were placed below the rectangular box to show the bricks that were available to solve the given problem. The bricks made available for the solution were yellow and blue, with the same number and same-sized bricks in each color. In addition, each brick was identified with a capital letter for ease of identification during the interaction between the participant and the researcher on Zoom.

On only the first Learning item, the researcher circled, with the cursor, the blue and the yellow bricks and said, “you can use however many of these bricks as you need to solve each problem." On each Learning item, the researcher used the cursor to circle the red LEGO® brick and told the participant to refer to it as the whole and to use it as a reference to solve the problem. The participants were able to identify the LEGO® bricks they selected for the solution by stating the letters that were used to label each brick. The participants told the researcher which bricks to select, and instructed the researcher where to place them in the workbox. Once the participants finished using the bricks to solve the problem, they were asked to provide an answer to the problem. See Appendix D for all Learning items.

Because the Learning Task was used as a manipulation check to assure that the instructional intervention was successful in students' learning of the procedure, the researcher guided the participants if they required help. If participants did not remember how to use the demonstrated procedure to solve the fraction division problems with the bricks (e.g., did not know what divisor brick to use, did not know what to do after the divisor bricks were placed), the researcher repeated the explanations from the Fractions Division videos to help the participants remember how to use the bricks. Feedback stopped once the participants were able to successfully use the procedure on any remaining Learning items. No feedback was provided if the participants incorrectly represented the dividend bricks on the Learning Task.

The instructions given to the researcher by the participants on how to manipulate the bricks to solve the problems was documented using the record feature on Zoom. The researcher assessed the participants' performance on the Learning Task using the Accuracy Score. To measure accuracy, one point was awarded if the participant got the correct solution, and 0 if the participant got the incorrect solution. Each participant's Accuracy Score was the mean number of correct responses on all attempted items. The Zoom recordings were also used to document the errors participants made when they solved the problems on the Learning Task.

Transfer Task. Each of the five Transfer items was presented on a separate Keynote slide. On each Transfer item, the researcher used the cursor to circle the red LEGO® brick and told the participant to refer to it as the whole and to use it as a reference to solve the problem. As in the Learning Task, the participants were able to identify the LEGO® bricks they selected for the solution by stating the letters that were used to label each brick. The participants told the researcher which bricks to select, and instructed the researcher where to place them in the workbox. Once the participants finished using the bricks to solve the problem, they were asked to provide an answer to the problem. See Appendix E for all Transfer items.

Each problem required a divisor that was larger than a 1 x 1 LEGO® brick (i.e., a brick that had more than one stud; see Figure 6). Smaller bricks (i.e., 1 x 1 bricks) were not available in the brick options to assess whether the participants would count the bricks or the studs using bricks with more than one stud. The administration procedure was the same as for the Learning Task. The researcher assessed the participants' performance on the Transfer Task using two dependent variables: (a) Accuracy Score, and (b) Distraction Score. The Accuracy Score was assessed the same way as in the Learning Task. The Distraction Score represented whether the participants counted the bricks or the studs during the Transfer Task. To measure distraction, 1 point was awarded if participants counted the bricks and a score of 0 if they counted the studs. Each participant's Distraction Score was the mean number of points across all attempted Transfer items. The Zoom recordings were also used to document the errors participants made when they solved the problems on the Transfer Task.

Procedure

I sent an email with the project's information to the principal of the participating school requesting approval of the project. I asked her to forward the information sheet to the Grade 5 and Grade 6 teachers at the school to recruit any who were interested in participating. Once I received approval from the participating teachers, I sent out a recruitment cover letter to the principal to forward to the parents of the students in Grades 5 and 6. Interested parents contacted me via email, after which I sent them a document providing a parent questionnaire (see Appendix F), a consent form, and the researcher's availabilities for a Zoom meeting. If the parents agreed to be part of the study, they were asked to reply to the email with the completed questionnaire, the signed consent form, and a preferred time to meet with a researcher via Zoom. When I confirmed a date and a time with the parents, I sent them a link to a scheduled Zoom meeting and a reminder email the day before the meeting. I also delivered envelopes that included the paper-and-pencil Fractions Test to the participants' school. The staff in the front office delivered the envelopes to the participating children's teachers.

Each envelope included a booklet for the Fractions Test, a pencil and an eraser, and a return stamped envelope to the researcher's address. The teachers gave these envelopes to the participating students to bring home. On the outside of the envelope was written, "Do not open until the day of the Zoom meeting."

The Zoom meeting was recorded using the software's recording feature. The researcher's microphone and camera were on and she asked the participants to share their audio and video. The researcher always had her screen shared with the participant. The reason the researcher had her screen shared was to facilitate the administration of the Fractions Test, the Learning Task, and the Transfer Task on Zoom. The researcher began each session by obtaining assent from the participant to confirm participation in the study. The procedure for obtaining assent involved describing the study, what the participant would be asked to do during the meeting, the benefits of participating and any potential risks, and how anonymity and privacy were assured. After obtaining assent, the researcher asked the participants to take out the Fractions Test, and to have the pencil and the eraser ready. The researcher then asked the participant to turn the cover page to the first item.

The researcher provided different levels of prompts to participants during the administration of the Fractions Test. Level 1 prompts were provided every minute to ensure that the participant was on the right track. An example of a level 1 prompt was “how’s it going?” If the participants showed any sign of confusion, the researcher provided a level 2 prompt, which was characterized by restating the instructions (e.g., “circle the fraction that shows what part of each circle below is gray”). If the participants still showed signs that they did not know how to solve the given problem, the researcher provided a level 3 prompt to encourage the participants to do their best (e.g., “try your best”). If the participants showed that they could not solve the problem, the researcher provided a level 4 prompt, “you can move on to the next problem.” The researcher also reminded the participants to inform her when they were done with each item so that the researcher could follow their progress through the test booklet.

After the Fractions Test was completed, the researcher began the instructional intervention, which was presented via Keynote using a laptop that ran on MacOS. After the intervention, the Learning Task and the Transfer Task were conducted through the sharing of Keynote on Zoom. The researchers shared the Learning Task and the Transfer Task with the participants, one item per slide.

During both the Learning Task and the Transfer Task, the researcher was responsible for manipulating the LEGO® bricks on the screen for the participants. The participants directed the researcher to which and how many LEGO® bricks should be placed in the workbox by naming the letters assigned to each brick. If necessary, to improve online communication about the visual representations and placements, the researcher used the cursor to direct attention to the specific bricks. The participant was asked to provide an answer to the problem and a justification for their answer to each item before moving on to the next problem. The research recorded the participants' answers on the Learning Task and the Transfer Task on a scoring sheet (see Appendix G).

Only the participants' questions about test administration were answered throughout the Fractions Test, the Learning Task, and the Transfer Task. If participants asked questions related to content, the researcher restated the instructions and told them to do 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 Zoom 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 booklet by mail (with the return stamped envelope that was provided) or return the booklet to the child's teacher.

Chapter 5: Results

The main objective of my study was to investigate whether the studs on LEGO® bricks act as irrelevant details in children's performance on fraction division problems in an instructional context. Recall that the Learning items required the use of a 1 x 1 divisor brick on each item, and the transfer items required a divisor brick with more than one stud. Thus, I was only able to observe whether children were distracted by the studs on the bricks on the Transfer Task because it allowed me to discern whether the students counted the studs or the bricks to solve the problems, which was not possible on the Learning Task. The Learning Task was used as a manipulative check for the procedure demonstrated in the instructional intervention and to evaluate students' problem-solving accuracy. The second objective was to examine whether children's prior knowledge of fractions played a role in the degree to which they were distracted by the studs on the LEGO® bricks. The third objective was to test whether there were prior knowledge effects on participants' problem-solving accuracy, assessed using the Learning and Transfer Tasks. The final objective was to provide a description of the strategies children used to solve fraction division problems with LEGO® bricks.

Grade Effects

To examine the role of prior knowledge on the degree to which students were distracted by the studs, a median split on the Fractions Test was conducted to divide the participants into low and high prior knowledge groups. Fourteen participants in the fifth grade (77.78%) and five in the sixth grade (25%) were placed in the low prior knowledge group (n = 19). In contrast, four fifth-grade students (22.22%) and 15 sixth-grade students (75%) were placed in the high prior knowledge group (n = 19). An independent samples t-test revealed a statistically significant difference between grades on the Fractions Test scores, $t(36) = -3.79$, $p = .001$. Specifically, sixth-grade participants had higher scores (*M* = 0.73, *SD* = .16) on the Fractions Test compared to fifth-grade participants (*M* = 0.50, *SD* = 0.20). Thus, grade was related to participants' performance on the Fractions Test.

All participants, regardless of grade level, performed similarly on the LEGO® Representation Task (fifth grade: *M* = .96, *SD* = .07; sixth grade: *M* = .94, *SD* = .16). In addition, fifth-grade participants (*M* = .89, *SD* = .29) performed as well as the sixth-grade participants (*M* = .89, *SD* = .31) on the Distraction Score. The results also showed that there was no main effect of grade on the Accuracy Score (across both Learning and Transfer Tasks: fifth grade, *M* = .75, *SD* = .05; sixth grade, *M* = .83, *SD* = .05), nor was there a grade by task type interaction on accuracy, all ps > .05.

Research Questions 1 and 2: Do Studs Act as Irrelevant Details and Does Prior Knowledge Play a Role?

Table 2 shows the means and the standard deviations for the LEGO® Representation Task and the Distraction Score, by prior knowledge. The mean scores on the LEGO® Representation Task and on the Distraction Score are similar between the low and high prior knowledge groups. In other words, all participants performed similarly on both measures. Additionally, the relatively high Distraction Scores observed in both prior knowledge groups indicated that the students tended to count the bricks more than the studs on the Transfer Task.

Table 2

Means and Standard Deviations for the LEGO® Representation Task and the Distraction Measure by Prior Knowledge

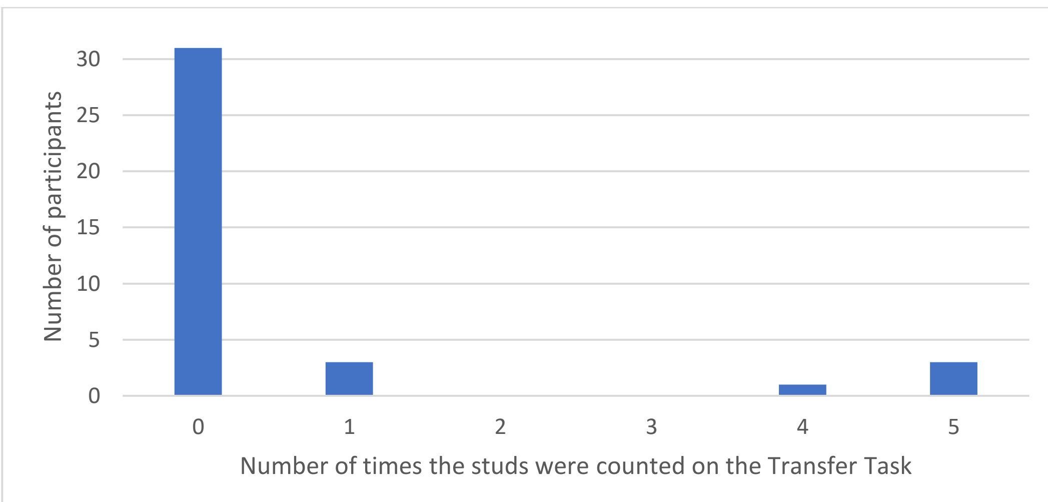
Measure	LEGO® Representation Task			Distraction Score		
	n	*M*	*SD*	*n*	*M*	*SD*

Low prior knowledge	19	.96	.07	19	.88	.31
High prior knowledge	19	.94	.16	19	.88	.29

To further examine whether the studs on the LEGO® bricks acted as irrelevant details in children's learning of the fraction division procedure with LEGO® bricks, I looked at how many participants, regardless of prior knowledge, counted the studs on the Transfer Task. Figure 9 shows a bar graph on the number of participants who counted the studs between 0 and 5 times across all five transfer items.

Figure 9

Number of Participants Who Counted the Studs Across the Five Transfer Items (N = 38)



The bar graph reveals that 31 participants (81.58% of the sample) never counted the studs on any of the items. Instead, they counted the bricks, which is the correct procedure to solve the fraction division problems. In addition, three participants (7.89%) counted the studs once across all five items, one participant (2.63%) counted the studs four times, and three participants (7.89%) counted the studs all five times. In total, 7 of the 38 participants (18.42% of the sample) got distracted by the number of studs on the LEGO® bricks at least once during the Transfer Task.

Table 3 shows the number of times participants counted the bricks and studs on the Transfer Task as a function of prior knowledge, using item as the unit of analysis. The data showed that prior knowledge was not related to the degree to which participants got distracted by the studs on the Transfer Task.

Table 3

Number of Times Participants Counted the Bricks and Studs on the Transfer Task by Prior Knowledge (N = 190)

Source	Counted studs		Counted bricks	
	n	%	*n*	%
Low prior knowledge	11	11.58	84	88.42
High prior knowledge	11	11.58	84	88.42

Note. n = 95 for each prior knowledge group. The percent represents the proportion of both strategies relative the total number of responses in each prior knowledge group.

Research Question 3: Is Prior Knowledge Related to Solution Accuracy on Fraction Division Problems with LEGO® Bricks?

Table 4 shows the means and the standard deviations for the Accuracy Scores on the Learning Task and the Transfer Task as a function of prior knowledge.

