K-2 STUDENT'S COMPOSING OF LEGO STRUCTURES

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Block building activities help develop students' spatial reasoning, but few studies focus on the development of block building skills beyond preschool. We worked with four kindergarten, four first grade, and four second grade students to learn more about their Lego block building. We compared students' accuracy, building strategies, and spatial language as they used manuals versus pictures of final Lego structures (presented in color versus grayscale) to build two Lego structures. On the first structure, students using color manuals or pictures had an easier time choosing correct bricks but had difficulty correctly placing them; students using grayscale manuals or pictures had difficulty picking the correct bricks but placed them more accurately. By the second design, students did better with the manuals, regardless of color. Students need more support to use specific spatial language and building with depth versus height.

Keywords: Elementary School Education; Geometry and Spatial Reasoning; Instructional Activities and Practices.

The K-2 mathematics standards in the United States emphasize geometric reasoning, which includes the ability to identify and describe shapes and to create structures by analyzing and predicting the outcome of composing and decomposing shapes (National Governors Association Center for Best Practices & the Council of Chief State School Officers, 2010). Children use geometric reasoning to make sense of the world through multiple practices (Goldenberg & Clements, 2014). The first practice in making sense of the world is classification, which involves children identifying the elements in the environment and establishing relationships among them. Then, children might use spatial relationships, which help identify an object's location relative to reference points by using spatial words (e.g., right, under, top) or numbers (e.g., 3 units away from an object). Another practice to understand the environment is noticing the transformations of objects at various orientations or distances (e.g., symmetry, rotation). Geometric reasoning also entails measuring or counting to identify the relationships between objects in the environment. To identify certain properties of the objects, direct measurements (e.g., length, area, volume), indirect measurements (e.g., comparing an object to another object being measured), or using various units (e.g., one-unit length, block should be placed in the middle) might be utilized (Goldenberg & Clements, 2014).

Play with blocks is a popular early childhood activity that helps children develop a variety of concepts, including geometric and spatial reasoning (Casey et al., 2008; Phelps & Hanline, 1999; Ramani et al., 2014), part-whole relationships (Gura, 1992), and other early mathematics concepts (e.g., aspect of numbers, lines, area surfaces, and volume; Cross et al., 2009; Gura, 1992; see also Kamii et al., 2004). There is also a 3D shape composition learning trajectory (Clements & Sarama, 2009) focused primarily on preschoolers' block-building; however, research on block building beyond the preschool has been limited. Since the development of block-building skills may not be fully established until school age, more research on block-building behaviors after preschool is needed (Tian et al., 2020).

Unstructured (free-play) and structured (guided) block building activities are two pedagogical approaches to building blocks. Unstructured tasks are more open-ended, allowing children to create their own structures without being given specific goals, i.e., “Build the best thing you can with these blocks” (Caldera et al., 1999, p. 860). In structured activities, children, on the other hand, copy and reproduce a specific structure from a design (Caldera et al., 1999; Stiles & Stern, 2009). Structured activities focused on improving skills in sorting and classifying blocks and sometimes focused on “...estimation, measurement, patterning, part-whole relationships, visualization, symmetry, transformation, and balance” (Casey & Bobb, 2003, p. 2). At the preschool level, Verdine et al. (2014) used the Test of Spatial Assembly (TOSA) to measure students’ block building accuracy. For these tasks, students must copy a block design (e.g., a three-piece Lego structure). However, Lego sets targeted at students ages 5-8 typically range from having about 50 pieces to multiple hundred pieces, and the features (i.e., use of color, types of pieces, orientation of pieces, placement of pieces) increase in complexity. Therefore, to better understand K-2 students’ block building behaviors, we need more investigations into how they coordinate these features and how pictures and manuals can support their efforts.

