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Can Video Comparison Facilitate Children's Stem Learning?

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CAN VIDEO COMPARISON FACILITATE CHILDREN'S STEM LEARNING?

ALEXIS R. COLWELL

61 Pages

The goal of the current study was to examine the effectiveness of a video comparison activity in teaching 6- and 7-year-old children that a diagonal brace provides stability in structures, which is an important engineering principle. Children were randomly assigned to one of three groups: Comparison, Single Model, or No Training. The children in the Comparison group saw two metal towers in a training video where the researcher pushed on the towers to demonstrate that one was stable (diagonal brace tower), and one was unstable (horizontal crosspiece tower). Children in the Single Model group saw a video of the one stable tower. Children in the Comparison and Single Model groups were asked to explain why the diagonally braced tower was strong. Children assigned to the No Training group did not see any training videos nor were they asked to explain them. All three groups then completed (a) a Relational Reasoning task, (b) a transfer task, and (c) a Mental Transformation task. Parents provided details about children's science, technology, engineering, and mathematics (STEM) interest and spatial language to examine the relation of these constructs with performance on the three child tasks. I hypothesized that children in the Comparison group would produce more brace-based explanations than children in the Single Model group after watching the training videos. This hypothesis was not supported. On the transfer task, I hypothesized that children in the Comparison group would perform better than both the Single Model and No Training groups. This hypothesis was not supported. I hypothesized that children's performance on all three tasks would be positively correlated with STEM interest and spatial language. This hypothesis was partially supported. Positive correlations were found between children's spatial language use and diagonal explanation production on the picture selection portion of the transfer task, as well as between children's spatial language and STEM interest. These findings provide support for the importance of spatial language in relation to spatial performance and STEM experiences, and they also highlight the need for research and testing of activities before switching from a physical to virtual format.

KEYWORDS: engineering; STEM; learning; comparison; explanation

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A Thesis Submitted in Partial
Fulfillment of the Requirements
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CAN VIDEO COMPARISON FACILITATE CHILDREN'S STEM LEARNING?

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A. R. C.

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CHAPTER I: INTRODUCTION

The Importance of Early STEM Education

Science, technology, engineering, and mathematics (STEM) jobs are projected to grow 10.5% in the United States between 2020 and 2030 (Bureau of Labor Statistics, 2022). Filling these jobs is important as STEM innovation improves everyday life. Improvements such as life changing medical discoveries, modern communication devices, and sustainable transportation depend on adequate availability of STEM workers. To meet the U.S. labor demands as well as drive further innovation, it is critical to attract more individuals to STEM fields.

Improving STEM education throughout childhood is of central importance to this objective. If children do not know about STEM topics or career opportunities, they are unlikely to pursue these career fields. For those who pursue STEM careers, early education equips them with skills they need to be successful in entering these fields. For individuals who do not go on to pursue STEM careers, science education can provide benefits such as the promotion of scientific thinking and literacy (Hazelkorn et al., 2015; Leas et al., 2017; Vieira & Tenreiro-Vieira, 2014) and curiosity (Jirout & Zimmerman, 2015; Klahr et al., 2011; Leas et al., 2017), which are helpful for informed citizens and employees outside of STEM fields. Thus, STEM education in childhood is important for individuals who will later pursue STEM degrees and careers (Sadler et al., 2012; Tyson et al., 2007), but it can also benefit those who do not pursue STEM careers.

Early exposure to STEM topics is important because many scientists and engineers report that their earliest memories of interest in science occurred before middle school (Maltese & Tai, 2010). Master et al. (2017) designed one early STEM intervention to test whether positive experience with technology could boost programming interest and self-efficacy in first-grade girls despite the children's reported stereotypes that boys are better at programming than girls. Children were randomly assigned to a robot treatment group, parallel activity control group, or no-activity control group. Children in the robot treatment group participated in a 20-minute smartphone activity where they programmed robots to follow a specified spatial path. The parallel activity group completed an unrelated storytelling activity, and the no-activity group did not participate in any activity. After the activities, all groups answered questions regarding their technology interest and self-efficacy. Girls who participated in the programming activity reported significantly higher scores regarding programming interest (e.g., "how fun is programming") and self-efficacy (e.g., "how good are you with robots") than girls in the two control groups. In addition, no gender differences were found on any of the three measures (programming interest, robot interest, and robot self-efficacy) between boys and girls in the programming activity group. However, boys had significantly higher scores than girls for all three measures in the control groups. As demonstrated by this activity, exposure to a STEM intervention at a young age can foster interest in children who might not otherwise express interest.

Spatial Skills

In addition to stimulation of STEM interest, another major area of focus for research and practice is improving spatial thinking. Spatial skills are correlated with STEM success (Shea et al., 2001; Wai et al., 2009). These skills are malleable throughout childhood and can be improved with training (Uttal et al., 2013). Given this malleability, activities that encourage spatial thinking should start early and continue throughout childhood. Newcombe (2010) suggests that teachers should foster children's spatial learning as early as preschool by providing age-appropriate activities such as simple experiments and jigsaw puzzles. Newcombe notes that as children enter elementary school, spatial thinking should be emphasized directly through more complex tasks. Some examples include highlighting spatial elements in math, using analogies to facilitate comparison, and practicing mapping skills.