Table 4

Means and Standard Deviations for Accuracy Scores on the Learning and Transfer Tasks by Prior Knowledge

Measure	Learning accuracy			Transfer accuracy		
	n	*M*	*SD*	*n*	*M*	*SD*

Low prior knowledge	19	.67	.25	19	.74	.31
High prior knowledge	19	.90	.14	19	.84	.29

I conducted a 2(prior knowledge: low, high) by 2(task type: learning, transfer) mixed ANOVA, with prior knowledge (i.e., low, high) as the between groups measure and task type (i.e., learning, transfer) as the within groups measure. The dependent measure used in the analysis was the Accuracy Score, which reflected whether the participant arrived at the correct solutions to the problems with the LEGO® bricks regardless of whether they counted the bricks or the studs. My prediction was that there would be a difference in children's performance on the Learning Task and the Transfer Task and that task type would interact with prior knowledge.

The results showed that there was a main effect of prior knowledge, $F(1, 36) = 5.53$, $p = .02$, with the high prior knowledge group ($M = .87$, $SD = .20$) outperforming the low prior knowledge group ($M = .71$, $SD = .23$) on the Accuracy Score. There was no main effect of task type nor a prior knowledge by task type interaction, however. These findings suggest that children with low prior knowledge had less accurate solutions than children with high prior knowledge, regardless of task type.

Research Question 4: What Strategies did Children Use When Solving Fraction Division Problems with LEGO® Bricks?

The descriptive analysis on students' strategy use provides information about the types of errors children made when solving fraction division problems with LEGO® bricks. The statistical analyses showed that there were differences in Accuracy Scores between participants who had low and high prior knowledge of fraction concepts. Although almost three quarters of the participants counted the bricks rather than the studs to solve the problems, their solutions were not always correct. To gain a descriptive portrait of how students used the LEGO® bricks to solve fraction division problems after instruction, I conducted an error analysis on participants' performance on the Learning Task and the Transfer Task as a function of prior knowledge.

Strategy Use with Student as Item of Analysis

To determine the types of errors participants made on the Learning Task and the Transfer Task, I looked at the participants who generated incorrect solutions. Then, I used the interview videos to observe why their solutions were not correct. I observed only one type of error during the Learning Task – namely, participants chose the wrong brick to represent the dividend fraction in the written problem. In addition, I found three types of errors during the Transfer Task: (a) participants counted the studs, (b) participants chose the wrong dividend brick, and (c) participants chose the wrong dividend brick and counted the studs. Figure 10 shows an example of participants choosing the wrong brick to represent the dividend on the Transfer Task.

Figure 10

Example of a Participant Choosing the Wrong Dividend Brick on the Transfer Task

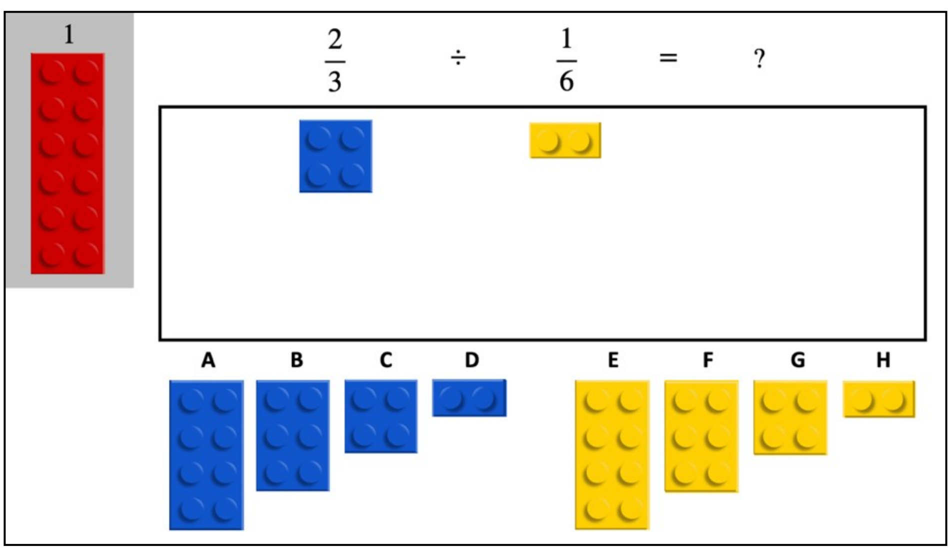


Table 5 shows the number of times each type of response (i.e., wrong dividend brick, correct response) was made during the Learning Task by prior knowledge, using item as the unit of analysis.

Table 5

Number of Times Incorrect and Correct Bricks were Chosen on the Learning Task by Prior Knowledge (N = 190)

Source	Wrong dividend brick		Correct dividend brick	
	n	%	*n*	%
Low prior knowledge	29	30.53[a]	66	69.47[a]
High prior knowledge	8	8.42[a]	87	91.58[a]
Total	37	19.47[b]	153	80.53[b]

[a]Percent represents the proportion of errors committed out of the total number of responses in each prior knowledge group (*n* = 95).

[b]Percent represents the proportion of all 190 responses.

A chi-square test examining the relation between prior knowledge and error type on the Learning Task revealed a significant association, $\chi^2(1, N = 190) = 14.8, p < .001$. Table 5 reveals that there was a greater proportion of items on which participants with low prior knowledge (30.53%) chose the wrong dividend brick compared to items completed by participants with high prior knowledge (8.42%).

Table 6 shows the number of times each type of response was made during the Transfer Task by prior knowledge, using item as the unit of analysis.

Table 6

Error Frequency on the Transfer Task by Prior Knowledge (N = 190)

Source	Counted studs	Wrong dividend brick	Wrong dividend brick and counted studs	Correct

	n	%	n	%	n	%	n	%
Low prior knowledge	7	7.37[a]	13	13.68[a]	4	4.21[a]	71	74.74[a]
High prior knowledge	11	11.58[a]	4	4.21[a]	0	0	80	84.21[a]
Total	18	9.47[b]	17	8.95[b]	4	2.11[b]	151	79.47[b]

[a]Percent represents the proportion of errors committed out of the total number of responses in each prior knowledge group (n = 95).

[b]Percent represents the proportion of all 190 responses.

A chi-square test examining the relation between prior knowledge and response type on the Transfer Task revealed a significant association, $\chi^2(3, N = 190) = 10.19, p = .02$. Table 6 shows that the proportion of items completed by participants with low and high prior knowledge differed by response type. More specifically, participants with low prior knowledge chose the wrong dividend brick on 17 items (17.89% of all 95 responses), whereas participants with high prior knowledge chose the wrong dividend brick on 4 items (4.21% of all 95 responses). In line with the statistical analyses on the Accuracy Scores, participants with high prior knowledge used the correct procedure on 84.21% of the 95 items, whereas participants with low prior knowledge chose the correct procedure on 74.74% of the 95 items.

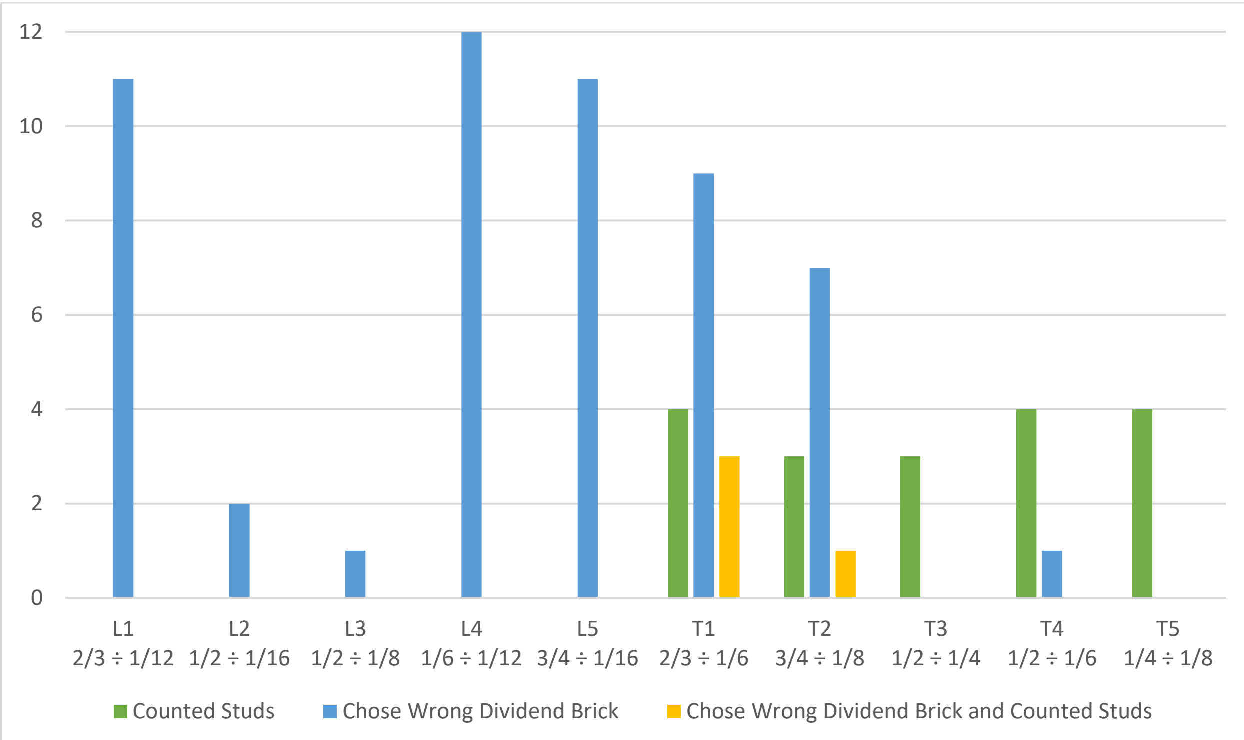
Interestingly, Table 6 also reveals that, despite the low incidents of errors overall, the most common type of error type produced by participants with low prior knowledge was choosing the wrong brick to represent the dividend fraction on the Transfer Task.

Item Analysis

Figure 11 shows the number of times each error type was made on each Learning and Transfer item, including the number of times the studs were counted on the Transfer Task, using participant as the unit of analysis.

Figure 11

Number of Times Each Error Type was Made by Item on the Learning and Transfer Tasks (N = 380)



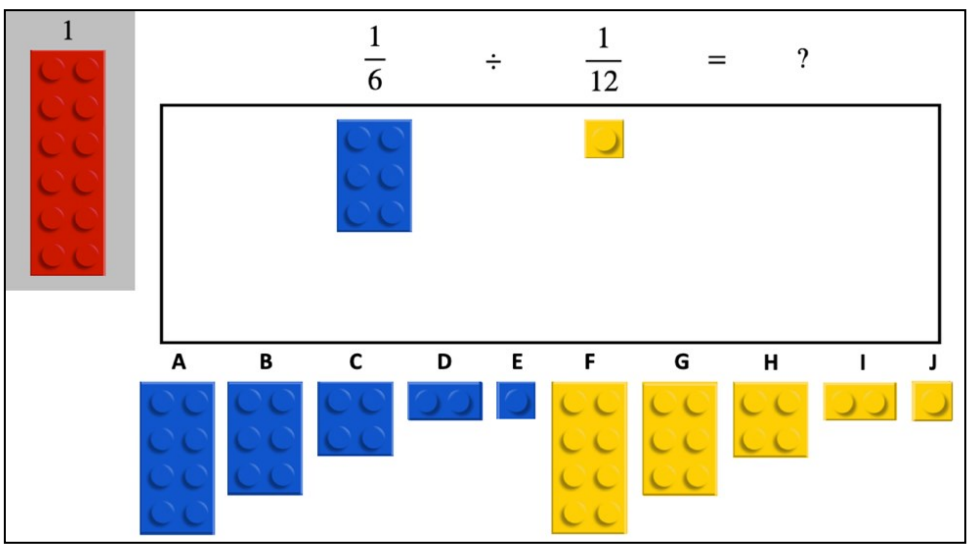
In total, participants made 76 errors across all Learning and Transfer items (20.00% of all 380 items). I hypothesized that participants would make more errors on the Transfer Task compared to the Learning Task because more types of errors were possible on the Transfer Task. The data revealed, however, that participants made as many errors on the Learning Task as on the Transfer Task. Specifically, of all 76 errors made, 37 of them were on the Learning Task (48.68% of all errors on the Learning Task), whereas on the Transfer Task, errors were made 39 times (51.32%).

On the Learning Task, excluding Learning item 4, participants chose the wrong dividend brick 22 times (59.46% of all 37 errors made on the Learning Task) when the fraction in the problem was a non-unit fraction (e.g., $\frac{2}{3}, \frac{3}{4}$). In contrast, they chose the wrong dividend brick 15 times (40.54% of errors made in the Learning Task) when the fraction in the problem was a unit fraction (e.g., $\frac{1}{2}$, $\frac{1}{4}$). In other words, children made the mistake of choosing the wrong dividend brick more times when the dividend was a non-unit fraction than a unit fraction.

Figure 11 shows that on Learning item 4, participants used a 3 x 2 brick to represent $\frac{1}{6}$, the dividend fraction, 12 times (32.43% of errors made on the Learning Task). The 3 x 2 brick in Figure 12 represents $\frac{1}{2}$ of the whole rather than $\frac{1}{6}$. Perhaps the participants chose the 3 x 2 brick in this case because it contained the same number of studs as the denominator in the dividend fraction (i.e., 6).