Framework

Worked examples are an instructional aid for helping students understand challenging concepts. Worked examples show step-by-step solutions to problems that help students understand the problem-solving process (Atkinson et al., 2000; Sweller & Cooper, 1985) while reducing cognitive load (Paas et al., 2003; Sweller et al., 1998). Analyzing worked examples promotes learning in different fields, such as in mathematics (Catrambone, 1998; Congdon et al., 2018; Durkin & Rittle-Johnson, 2012) and programming (Bofferding et al., 2022; Joentausta & Hellas, 2018; Margulieux & Catrambone, 2016). Congdon et al. (2018) investigated first-graders' ability to measure using rulers starting at zero or a whole number. The students’ measurement conceptions improved when they analyzed worked examples of taking measurements that were not aligned with the zero point.

Worked examples organized by subgoals, on the other hand, may help students learn since subgoals make problem steps explicit by explaining the purpose of each step and providing clues on how to achieve them (Atkinson et al., 2003; Atkinson & Derry, 2000; Catrambone, 1998). Additionally, students can concentrate on the important components in the worked examples (Margulieux et al., 2016) and engage in more self-explanations (Catrambone, 1998; Renkl & Atkinson, 2002).

Studies of young children’s block building provide some insight into factors that children pay attention to (e.g., spatial language, see Bower et al., 2020; Cohen & Emmons, 2017; Pruden & Levine, 2017) or struggle with when recreating block structures (e.g., placement, see Stiles & Stern, 2009; Verdine et al., 2017). For example, Verdine et al. (2014) evaluated 102 children's (38 to 48 months) spatial assembly skills beyond basic building accuracy as they attempted to construct seven models using 2 to 4 Mega Blocks of various sizes and colors. When determining if the children's constructions matched the models, the researchers created a dimensions score. They scored the accuracy of blocks relative to the base block, taking into account the *vertical* location of the blocks, *rotation* of the blocks, and the *translation* or horizontal location of the blocks based on the child placing the blocks on the right studs. Based on children's decreasing dimension scores, they had difficulty coordinating rotation and translation as the number of pieces (e.g., 2 versus 3 pieces) or the spatial complexity (e.g., two blocks sharing the two-studs width of the base) increased.

Other researchers have investigated the language children use as they work with blocks for insight into the factors they find important. Pruden and Levine (2017) investigated boys versus girls' (14-46 months) spatial language in terms of dimensions (e.g., big, little, tall, short), shape terms (e.g., circle, square), and spatial features (e.g., curvy, bent). Compared with girls, boys produced more spatial words in preschool years. On the other hand, Cohen and Emmons (2017) investigated school aged children's (4-12 years) production of spatial language during structured block building activities. Like Pruden and Levine (2017), Cohen and Emmons (2017) identified children's spatial language regarding dimensions (e.g., big, wide, length), shapes (e.g., square), and spatial features (e.g., vertical, flat, curvy, side, corner). Additionally, they identified children's spatial language regarding location/direction referring to relative position of blocks (e.g., high, under, up), orientation/transformation referring to relative orientation or transformation (e.g., rotate, upright, right side up), continuous amount (e.g., a lot, same, half, inch), deictic (e.g., here, there, anywhere), and pattern (e.g., order, next, first, increase)(Cohen & Emmons, 2017). Children were more likely to produce words in the location/direction category than they were in the shape and orientation categories (Cohen & Emmons, 2017).

Current Study

Block features (e.g., length, color, shape, size) contribute to spatial complexity, especially as the number of blocks increases. The preschool studies involved a few bricks (e.g., up to 4, Verdine et al., 2014; up to 8, Stiles & Stern, 2009) and typically focused on children's final structures. Instead, we explored how school-aged children deal with spatial complexity by concentrating on the process, particularly what is easy or difficult for them and what they pay attention to in relation to language while building 30-40 piece Lego structures.

Structured (guided) block building can be interpreted as a form of using worked examples, where the final structure is shown but also includes all information needed to build it (e.g., someone can trace the steps from bottom to top and see the needed pieces). Manuals, such as those included in Lego sets, can be interpreted as a worked example with subgoals, where the final structure is broken down into smaller chunks to help explain how the pieces fit together to make the final structure. Subgoal labels may be of increasing importance as structures increase in size and complexity because they make each step explicit. Likewise, colors might reduce cognitive load when structural complexity increases by helping children distinguish among pieces.