Although developing spatial skills is important for success in many STEM fields, such as engineering and architecture, classroom teaching directed towards these skills is often neglected in favor of learning that focuses on mathematical and verbal ability. In addition to the lost opportunity to strengthen existing spatial skills and interest in young children, this lack of attention toward spatial skills has lasting effects. Tests that focus on the types of verbal and mathematical skills typically emphasized in the classroom may miss recognizing spatially talented students if they do not also achieve high verbal and math scores (Webb et al., 2007). Webb et al. concluded that spatial ability is a unique indicator of possible success in STEM fields beyond other cognitive abilities (verbal and mathematical), and traditional aptitude tests can result in capable students being overlooked at a time where their strengths could be fostered to increase motivation and encourage development in STEM subjects.

It is important to assess spatial skills to identify starting points and facilitate growth that might support STEM success. Mental transformation is one spatial skill that is trainable and therefore an opportunity for STEM-relevant growth (De Lisi & Wolford, 2002; Uttal et al., 2013). Mental transformation involves mentally combining, rotating, or otherwise manipulating stimuli from a given starting point. A longitudinal study by Frick (2019) showed associations between children's early mental transformation ability and later mathematics performance. Cheng and Mix (2014) found that spatial training improved 6- to 8-year-old children's mental transformation skills as well as their scores on a math test. Children who were in a spatial training group and completed mental transformation problems from Erlich et al. (2006) showed significant improvement on the posttest after one training session with the task. Children in the training group also showed significant improvement at posttest on calculation problems as compared to a control group who completed crossword puzzles. This increase in performance was primarily seen on missing term problems (e.g., 4 + __ = 12). Mathematics ability is important throughout STEM education and careers, so improving mental transformation skills early would be beneficial for children who will eventually enter STEM careers.

Relational reasoning is another spatial skill that can be improved and is important in STEM fields (Alexander, 2017; Alexander et al., 2016). Relational reasoning refers to the ability to notice and think about patterns or associations between multiple stimuli or situations. A longitudinal study by Green et al. (2017) showed that fluid reasoning was a significant predictor of 6- to 21-year-old participants' later math achievement. In addition to math achievement, relational reasoning ability was shown to be a predictor of innovation in design engineers (Dumas & Schmidt, 2015) and has demonstrated importance in science, medical, and engineering careers (Dumas, 2017). Given the benefits of improving relational reasoning and mental transformation, it is helpful to understand experiences that support spatial learning and skill development, including spatial play and spatial language.

Spatial Play

Parents and teachers can help facilitate spatial learning for young children in a variety of settings by focusing on spatial play. Research by Tõugu et al. (2017) demonstrates that children's play activities that provide an opportunity to improve spatial ability are related to improved performance on STEM activities. Children with spatial play experience involving puzzles, board games, and math games performed better on a building task requiring engineering problem-solving skills than peers with less spatial play experience. Children with greater spatial play experience produced sturdier structures after seeing an engineering demonstration showing the stabilizing effects of diagonal bracing than did peers with less spatial play experience who saw the same demonstration.

Polinsky et al. (2021) found that 3- and 4-year-old children's performance on two spatial touchscreen games was associated with their spatial abilities as determined by their performance on 2-D and 3-D Tests of Spatial Ability (TOSA). In addition, their study noted several benefits of technology-based spatial play including the "endless blocks, puzzle pieces, spaces to build" (p.13) as opposed to the building toys children have that are limited by cost and space. This consideration is critical as research shows children from low-socioeconomic (SES) backgrounds are already falling behind other children in spatial skills by age 3 years. In a 3-D Test of Spatial Ability task conducted by Verdine et al. (2014), preschool children from lower SES families performed significantly worse at combining blocks to match an existing block construction than children from higher SES families. This difference was seen on the more difficult tasks that required knowledge beyond color and length of the blocks. The researchers suggested this difference may be due to children from lower SES households having less play experience with block toys at home. It is necessary to address gaps in experience in early childhood for all children to have the best chance at developing STEM skills and interest.

Spatial Language

Spatial language is of interest because children's production of spatial terms has a demonstrated positive association with performance on spatial tasks (Pruden et al., 2011; Turan & De Smedt, 2022). According to Gentner (2016), language acts as a cognitive tool kit that benefits relational reasoning abilities. Relational language (e.g., spatial language) invites comparison between multiple situations labeled with the same term, and this comparison can help children understand commonalities between the two situations that they otherwise would not have understood. This understanding can then be applied to new situations, which facilitates further learning. For example, children who understand the word middle could make use of this label in a novel situation. If a parent tells their child that there are snacks in the middle drawer of their work desk, the child would be able to use this label to find the snacks even if they had not seen this specific desk before. The spatial label invites the child to compare between the current situation and a previous situation where they heard the word middle used. Spatial labels facilitate children's relational reasoning and allow them to reason in new situations with less guidance. Given the benefits of spatial language, it is important to consider children's spatial language abilities when assessing spatial task performance. It is also important to create opportunities to increase comprehension and production of spatial terms for children.