Figure 12

Example of a Participant Choosing the Wrong Dividend Brick to Solve Learning Item 4



On the Transfer Task, the studs error was evenly distributed across the items, which suggests the participants were not more likely to count studs on certain types of items over others. In contrast, a more striking error pattern emerged for the wrong dividend error than on the Learning Task. Specifically, participants chose the wrong dividend brick 20 times on the Transfer Task (95.24% of all wrong dividend errors) when the fraction in the problem was a non-unit fraction (i.e., transfer items 1 and 2). In contrast, participants chose the wrong dividend brick only one time when the fraction in the problem was a unit fraction. In other words, children made the mistake of choosing the wrong dividend brick more times when the dividend was a non-unit fraction compared to a unit fraction.

Table 7 shows the number of items on which the wrong dividend brick error was committed as a function of item type (i.e., non-unit and unit dividends) on the Learning Task, by prior knowledge.

Table 7

Number of Times Participants Chose Wrong Dividend Brick on Problems with Non-Unit and Unit Dividends on the Learning Task by Prior Knowledge (N = 37)

Source	Non-unit fraction		Unit fraction	
	n	%	*n*	%
Low prior knowledge	18	62.07	11	37.93
High prior knowledge	4	50.00	4	50.00

Note. Low prior knowledge (n = 29) and high prior knowledge (n = 8). The percent represents the proportion of all errors committed relative the total number of responses in each prior knowledge group.

A chi-square test examining the relation between prior knowledge and item type on the Learning Task did not reveal a significant association, $\chi^2(1, N = 37) = .379, p = .538$. These results indicate no relation between prior knowledge and item type on wrong dividend errors.

Table 8 shows the number of items on which the wrong dividend brick error was committed as a function of item type (i.e., non-unit and unit dividends) on the Transfer Task, by prior knowledge, using item as the unit of analysis.

Table 8

Number of Times Participants Chose Wrong Dividend Brick on Non-Unit and Unit Dividends on the Transfer Task by Prior Knowledge (N = 21)

Source	Non-unit fraction		Unit fraction	
	n	%	*n*	%
Low prior knowledge	16	94.12	1	5.88
High prior knowledge	4	100.00	0	0

Note. Low prior knowledge (n = 17) and how prior knowledge (n = 4). The percent represents the proportion of all errors committed relative the total number of responses in each prior knowledge group.

A chi-square test examining the relation between prior knowledge and item type on the Transfer Task did not reveal a significant association, $\chi^2(1, N = 21) = .247, p = .538$. These results indicate no relation between prior knowledge and item type on wrong dividend errors.

Chapter 6: Discussion

The present study examined fifth- and sixth-graders' performance on fraction division problems using LEGO® bricks following an instructional intervention. The first objective of the study was to investigate whether the studs on the LEGO® bricks act as irrelevant details in children's learning of the procedure to solve fraction division problems with LEGO® bricks. The second objective was to examine whether children's prior knowledge of fractions predict the degree to which they were distracted by the studs on the LEGO® bricks. The third objective was to determine whether prior knowledge is predictive of students' performance accuracy on the Learning and Transfer Tasks. Given that little is known about how children use LEGO® bricks in mathematical contexts, the final objective was to document the ways in which participants used the LEGO® bricks to solve fraction division problems.

With respect to the first research question, I predicted that the studs would distract the participants on the Transfer Task when they counted the number of times the divisor fits into the dividend brick. This prediction was supported by existing literature suggesting that irrelevant details on concrete and non-concrete representations may hinder students' learning in mathematics. For instance, McNeil et al. (2009) speculated that perceptually rich bills and coins possessed features that hindered problem-solving performance. Similarly, Uttal et al. (2013) speculated that colors and patterns on manipulatives distracted children from solving mathematics problems in appropriate ways, which made it difficult for them to create connections between the manipulatives and their written representations. Lastly, Kaminski and Sloutsky (2013) concluded that the presence of images in bar graphs distracted children from using appropriate strategies for reading bar graphs.

The data from the present study did not support my hypothesis, however, as the findings revealed that the studs did not act as irrelevant details when solving fraction division problems with LEGO® bricks. In fact, only seven of the 38 participants counted the studs at least once, regardless of prior knowledge. Explaining these findings is challenging because little is still known about the types of irrelevant features in instructional representations that may hinder or facilitate mathematics learning. More specifically, to my knowledge, there is no literature that explores the effects of the physical features of LEGO® bricks when they are used as manipulatives in mathematical contexts. Some recent research on the irrelevant details effect may provide clues to explain the findings, however. Sitzmann and Johnson (2014) speculated that when participants have sufficient time to review their work, the irrelevant details effect may not emerge. This may in part explain why the effects were not detected in the present study: The participants were not given a time limit on either the Learning or Transfer Task, possibly affording them the time to reflect on whether the studs were relevant or not.

Additionally, Sundararajan and Adesope (2020) conducted a meta-analysis on the irrelevant details effect, and they shared several moderators that may influence the irrelevant details effect. For instance, the authors explained that there may be differences between static and dynamic irrelevant details. The authors defined a static representation as a non-animated image on display when learning, and a dynamic representation as a GIF or a video. Specifically, irrelevant details that remain static were found to have negative effects on learning (i.e., they are distracting), whereas dynamic ones were found to have no significant impact on learning. Sundararajan and Adesope (2020) speculated that static representations may imply importance or salience (relative to dynamic ones), and the resulting attention paid to the representation would include the processing of the irrelevant details, disrupting the creation of a coherent mental model. In the current study, the instructional intervention included animation, which, according to Sundararajan and Adesope (2020), is a dynamic representation. Therefore, perhaps the fifth- and sixth-grade students did not get distracted by the studs because the dynamic representations in the instructional videos were perceived as less salient.

Similarly, in their meta-analysis, Sundararajan and Adesope (2020) found that delivery format can play a role on the effects of irrelevant details. For example, the authors found that irrelevant details have a larger negative effect on learning when the material is presented on paper compared to when it is presented digitally. The authors speculated that paper-based materials include static irrelevant details, which may create disruption to participants' mental models. Rey et al. (2019) also explain that digital presentations can be designed to sequence instruction in meaningful ways for the learner, which can promote better learning outcomes. Thus, in addition to the current study being presented in a digital format, the videos included in the instructional intervention were also designed to present the material in a sequence that promotes learning. Perhaps this is another reason why the studs were not found to be as distracting as I had hypothesized.

The fact that the current study was conducted online may have reduced the irrelevant details effect. For instance, on the Learning and Transfer Tasks, the participants instructed the researcher to place divisor bricks on the dividend brick on each problem. Online, however, placing the bricks on the dividend could only be done one at a time, perhaps prompting the students to count the bricks while they were being placed. Using physical LEGO® bricks might have had a different outcome on the Transfer Task: Students may have taken more than one 2 x 1 divisor bricks at a time, and only after having placed all of them, counted the studs on the dividend. A replication of the present study is therefore necessary with physical LEGO® bricks.

Furthermore, perhaps participants were not distracted by the studs because the instructional intervention was particularly effective in teaching the participants the conceptual underpinnings of measurement division with fractions. In fact, instruction that emphasizes the underlying concepts supports students' conceptual understanding, promotes transfer, and can generate accurate and flexible problem-solving procedures (Rittle-Johnson & Alibali, 1999). Rittle-Johnson and Alibali (1999) also found that children who receive conceptual instruction are more likely to learn a correct procedure, which in the case of the present study, is counting the number of divisor bricks in the dividend. In the current study, the concepts behind fraction division were emphasized in the instructional intervention, with specific conceptual instructions repeated six times during the Fractions Division video. An example of the conceptual explanation that was provided for solving all three problems was, "to solve the problem, I need to find how many $\frac{1}{16}$ths there are in $\frac{1}{4}$." This explanation hinged more on the concepts behind measurement division than had the narrator said, for example, "now watch what I am counting to get the answer." The conceptual explanation was narrated before and each time the procedure was shown to the participants. Anecdotally, some of the participants repeated this explanation to the researcher when they were asked to justify their answers during the Learning Task and the Transfer Task. The fact that participants repeated and perhaps understood the conceptual instruction provided in the Fractions Division video could explain why the studs were not found to be distracting.

A follow-up study that should be considered would be an investigation into the instructional factors (e.g., conceptual versus procedural) that may moderate the irrelevant details effect. It would be important to test if the conceptual instruction provided in the instructional intervention compensated for any negative effects of the irrelevant details (i.e., counting the studs on the LEGO® bricks). To do this, participants could be assigned to a condition receiving conceptual instruction of fraction division, while the other condition would receive procedural instruction without any explanation of relevant concepts. Based on the results of the current study, I would predict that the participants who would receive the conceptual instruction would be less distracted by the studs on the LEGO® bricks compared to the participants receiving the procedural instruction.

The second research question aimed to test the relation between prior knowledge and the degree to which participants got distracted by the studs. I hypothesized that participants with low prior knowledge would obtain a lower Distraction Score (i.e., more distracted) compared to participants with high prior knowledge (Kalyuga, 2007; Magner et al., 2014; Maloy et al., 2019; Park et al., 2011; Sweller, 2010). In contrast, I predicted that the participants with high prior knowledge would receive a higher Distraction Score (i.e., less distracted), because their higher prior knowledge would allow them to overcome the irrelevant details on the Transfer Task (Harp & Mayer, 1998; Magner et al., 2014; Star et al., 2009; Wang & Adesope, 2016). Magner et al. (2014) speculated that high prior knowledge learners may not be affected by irrelevant details because their greater working memory capacity would allow them to chunk new information and overcome the additional cognitive load created by irrelevant details. This would enable learners with higher prior knowledge to ignore irrelevant details by focusing their attention on the relevant information, organizing selected information into coherent mental representations, and integrating these mental representations with prior knowledge from their long-term memory (Magner et al., 2014). In contrast, low prior knowledge learners may not have the cognitive capacity to store meaningful chunks of incoming information. For these learners, irrelevant information may cause a working memory overload (Kalyuga, 2007; Magner et al., 2014; Maloy et al., 2019; Park et al., 2011; Sweller, 2010), and as a result, students with low prior knowledge may direct their attention to the irrelevant details, hindering learning and performance (Harp & Mayer, 1998, p. 415). The results of the present study did not support any prior knowledge effects on the degree to which the participants were distracted by the studs on the LEGO® bricks, presumably because very few participants in the sample were negatively impacted by what I hypothesized would be irrelevant details.

The third research question entailed testing for a relation between prior knowledge and participants' solution accuracy on the fraction division problems with LEGO® bricks. Specifically, I predicted that participants with high prior knowledge would receive a higher Accuracy Score compared to participants with low prior knowledge. The data supported this hypothesis; the results showed that there was a main effect of prior knowledge on the Accuracy Score, with the low prior knowledge group generating less accurate solutions than children with high prior knowledge, regardless of task type (i.e., learning and transfer). No interaction was found between prior knowledge and task type. Together, these results suggest that having high prior knowledge on fractions concepts supported the participants' performance accuracy on the fraction division problems on both Learning and Transfer Tasks.

The observed prior knowledge effect on solution accuracy is in line with previous research showing that prior knowledge is related to mathematics learning, because it allows learners to connect previously learned information to new information (Kalyuga, 2007; Sweller, 2010). In the current study, participants with high prior knowledge generated a more accurate solutions and made fewer errors than their low prior knowledge counterparts. Rittle-Johnson et al. (2001) found that high prior conceptual knowledge of decimal fractions predicted performance on transfer of procedures to novel problems. These authors speculated that prior conceptual knowledge can guide children's choices among alternative procedures. In turn, children may use their conceptual knowledge to evaluate the relevance of known procedures to novel problems. Therefore, it is likely that participants in the current study with high prior knowledge were more accurate on the fraction division problems because their conceptual knowledge of fractions could have assisted them to evaluate the relevance of the division procedure and thus apply their knowledge to the novel problem on the Transfer Task.

The fourth and final research question aimed to describe the strategies children used when solving fraction division problems with LEGO® bricks. The statistical analyses revealed that there was a difference between the low and high prior knowledge participants on their accuracy when solving fraction division problems. Although almost three quarters of the participants counted the bricks rather than the studs to solve the problems, and that no prior knowledge differences emerged on the extent to which they were distracted by the studs on the Transfer Task, their solutions were not always correct. The descriptive analyses revealed that children used correct strategies and a variety of incorrect strategies when solving the fraction division problems with LEGO® bricks. In terms of their errors, I observed a single type of error on the Learning Task: Participants chose the wrong brick to represent the dividend fraction in the problems. In addition, I found three types of errors on the Transfer Task: (a) Participants counted the studs, (b) participants chose the wrong dividend brick, and (c) participants chose the wrong dividend brick and counted the studs.

The descriptive analyses also revealed that the number of errors generated differed according to the students' prior knowledge. Although the number of errors were few in both prior knowledge groups, participants with low prior knowledge chose the wrong dividend brick more times than the high prior knowledge participants. Additionally, although all participants, regardless of prior knowledge, made a greater number of wrong-dividend errors when the dividend fraction was a non-unit fraction than a unit fraction on both Learning and Transfer items, this pattern did not differ by prior knowledge.

In sum, although the students still committed errors on both the Learning and Transfer Tasks, the data revealed that the majority of the students learned the correct procedure to solve fraction division problems (i.e., counted the bricks rather than the studs). This is important because while students may still struggle to represent fractional quantities using LEGO® bricks, they are still able to demonstrate an understanding of how to solve measurement division problems with fractions.