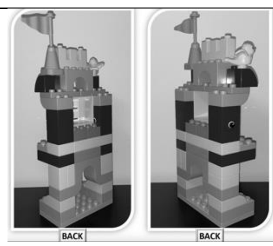
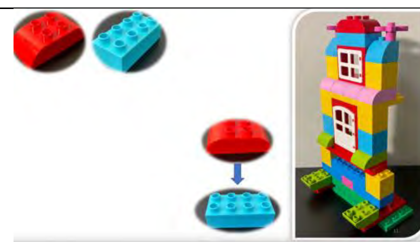
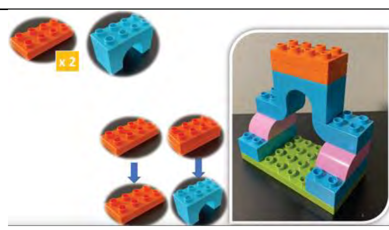
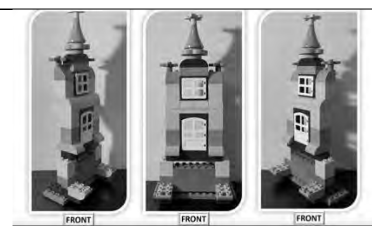
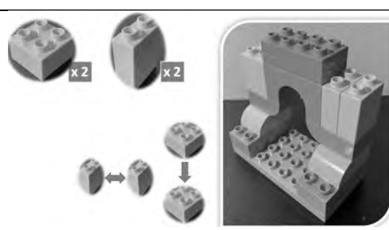
In this study, we explored: How do students' composing of Lego structures compare when they build with manuals of steps versus a picture of the final structures? (a) What spatial language do they use? (b) Which Lego brick features (i.e., location, size, orientation, shape, color) are most difficult to coordinate in their building?

Method

For this study, we analyzed data from four kindergarteners, four first graders, and four second graders in an afterschool program at a Montessori school in the midwestern United States. We tried to strike a balance in regard to students' gender and background. During three sessions of a Lego building project, the students composed, decomposed, and fixed Lego structures. We met with students individually and video recorded them using two cameras to capture the front and back of their Lego structure. Interviewers also asked students questions about where they were looking in the picture or manual as they built, how they knew which brick to use and where to place it. The data for this study comes from the composing portions of the tasks from the project's first two sessions.

In the first session, the students either used a picture (as a worked example) or a step-by-step manual (as a worked example with subgoals) to build a Lego structure (see Table 1). We showed the picture or manual in color to half of the students and in grayscale to the other half. The students built a different Lego structure in the second session but started with half of the structure already built. Students who used a manual in the first session used a picture in the second session (and vice versa). Likewise, students used a color picture or manual in the first session used a grayscale one in the second session (and vice versa).

Table 1: Examples of Pictures and Manuals Used for Each Design

	Design 1	Design 2
Order 1	 Example color pictures	 Example grayscale manual steps
Order 2	 Example grayscale pictures	 Example color manual steps
Order 3	 Example color manual steps	 Example grayscale pictures
Order 4	 Example grayscale manual steps	 Example color pictures

Analysis

In order to analyze students' building process, we first recorded the number of differences between students' structures and the given picture or manual. Differences were divided into several categories based on Verdine et al.'s (2014) coding scheme and included students using the wrong brick, including an extra brick, leaving out a brick, placing a brick with an incorrect orientation, and placing a piece with an incorrect left-to-right, forward-to-backward, or vertical placement. We took notes of the specific bricks students had difficulty with in order to identify patterns. Next, we coded the students' building process based on how they used the bricks, pictures, and manuals (see Table 2 for description of codes). During this process, we also took notes of changes students made as they built as well as any help they received from the interviewers.