Limitations

There were a few limitations of the present study. First, a ceiling effect was found on the LEGO® Representation Task. This prevented the researcher from using the scores on the LEGO® Representation Task to further characterize the prior knowledge groups. Second, perhaps the Fractions Division video was effective in teaching the fifth- and sixth-grade students the conceptual meaning of measurement division in the context of solving fraction division problems with LEGO® bricks. This is considered a weakness in the present study because it is possible that the participants, understanding what it means to "count the number of times the divisor goes into the dividend" resulted in overcoming the studs as irrelevant on the Transfer Task. Finally, perhaps all participants in the study had sufficient prior knowledge to overcome the hypothesized irrelevant details on the Transfer Task. A future study should therefore replicate the present study, but with students from lower grade levels (e.g., Grade 4).

Third, the setting of the study was a major limitation. Specifically, because of COVID-19-related restrictions, the participant interviews had to be conducted via Zoom with the participants at home. Perhaps the home setting played a role in their overall performance. For instance, the data may have been compromised because of distractions (e.g., noises) in the home. There was also no control over the test administration. For example, the parents were instructed not to open the envelope that contained the Fractions Test until the Zoom interview with the researcher began. However, it is possible that participants opened the envelope prior to the interview. Another example is that although I had intended for a 10-minute limit to complete the Fractions Test, the online administration prevented me from controlling this procedure.

Additionally, the study materials had to be designed for online purposes. The instructional intervention (i.e., videos and the LEGO® Representation Task), as well as the Learning Task and the Transfer Task, had to include computerized images of LEGO® bricks instead of real LEGO® bricks. This is considered a limitation because the fact that participants were not able to physically manipulate the LEGO® bricks may have played a role in their overall performance during the Learning and Transfer Tasks. As a matter of fact, Manches et al. (2010) reported that virtual manipulatives generated constraints that did not exist with physical manipulatives, which influenced the types of strategies children used to solve problems. For example, children who used virtual manipulatives were only able to move one object at a time, whereas children who used physical manipulatives were able to move multiple objects at a time, thus influencing different types of strategies. In the context of the present study, because the children were only able to ask the researcher to place the bricks on the dividend one at a time, this may have encouraged them to count the bricks and not the studs. Therefore, future research should be conducted using real LEGO® bricks because there may be differences in the ways children use the physical bricks to solve the fraction division problems.

Contributions and Educational Implications

The present study contributes to the literature on using LEGO® bricks as supports for mathematics learning because it is the first to assess the use of bricks as manipulatives in children's solving of fraction division problems. Previous studies on LEGO® robotics (e.g., Chalmers, 2018; Coxon et al., 2018; Leonard et al., 2016) and LEGO® play (e.g., Nath & Szücs, 2014; Simoncini et al., 2020; Wolfgang et al., 2003) aimed to assess whether their LEGO® interventions impacted children's computational thinking skills and mathematics achievement, respectively. One of the weaknesses of this research, however, is that the students were not assessed on their uses of the LEGO® bricks after having interacted with them. For instance, Chalmers (2018) used teacher questionnaires and reflections to assess how LEGO® robotics may have supported children's computational skills. Further, Nath and Szücs (2014) tested children's cognitive abilities and mathematical performance using standardized measures after children played with LEGO® bricks. The design of these studies does not allow for conclusions about what specific mathematical concepts the students can learn about LEGO® or how the bricks can be used to solve mathematical problems. Thus, a strength of the current study is that the outcome measures directly assessed students' performance with LEGO® bricks, allowing for more educationally relevant implications for elementary instruction.

Although the studs were found not to distract students' performance, the present study found that prior knowledge on fraction concepts was correlated with accuracy performance on solving fraction division problems with LEGO® bricks. In other words, prior knowledge may play a critical role in children's use of LEGO® bricks in a mathematical context. The present study is also the first to observe the strategies children use when solving fraction division problems. Specifically, the results showed that students generated a variety of strategies when solving the problems. The most prevalent error observed was selecting the wrong dividend bricks to represent the fractions in the problems.

An educational implication of the present study is the importance and the benefits of having high conceptual understanding of fractions. The fact that there was a main effect of prior knowledge on performance shows that knowledge of fractions concepts plays an important role in learning the procedures for solving such problems with LEGO® bricks. In the classroom, before incorporating LEGO® bricks into instruction, teachers may wish to first emphasize the conceptual foundations of fractions to prepare them to learn new mathematical strategies for solving problems. Because conceptual knowledge is related to using correct procedures with LEGO® bricks (Rittle-Johnson & Alibali, 1999), preparing students by emphasizing fractions concepts is important. As a result, children will likely be better able to represent fractions and to solve fraction division problems with LEGO® bricks.

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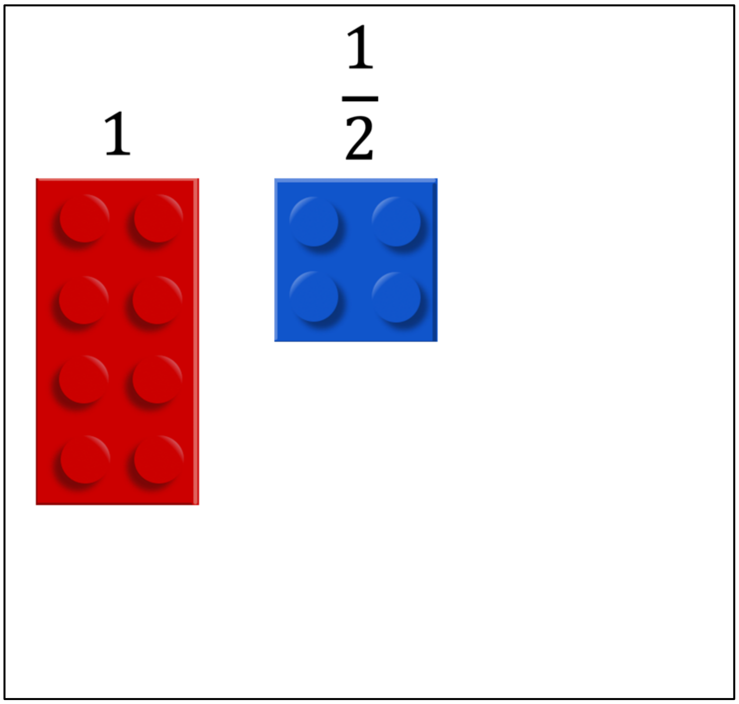
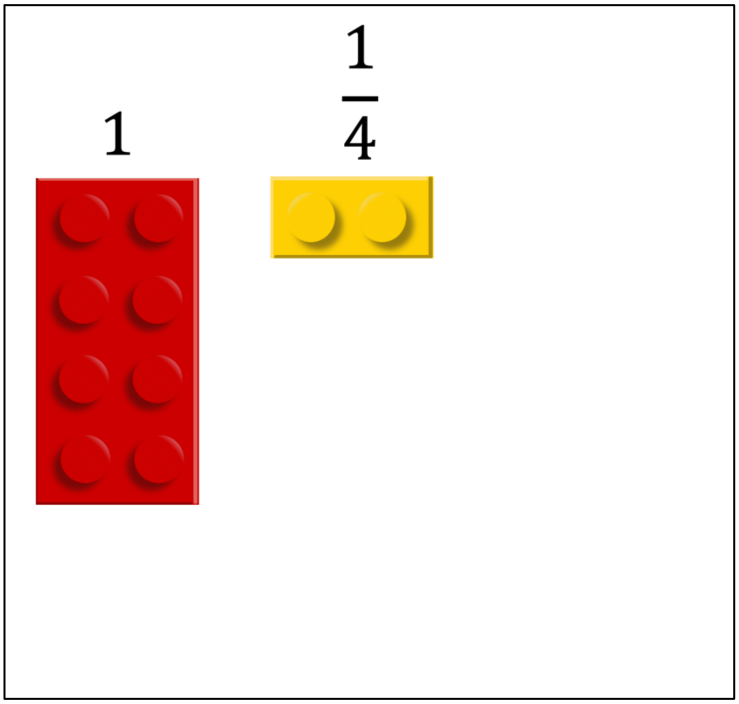
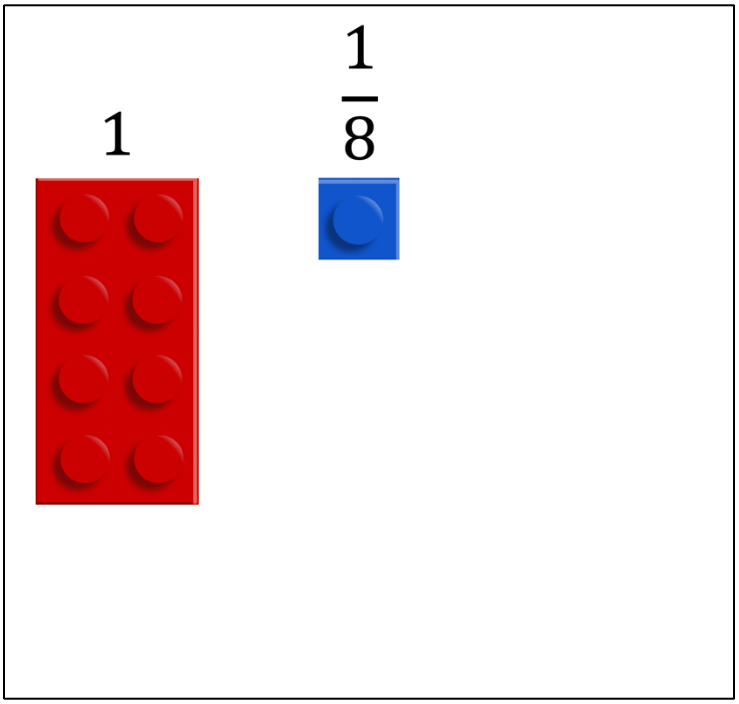
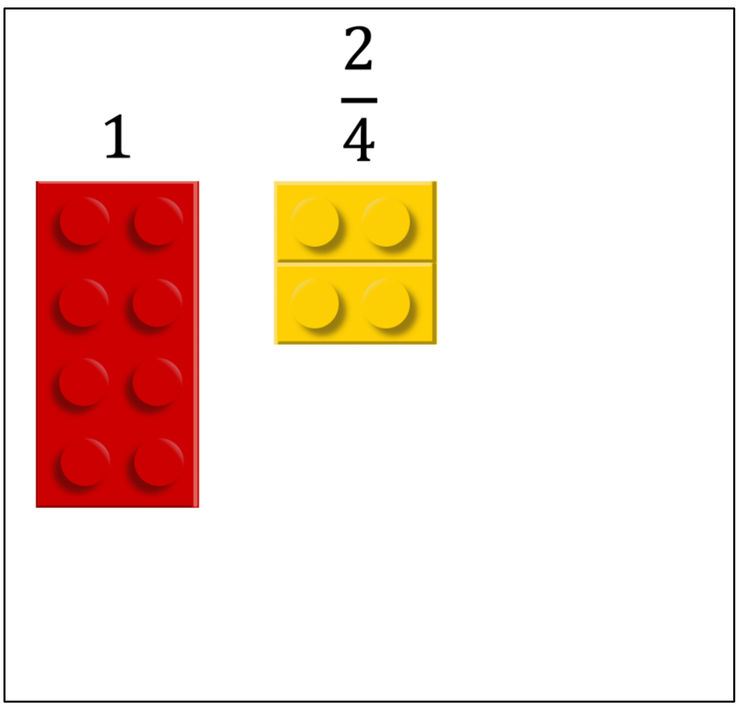
Appendix A

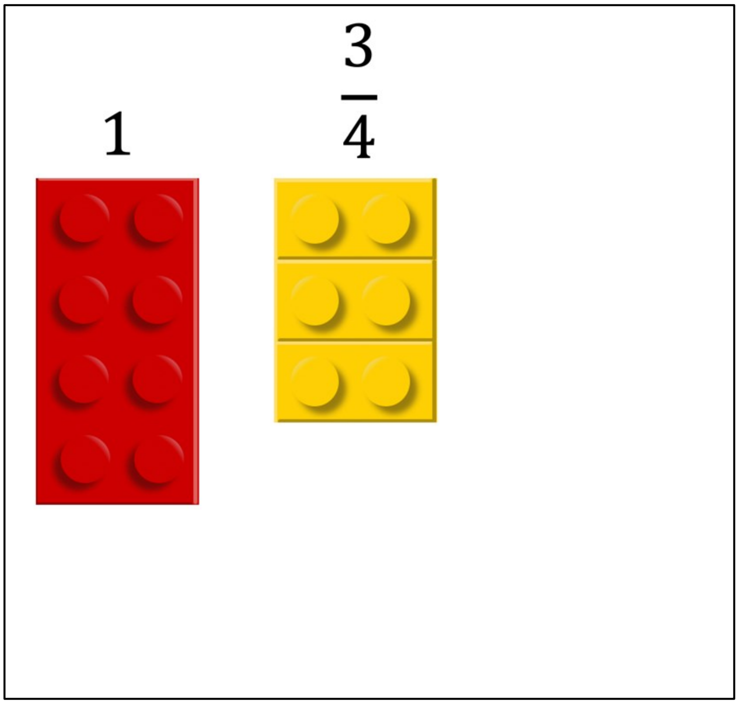
Examples of Fractions Represented in Phase 1 (In Order of Appearance)

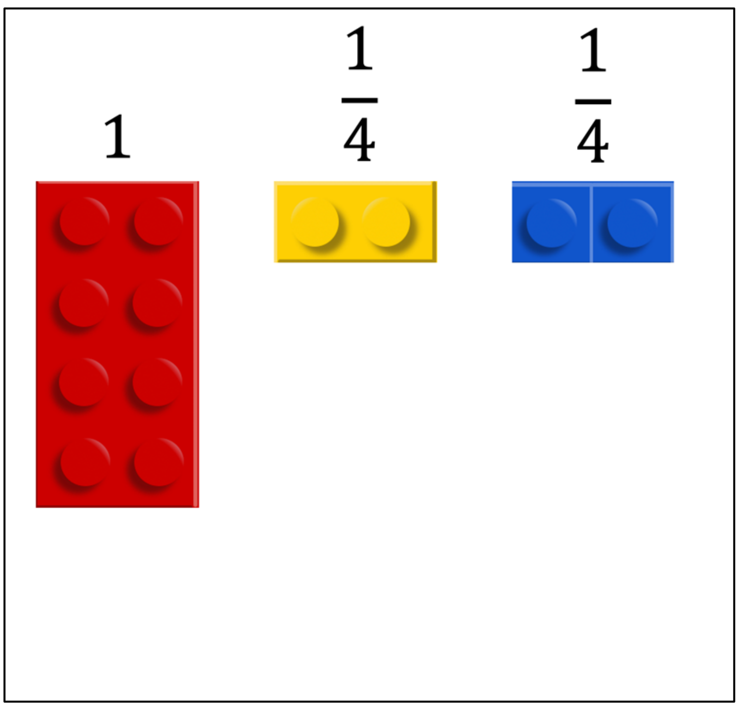


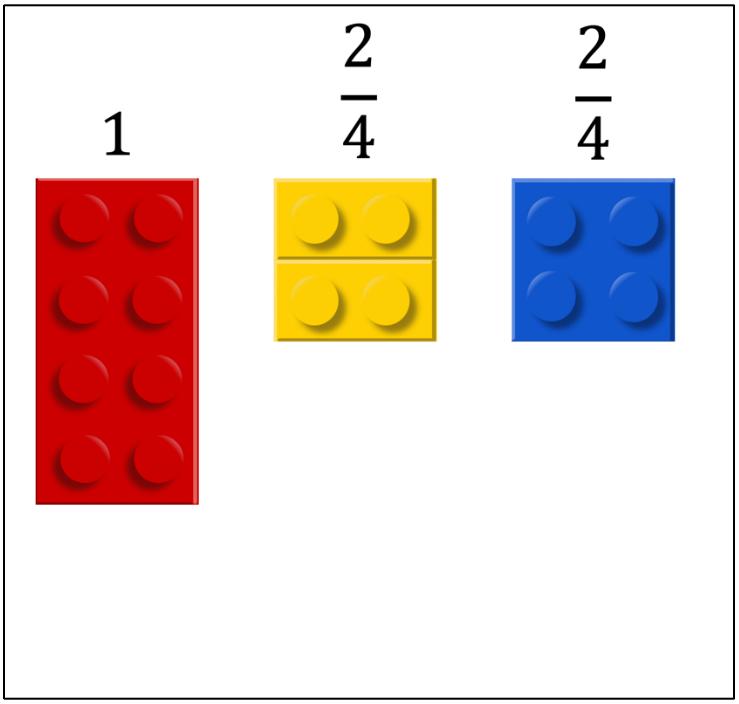


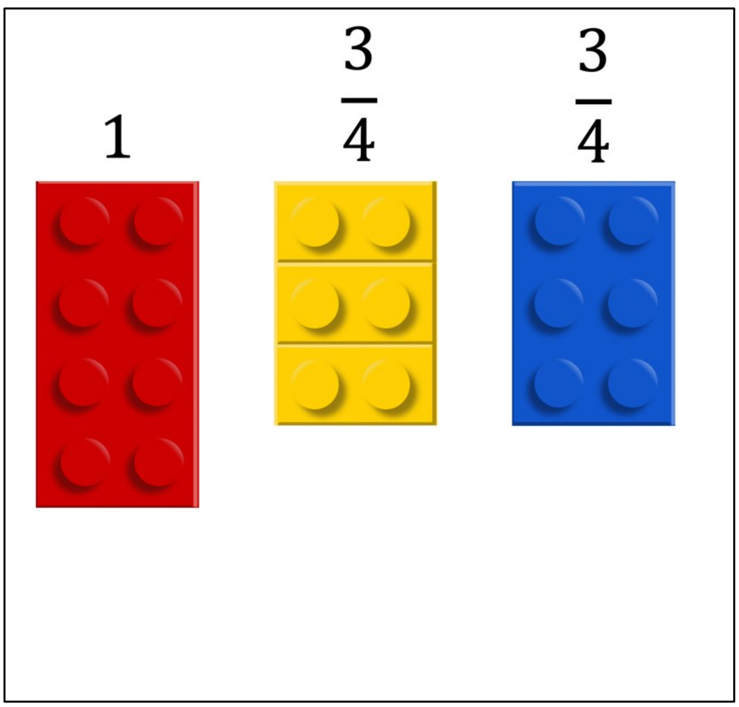

1
$\frac{1}{8}$

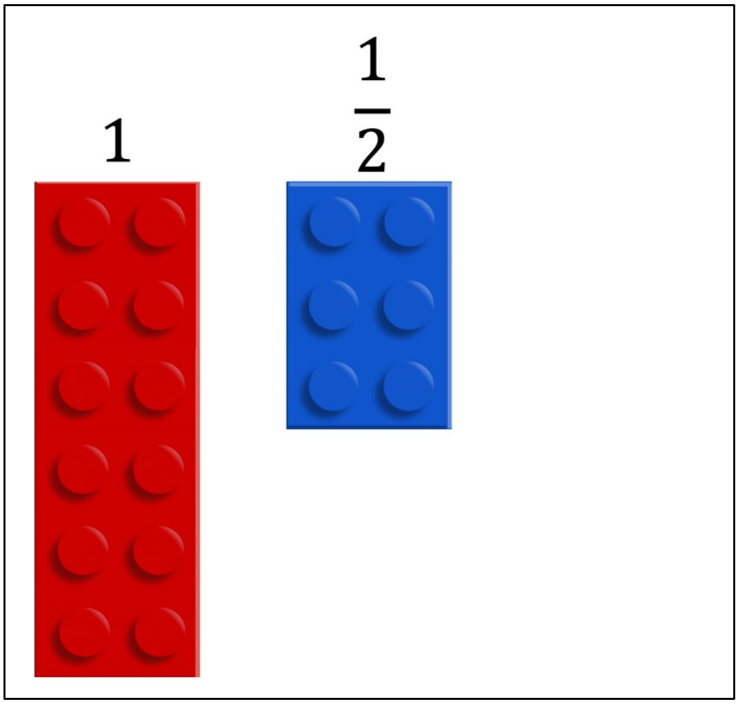

1
$\frac{2}{4}$

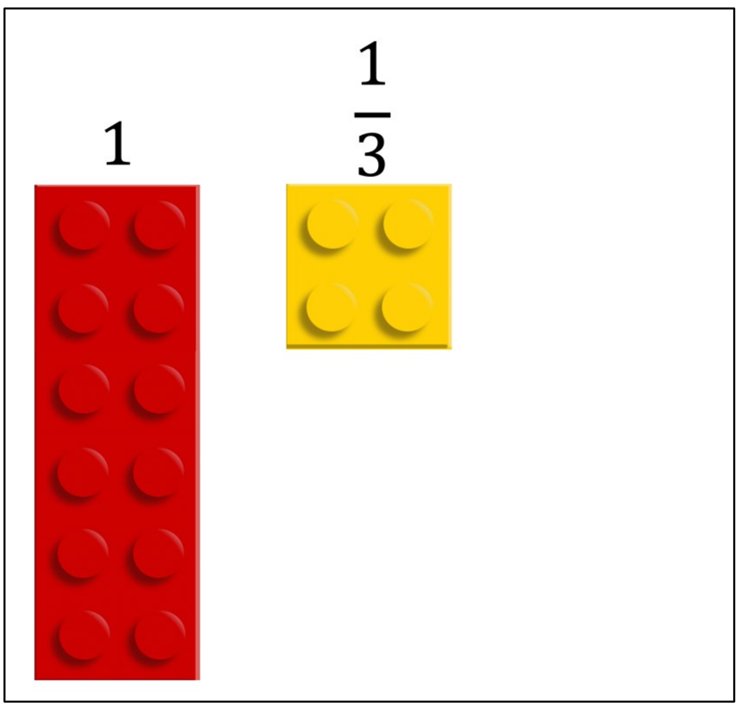

1
3/4

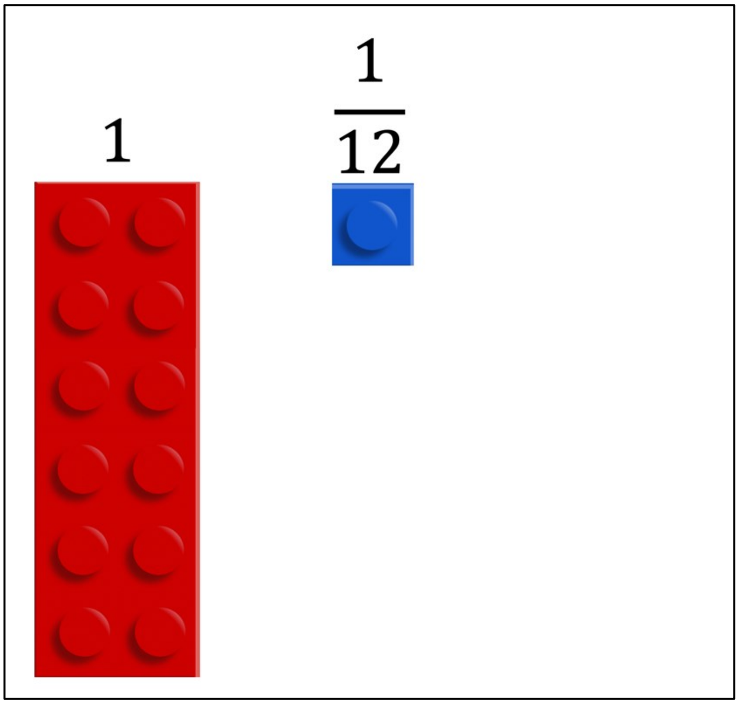

1
1/4
1/4

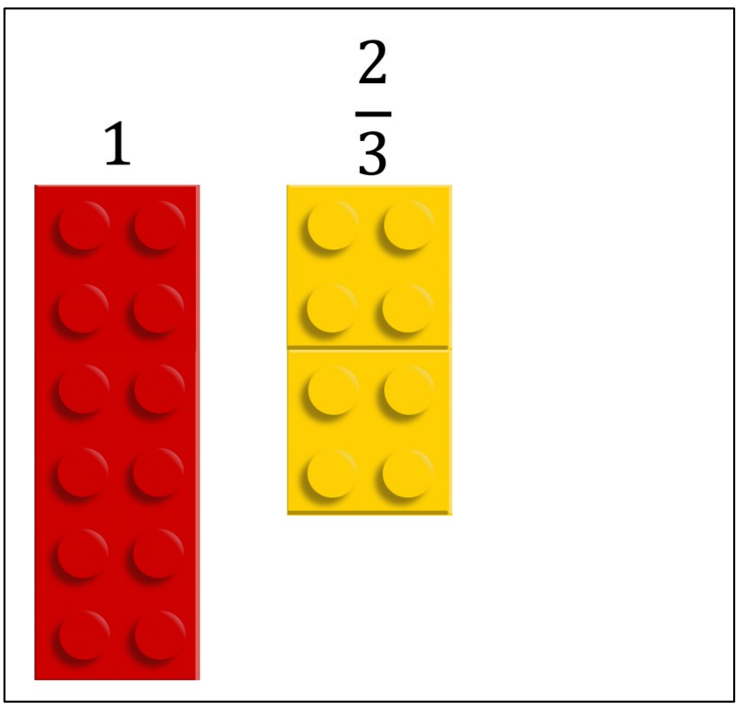

1
$\frac{2}{4}$
$\frac{2}{4}$

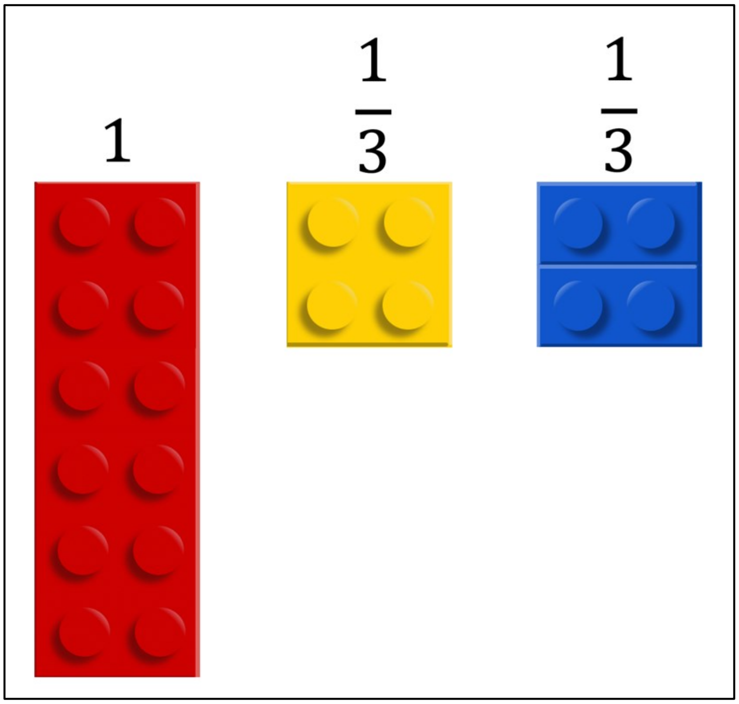

1
$\frac{3}{4}$
$\frac{3}{4}$

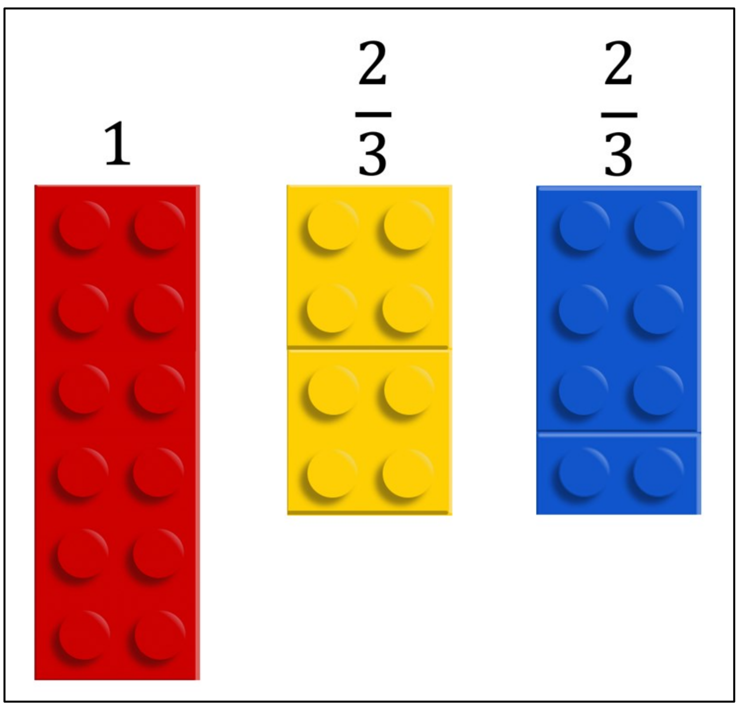

1
1/2


1
1/3


1
1/12


1
2/3

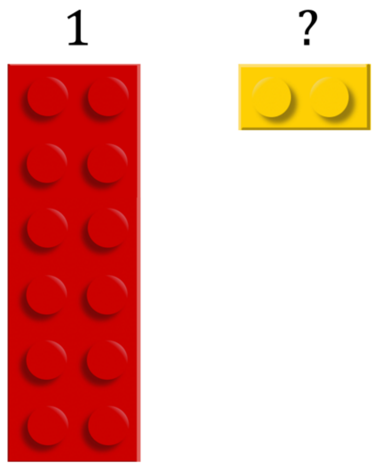

1
$\frac{1}{3}$
$\frac{1}{3}$


1
$\frac{2}{3}$
$\frac{2}{3}$

Appendix B

Multiple-Choice Items (In Order of Appearance)

What does the yellow represent if the red brick is your whole?

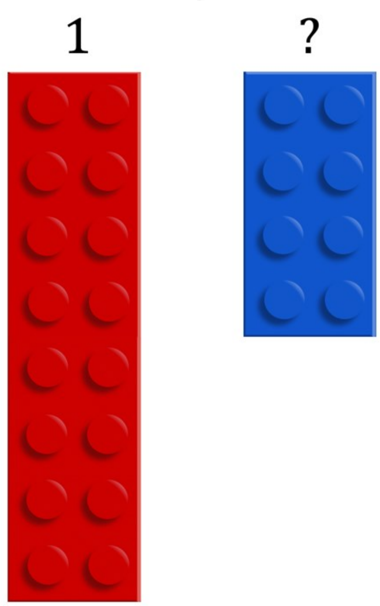


a) $\frac{1}{6}$

b) $\frac{1}{12}$

c) 2

What does the blue represent if the red brick is your whole?

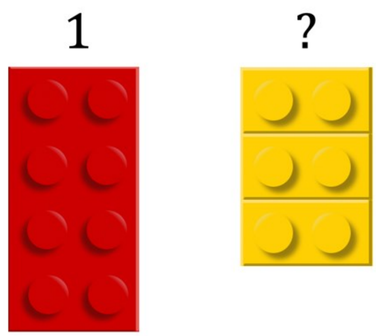


a) $\frac{1}{2}$

b) $\frac{1}{16}$

c) 8

What does the yellow represent if the red brick is your whole?

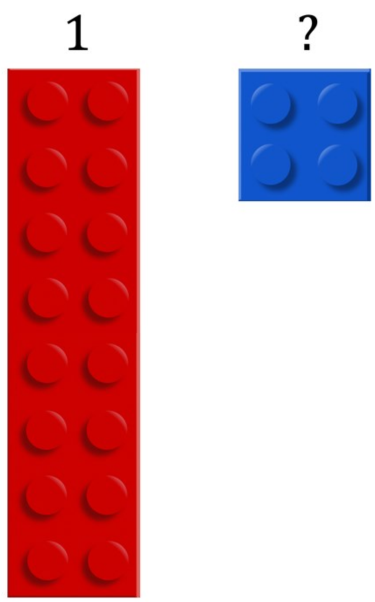


a) $\frac{3}{4}$

b) $\frac{3}{8}$

c) 6

What does the blue represent if the red brick is your whole?

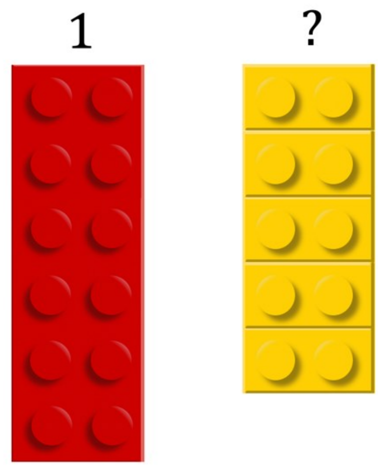


a) $\frac{1}{4}$

b) $\frac{1}{16}$

c) 4

What does the yellow represent if the red brick is your whole?

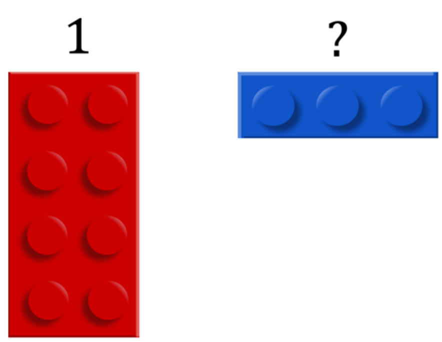


a) $\frac{5}{6}$

b) $\frac{5}{12}$

c) 10

What does the blue represent if the red brick is your whole?



a) $\frac{3}{8}$

b) $\frac{1}{8}$

c) 3

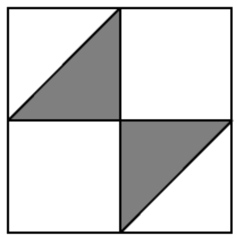