Table 2: Codes for How Students Composed the Lego Structure

Composing strategy	**Description**
Resource	Where students referred when building and explaining:
Picture of structure	The composed picture of the structure (solo picture/in manual)
Manual of steps	Steps in manual for how to compose the bricks
Lego structure	Parts of the Lego structure
Turning pieces	Turned the direction of bricks horizontally
Flipping pieces	Turned the direction of bricks vertically
Turning structure	Turned the direction of the Lego structure
Direction	Built the structure from *bottom to top* or *top to bottom*
Symmetric	Built one side and a similar brick on the other side (1 piece, 2 pieces, or 3 pieces at a time)
One side	Built up more than 3 bricks of one side, then did the other side
Lines	Used the lines between bricks on the picture
Counting studs	Counted raised dots on bricks to decide the location or brick

Finally, we used Cohen and Emmons' (2017) classification to code students' spatial language as they built and answered questions about the building of the Lego structures. We did not use their pattern category, but we also included a separate color category given our design focus on the role of color in building (see Table 3). We calculated the percent of students' language for each of the categories to look for trends.

Table 3: Codes for How Students Composed the Lego Structure

Language (Cohen & Emmons, 2017)	**Description**
Dimension	Length and Width: Students reference the brick size using specific numbers (4x2) or in generic terms (e.g., long, big, wide) Height: Students reference the brick's thickness (e.g., thick, thin) or how tall it is.
Shapes	Specific: Students use shape words or names of the bricks (e.g., square, window, flower) Generic: Students refer to the brick using "this" "that" or other generic referents

Location/Direction	Specific: Students use the number of studs on Lego bricks or number of bricks to justify placement Generic: Students refer to locations without using numbers (e.g., on the top, the other side, on the right)
Orientation/ Transformation	Students talk about turning or flipping bricks
Continuous amount	Students use number words to describe number of pieces or the count pieces using numbers
Deictic	Students use generic language (e.g., here, there) to describe brick placement
Spatial features	Students describe the appearance or features of the brick (e.g., sharp, slanted, curved, has a shadow, has an eye) Generic: Students describe the appearance using vague language and actions (e.g., “like this,” “the same,” “looks good”)
Color (we separated this out from spatial features)	Students refer to the color or shading of a brick (e.g., red, darker)

Results

Design One

When building design 1, all students built from the bottom to the top and used the lines between bricks to help guide their building. Further, one student composed several bricks into a substructure on one side before building the same sub-structure on the other side; whereas, the other 11 students built symmetrically (see Figure 1), placing bricks back and forth between sides. Students used more spatial language as their grade level increased, but overall their language was pretty generic. They referred to the bricks in general shape terms (27% of language terms) and often paired it with a continuous amount (e.g., this one, those two; 24% of terms), leading to those categories having the highest percentage. Their language involved specific location terms 11% of the time and general location terms (e.g., “there”) 13% of the time. Overall, students had a median of six differences with the target structure (ranging from 2 to 17) when composing the first Lego structure. Students who used the grayscale picture had a total of 38 differences, those who used the color picture had 21 differences, those who used the color manual had 16 differences, and those who used the grayscale manual had 14 differences. Participants who had the highest numbers of differences left out chunks of the structure (e.g., the window and surrounding pieces or arch and surrounding pieces) and referred to the picture of the final structure.