Appendix C

Fractions Test

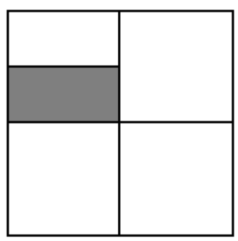
Prénom et Nom : ____ Code : _____

Classe : __________________________

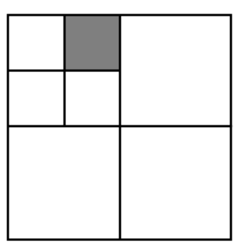
1. Pour chaque image, écris une fraction qui représente la partie grise.

a) 

a) __________

b) 

b) __________

c) 

c) __________

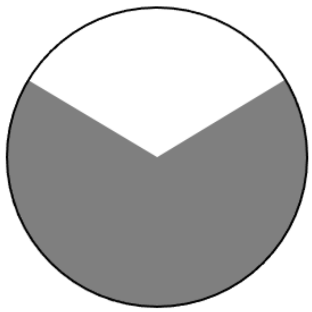
1

Prénom et Nom : ____ Code : ______

Classe : ___________________________

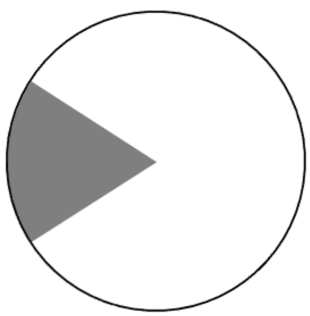
2. Entoure la fraction qui représente le mieux la partie grise.

a)



a) $\frac{1}{4}$ $\frac{3}{5}$ $\frac{9}{10}$

b)

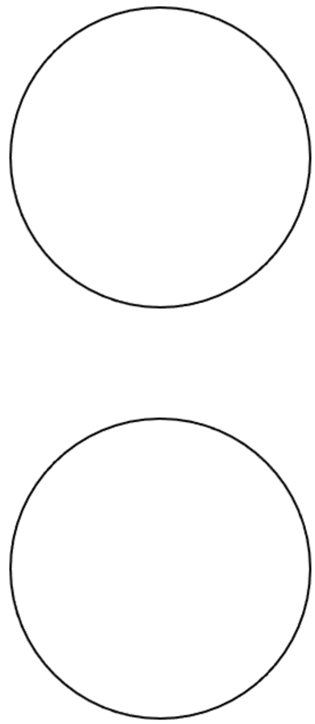


b) $\frac{1}{9}$ $\frac{1}{3}$ $\frac{2}{5}$

Prénom et Nom : ____ Code : _____

Classe : ___________________________

3. a) Quatre personnes vont partager deux pizzas également. Dessine la partie pour une personne.



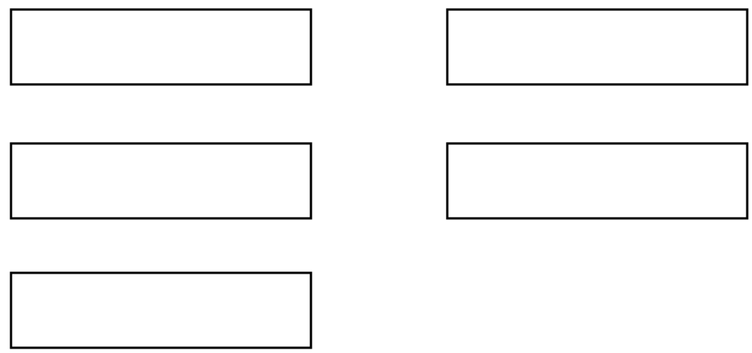
b) Écris la fraction qui représente la partie d'une pizza que cette personne a mangée :

____

Prénom et Nom : ____ Code : ______

Classe : ___________________________

4. a) Six personnes vont partager cinq barres de chocolat également. Dessine la partie pour une personne.



b) Écris la fraction qui représente la partie d'une barre de chocolat que cette personne a mangée :

____

Prénom et Nom : ____ Code : _____

Classe : ___________________________

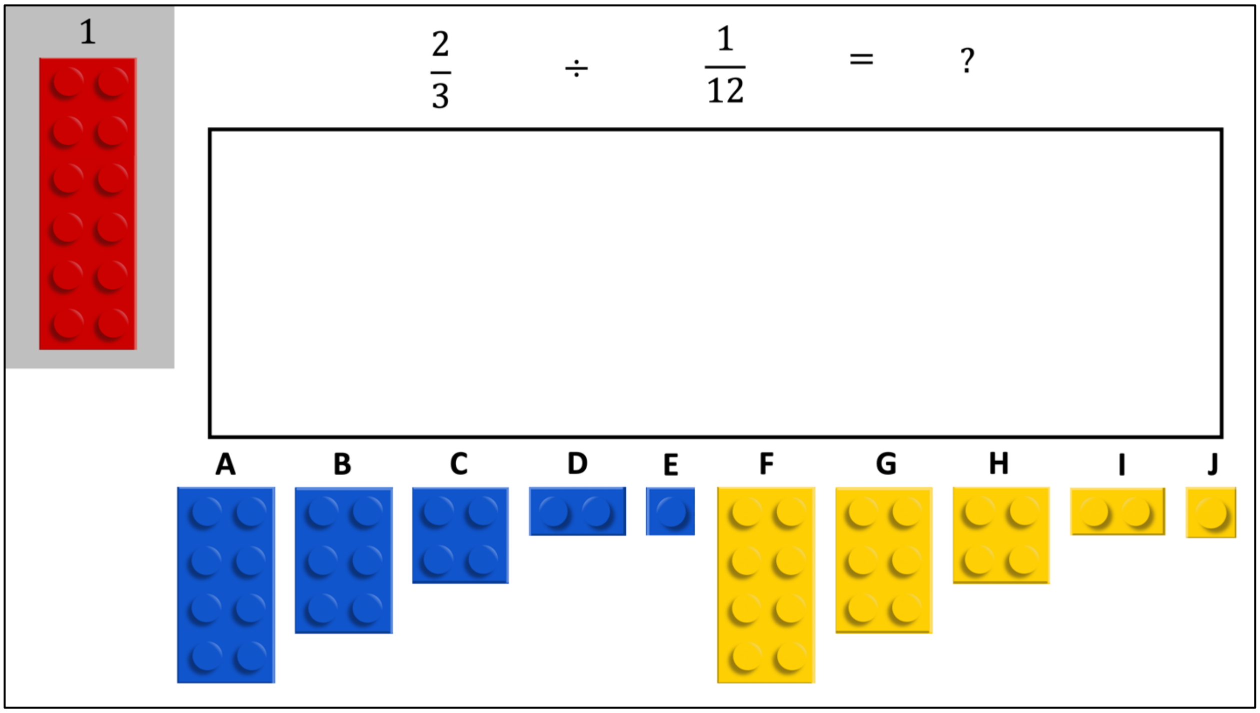
5. a) Jean a couru $\frac{2}{5}$ kilomètres jeudi, et $\frac{3}{5}$ kilomètres vendredi. Combien de kilomètre(s) a-t-il couru au total les deux jours?

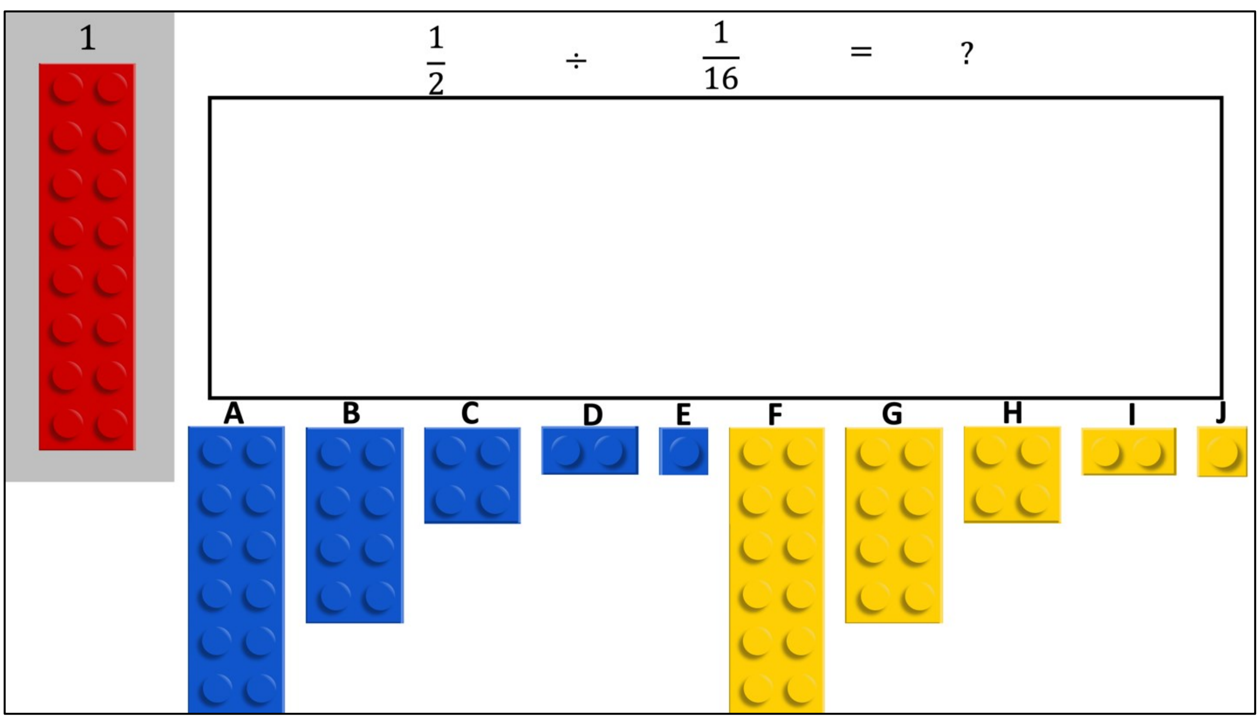
____

b) Dessine une image pour montrer ton travail.

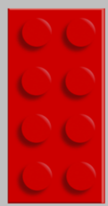
Appendix D

Learning Items (In Order of Appearance)

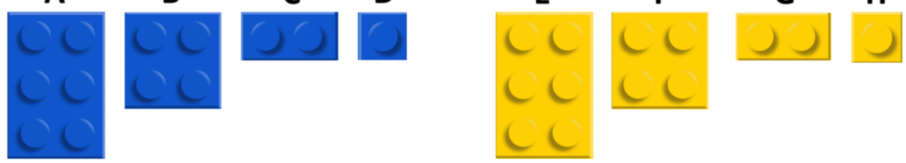




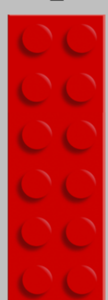
1



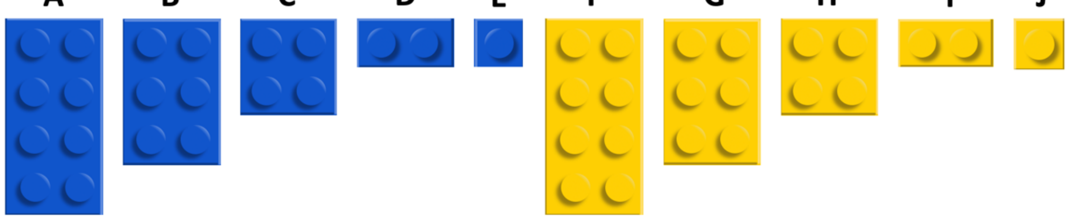
$$\frac{1}{2} \quad \div \quad \frac{1}{8} \quad = \quad ?$$