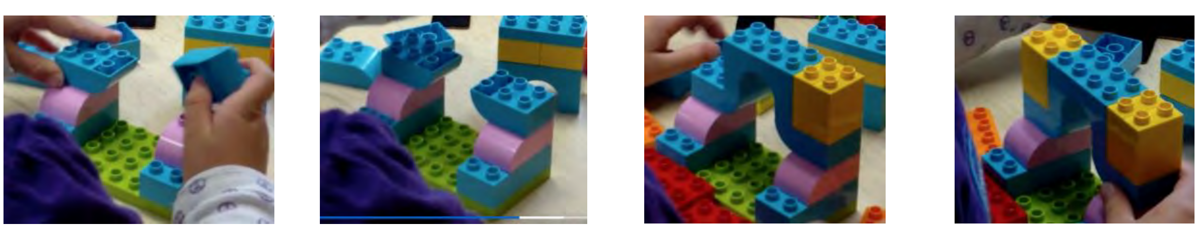


Figure 1: Second Grader Building Symmetrically

Aside from general differences between students who built using the manual versus the picture, there were interesting differences between students who used color pictures or manuals and those who only used grayscale pictures or manuals. Students in the color conditions had more difficulty placing Lego bricks in the correct spots; their typical difficulties in placing the bricks aligned with students not making proper use of the forward/backward dimension (see Figure 2). Students in the grayscale conditions had more difficulty using the correct Lego bricks; their typical difficulties with pieces involved using the incorrect thickness of pieces, regular 2x2 bricks instead of taller 2x1 bricks, or incorrect dimensions (see Figure 3).

Incorrect: red brick does not overhang	Correct overhang for red bricks	Incorrect: window and blue 4x2s set back	Correct placement of window and blue 4x2s

Figure 2: Difficulty with Placing Lego Bricks

Incorrect: 4x2 curved bricks instead of 3x2	Correct use of 3x2 curved bricks	Incorrect: 2 stacked 2x2 bricks on right	Correct use of tall 2x1 bricks on right

Figure 3: Difficulty with Choosing Lego Bricks

Design Two

In general, most students had fewer differences when they completed design 2, which was not surprising since they only had to build half of the structure. Students also did not have much difficulty figuring out where to start from the manual or general picture. They continued to build symmetrically from the bottom up but only eight continued to use the lines between bricks to guide them. As with the first design, they continued to use generic language, referring to bricks in generic ways (21% of language terms) and paired this with continuous amounts (20% of terms). They also continued to refer to locations in generic ways (13% of terms) and increased their focus on the bricks' colors or shading (e.g., darker; 11% of terms). Overall, students had a median of two differences in their final designs (ranging from zero to six difficulties, excluding one kindergartener who left off 10 bricks). Interestingly, there were fewer differences between the color and grayscale conditions with this design. Rather, the biggest difference occurred between students who used a manual (who had a total of six differences in their final structures) versus those who used the picture (who had a total of 29 differences in their final structures). Students' difficulties were similar to those from the first design.

Discussion

Overall, students who built the Lego structures using the manuals had fewer differences than those who built the Lego structures using the pictures. Manuals (a kind of worked example with subgoals) may reduce students' cognitive load by engaging them in more self-explanation (Atkinson et al., 2003; Catrambone, 1998; Renkl & Atkinson, 2002) and helping them focus on transformations (Goldenberg & Clements, 2014). There were benefits and drawbacks to students' building their first design using the *color* picture or manual. These students were largely able to pick out the correct pieces, perhaps aided by the color (see also classification, Goldenberg & Clements, 2014) and a reduction to cognitive load (Atkinson et al., 2000; Paas et al., 2003; Sweller et al., 1998); however, they had difficulty placing them, especially in relation to the forward-backward dimension (see also transformation, Goldenberg & Clements, 2014). One potential reason may be that their focus was more on the correct use of pieces vertically in relation to each other. Students who saw the pictures and manuals in grayscale may have looked more closely at the placement to help them figure out both the pieces involved as well as how to place them because they did not have the color cues. The Lego structures were designed to emphasize the vertical element, so future work could explore if students have similar color-placement difficulty with Lego structures that involve a stronger depth element and little vertical change. Another possible avenue to explore would be to give students manuals where the pieces for the sub-goals are in color but the composed structure is in grayscale. This change might help students find the correct pieces but then encourage them to examine the picture more closely to interpret how to place the pieces. In fact, by design 2, the advantage of having color appeared to wane, and the benefits of the manual, with its sub-goals, took on more importance. Interestingly, students were more likely to use general words than specific words to describe the bricks and their locations, similar to findings from Cohen and Emmons (2017). Therefore, another fruitful avenue may be to help students use specific language when building to determine if that helps them have a better sense of the spatial dimensions in the pictures or manuals.

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