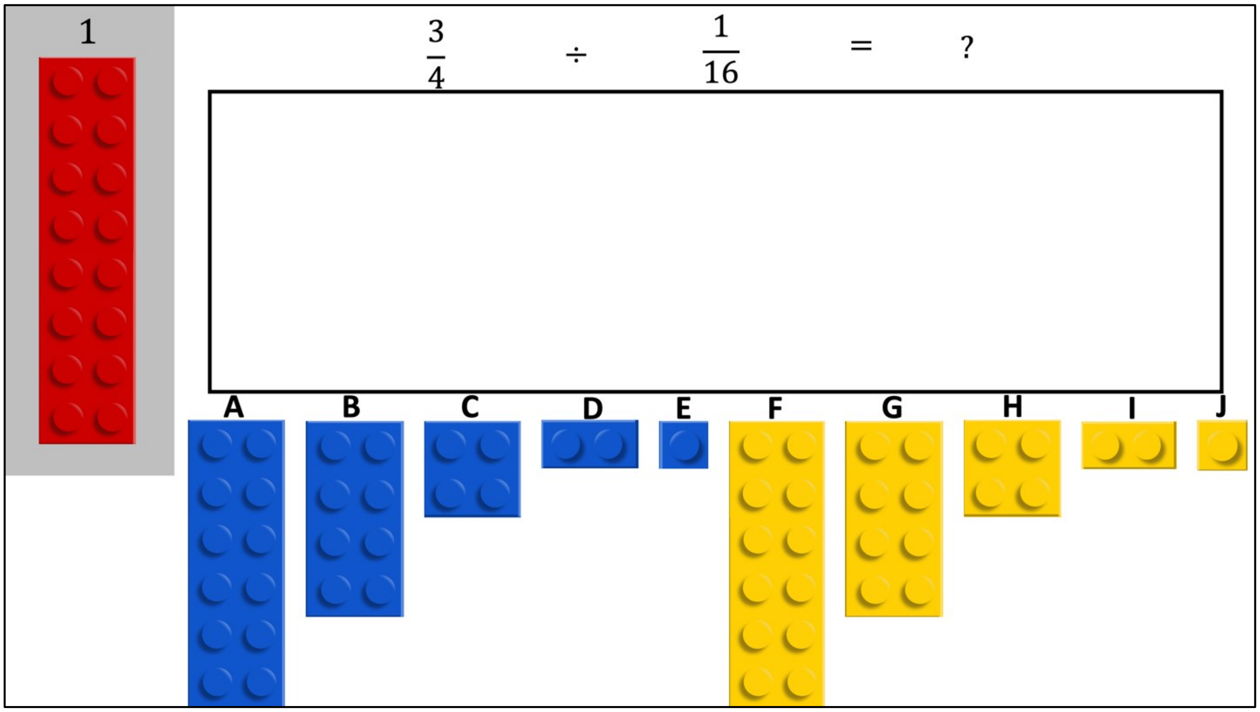


1



$$\frac{1}{6} \quad \div \quad \frac{1}{12} \quad = \quad ?$$

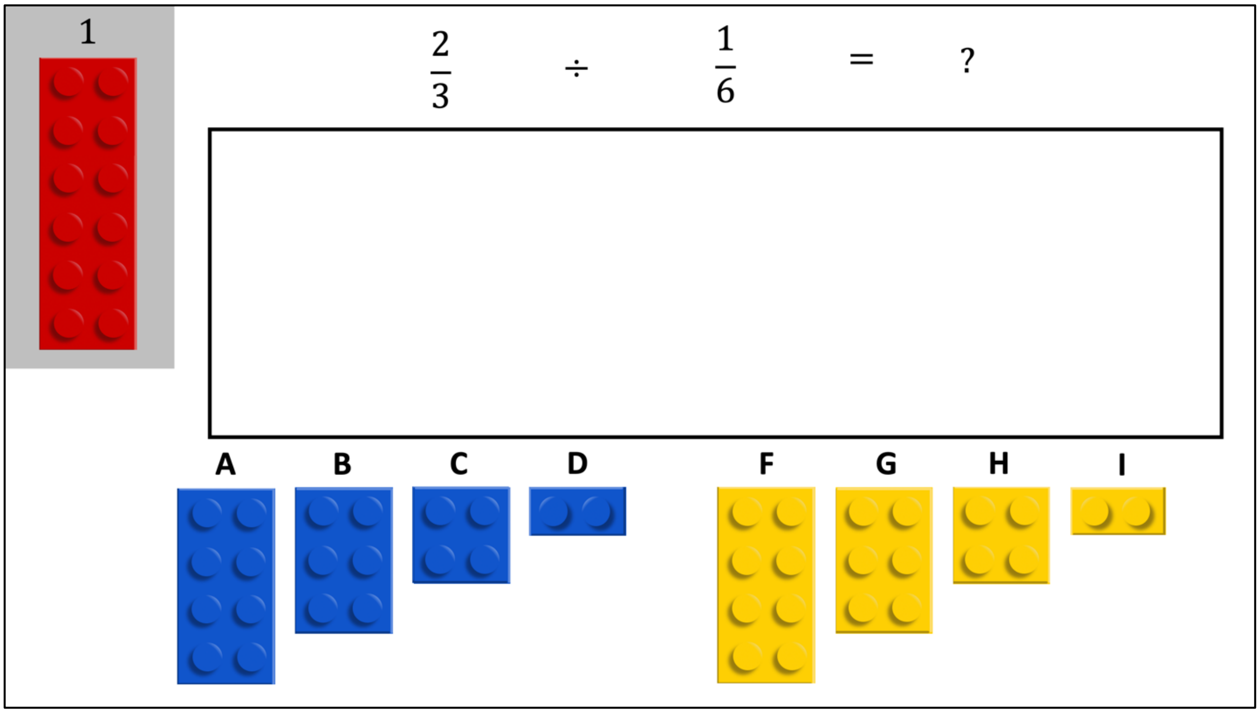


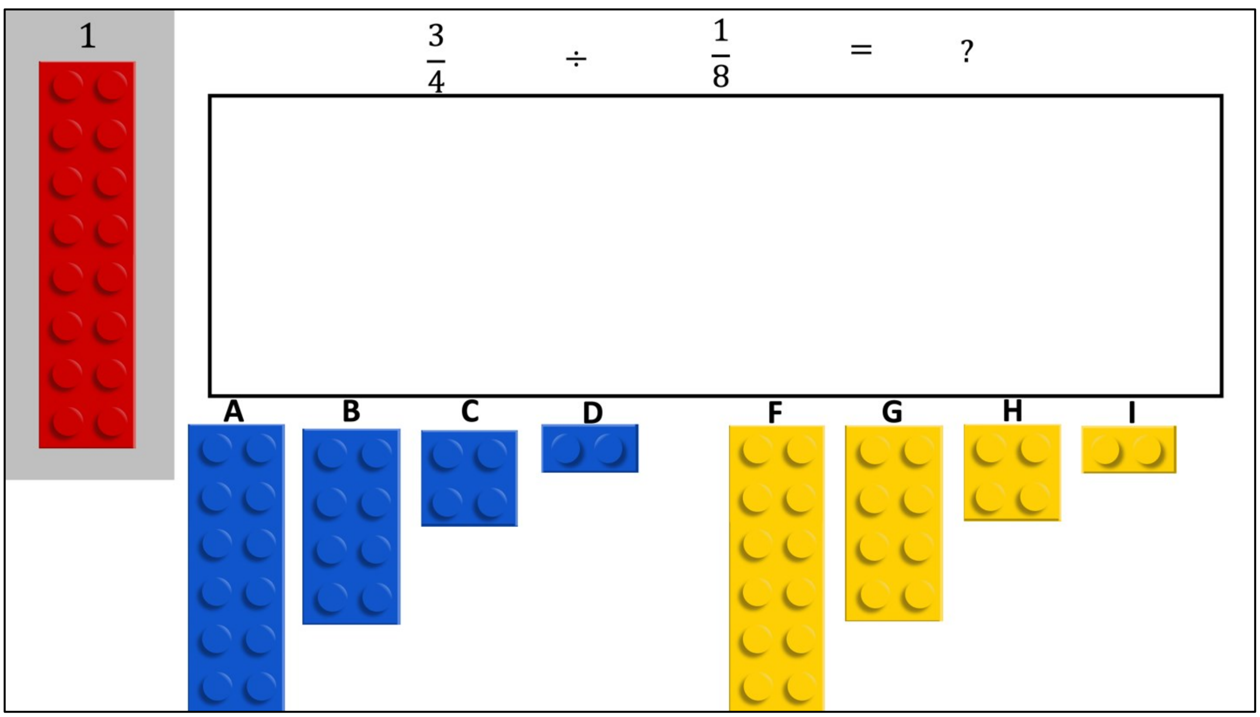


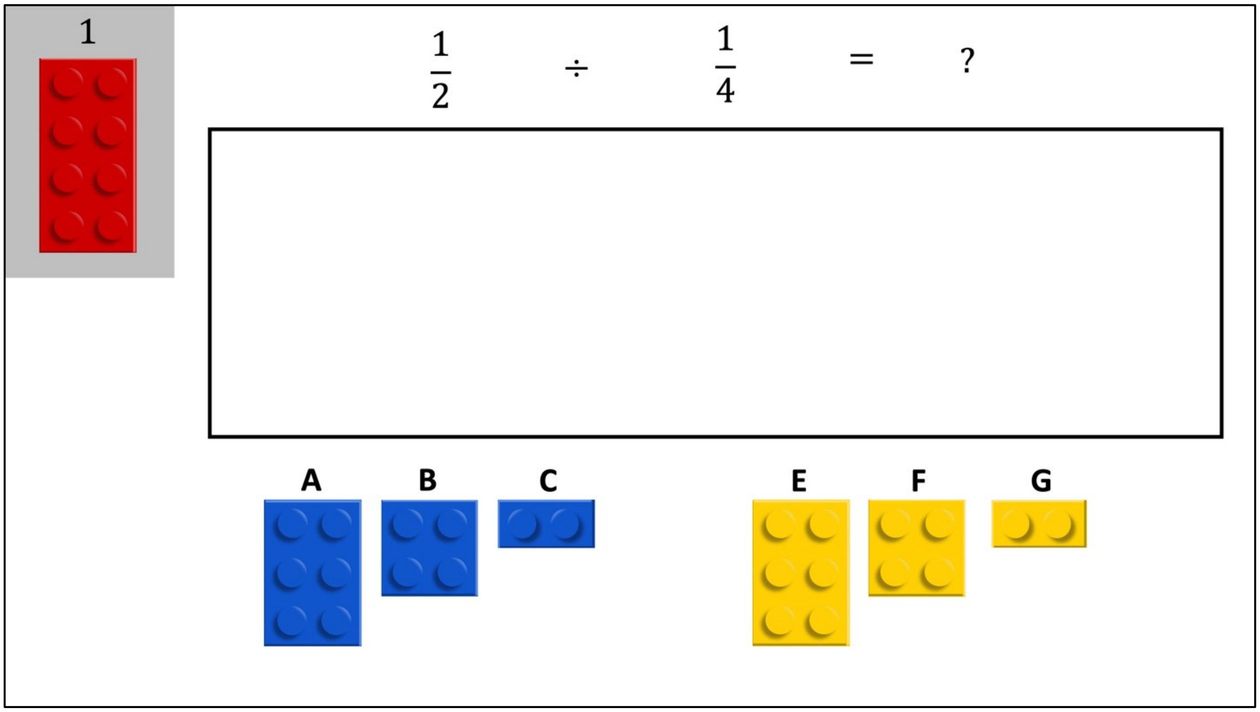
1
$\frac{3}{4} \div \frac{1}{16} = ?$
A
B
C
D
E
F
G
H
I
J

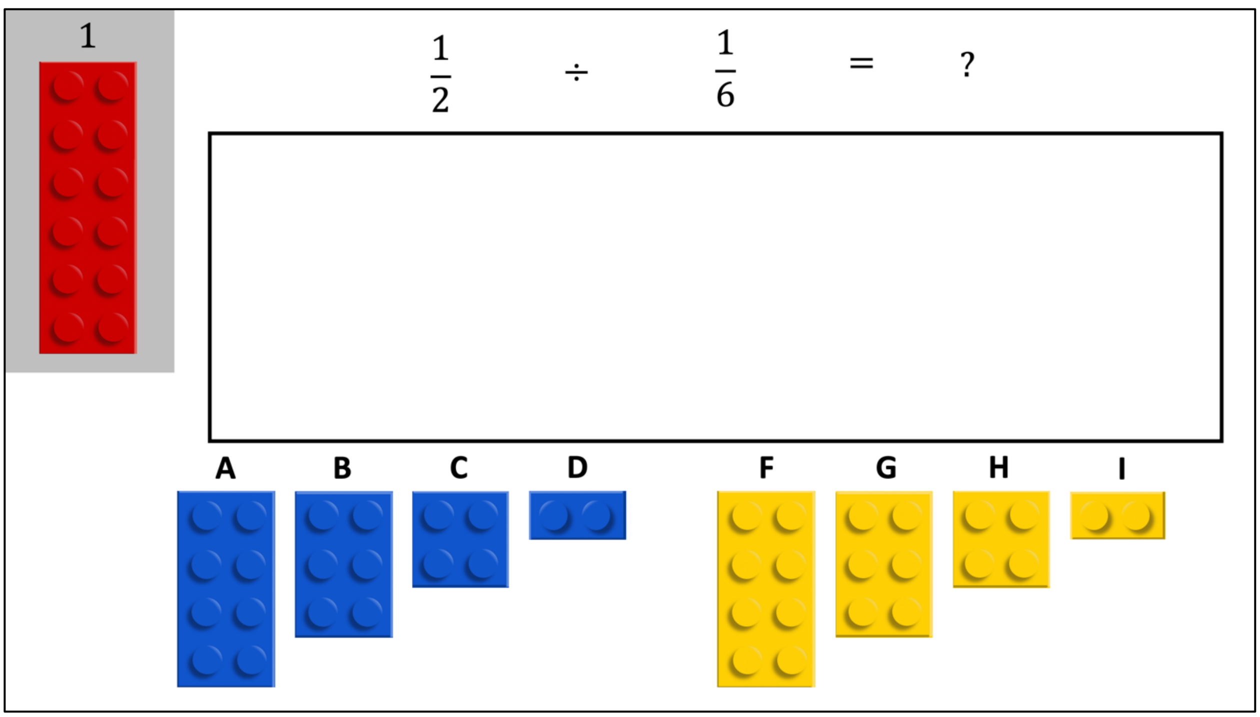
Appendix E

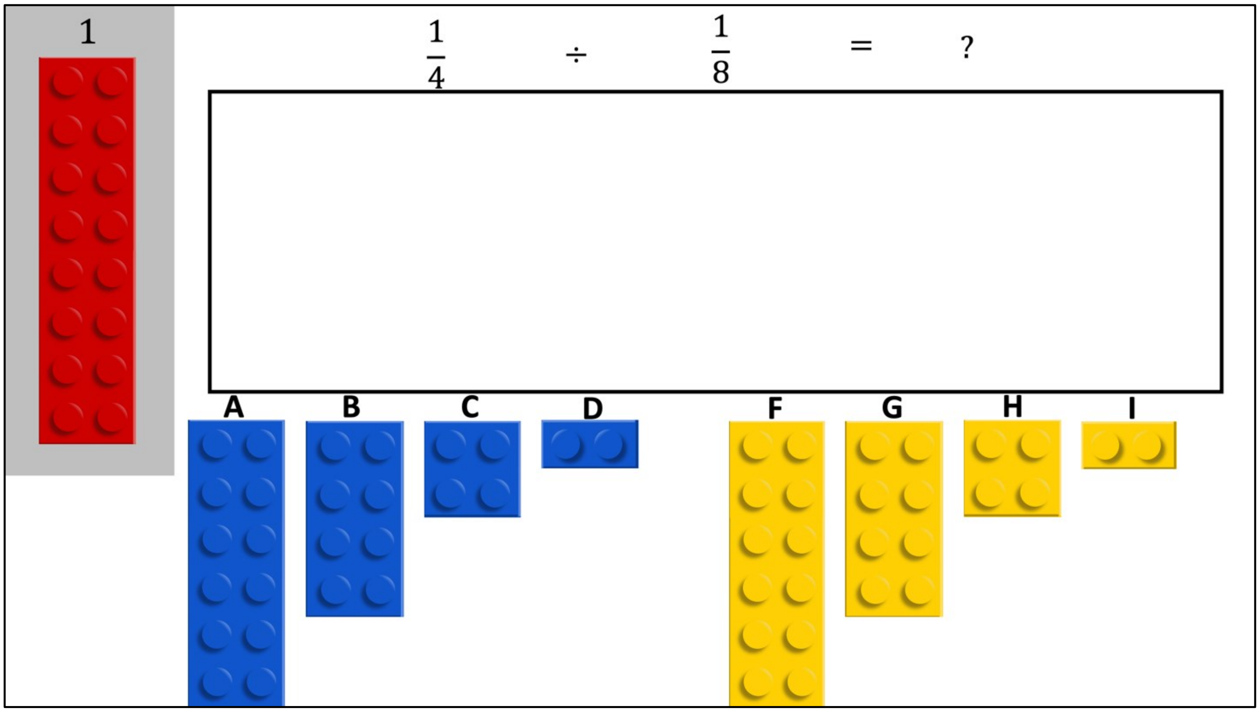
Transfer Items (In Order of Appearance)






1
$\frac{1}{2} \div \frac{1}{4} = ?$
A
B
C
E
F
G


1
$\frac{1}{2} \div \frac{1}{6} = ?$
A
B
C
D
F
G
H
I


1
$\frac{1}{4} \div \frac{1}{8} = ?$
A
B
C
D
F
G
H
I

Appendix F

Parent Questionnaire

Date de complétion : ___ / ___ / 2021

1. Quel est votre lien de parenté avec l'enfant ? (Cochez la bonne case)
☐ Mère ☐ Père ☐ Autre. Précisez : __________________

2. Code donné par l'assistant de recherche par email : __________________

3. Date de naissance de l'enfant : __________________

4. Âge de l'enfant : __________________

5. École / Classe de l'enfant : __________________

6. Genre de l'enfant (Cochez la bonne case) : ☐ Garçon ☐ Fille

7. Pays / Province : __________________

8. Numéro de téléphone : __________________

9. Courriel : __________________

10. Quel est votre revenu familial ? (Cochez la bonne case)
☐ < 20 000 ☐ 20 000 – 40 000 ☐ 40 000 – 60 000
☐ 60 000 – 80 000 ☐ 80 000 – 100 000 ☐ > 100 000

11. Votre enfant présente-t-il/elle ? (Cochez la ou les bonnes cases)
☐ Aucune difficulté particulière en mathématiques
☐ Des difficultés en mathématiques
☐ Un Trouble des Apprentissages en Mathématiques (une dyscalculie) diagnostiqué

12. Est-ce que votre enfant… : (Cochez la ou les bonnes case)
☐ A reçu un diagnostic de daltonisme?
☐ Est daltonien(ne) selon vos observations?

13. Votre enfant présente-t-il/elle ? (Cochez la ou les bonnes cases)
☐ Une déficience sensorielle
☐ Une déficience intellectuelle
☐ Une déficience motrice
☐ Un trouble neurologique
☐ Un trouble psychosocial
☐ Un trouble de l'attention : ☐ Médicamenté ☐ Non Médicamenté
☐ Un trouble du langage diagnostiqué
☐ Un Trouble des Apprentissages en Lecture/Orthographe (une dyslexie / dysorthographie)

14. Quelle(s) langue(s) est / sont parlée(s) à la maison ?
☐ Français ☐ Anglais ☐ Autre. Précisez : __________________

15. Commentaires
____
____

C'est la fin du questionnaire. Merci de votre temps et de votre participation !

Appendix G

Scoring Sheet

Multiple-Choice Items

#	Problèmes	Réponses	Réponses de l'enfant	Commentaires
1	Rouge : 6 x 2 Jaune : 2 x 1	$\frac{1}{6}$		
2	Rouge : 8 x 2 Bleu : 4 x 2	$\frac{1}{2}$		
3	Rouge : 4 x 2 Jaune : Trois 2 x 1	$\frac{3}{4}$		
4	Rouge : 8 x 2 Bleu : 2 x 2	$\frac{1}{4}$		
5	Rouge : 6 x 2 Jaune : Cinq 2 x 1	$\frac{5}{6}$		
6	Rouge : 4 x 1 Bleu : 3 x 1	$\frac{3}{8}$		

Learning Task

#	Problèmes	Réponses	Réponses de l'enfant	Commentaires
1	$\frac{2}{3} \div \frac{1}{12} = ?$	8		
2	$\frac{1}{2} \div \frac{1}{16} = ?$	8		
3	$\frac{1}{2} \div \frac{1}{8} = ?$	4		
4	$\frac{1}{6} \div \frac{1}{12} = ?$	2		
5	$\frac{3}{4} \div \frac{1}{16} = ?$	12		

Transfer Task

#	Problèmes	Réponses	Réponses de l'enfant	Commentaires
1	$\frac{2}{3} \div \frac{1}{6} = ?$	4		
2	$\frac{3}{4} \div \frac{1}{8} = ?$	6		
3	$\frac{1}{2} \div \frac{1}{4} = ?$	2		
4	$\frac{1}{2} \div \frac{1}{6} = ?$	3		
5	$\frac{1}{4} \div \frac{1}{8} = ?$	2		