One way to increase children's spatial language production is to design learning and play activities to encourage the use of spatial terms. A study by Ferrara et al. (2011) demonstrated a link between block play and spatial language use. Three- and four-year-old children and their parents were randomly assigned to one of three conditions: free play, guided play, or preassembled play. Children and parents played with a set of blocks, and the blocks could be assembled to make a garage or a helipad. In the *free play* condition, children and parents were told to "play with the set of blocks as they would at home." In the *guided play* condition, children and parents were given pictures instructing them how to build either the garage or helipad. In the *preassembled play* condition, the children and parents were given an assembled model of either the garage or helipad. Ferrara et al. found that parents in the guided play condition used more spatial language with their children than did parents in both the free play and preassembled conditions. Children in the guided play condition used more spatial language while playing than children in the free play condition. Ferrara et al. concluded that increased spatial language was a benefit of playing with construction materials, as parents and children did not show the same levels of spatial language in ordinary interactions.

Because block play has been demonstrated to increase parent's spatial language use and lower SES children are not playing with blocks as often as their peers, they may be missing out on early exposure to spatial language in construction play settings. This lack of early spatial play and spatial language exposure may be contributing to the differences in spatial skills seen between children from lower and higher SES backgrounds by age 3 years.

Technology-Based Learning

Although spatial skills differ between children from lower SES backgrounds and their peers from higher SES backgrounds at a young age, there are some promising avenues for addressing this gap. As children from lower SES backgrounds have higher overall screen time (e.g., TV, online videos, video games, electronic reading, virtual reality headset, video-chatting) than children from higher SES backgrounds (Rideout & Robb, 2020), adapting spatial learning activities to be technology-based may make them more widely available and less expensive than other learning opportunities. This accessibility could provide exposure to young learners who might typically miss out on STEM activities at home. Technology-based learning activities could take several formats including videos, apps, video games, and e-books.

One successful example of technology-based learning comes from Bower et al. (2021) where the researchers adapted a concrete spatial puzzle task to an app format. They tested the effectiveness of the concrete and virtual versions of the spatial puzzle over a five-week training period with preschoolers from under-resourced backgrounds. Increases in performance did not significantly differ between those who trained with the app and those who trained with concrete objects.

Klahr et al. (2007) demonstrated that a hands-on virtual engineering activity was as effective as a hands-on physical engineering activity for children's learning. Seventh and eighth grade students constructed and tested either physical mousetrap cars or virtual mousetrap cars with the goal of designing a car that would travel the farthest. Children successfully learned what factors caused the cars to travel farther regardless of condition. The researchers also point out the convenience of the virtual activity because much less space was needed for the participant than in the physical condition, the virtual materials could be shared to others with computers, and children were able to construct and test cars more quickly than the children who built physical cars. Triona and Klahr (2003) showed that third and fourth graders learned the control-of-variables strategy in virtual or physical settings, again documenting the utility of virtual activities for science learning. Success with app-based and computer-based learning shows that children can learn STEM-relevant material from screen-based activities, and I predict that children would be similarly successful at learning from video-based STEM material.

Learning From Video

In the current study, I focused on computer-based video learning because the planned learning activity could be adapted to this format, and children of the target age (6 and 7 years old) are already frequently accessing videos via sources such as YouTube (Rideout & Robb, 2020). Given children's familiarity with videos, this format provides an opportunity to teach children about STEM topics outside of the classroom provided the videos are designed in a way that facilitates children's learning.

Much research on video-based learning focuses on very young children's ability to use video as a representation of everyday details. For example, Troseth and DeLoache (1998) found that 2-year-old children struggled to use information from a video to find a toy hidden in a room despite the children watching the toy being hidden on the screen. This finding suggested that 2-year-old children did not understand that the video was a representation of the room and thus, the information from the video could be used to find the toy in the room. The researchers found that by 2 ½ years of age, children were more successful at retrieving the toy after watching the video. The results demonstrated that although young children may initially struggle to use information learned from video in other situations, this ability improves with age.

Strouse and Troseth (2014) found that 24-month-olds were able to transfer a word learned from video to reality with minimal scaffolding from parents. When parents pointed out that real life objects were the same as the objects children were seeing in a video, children were able to identify a 3-D object when the experimenter said the label given to it by the character in the learning video. Anderson and Hanson (2010) maintain that children's video deficit (the observation that young children learn more from real life experiences than from equivalent video) disappears by age 5 years and adult-like video comprehension is achieved by 13 years. In one study, researchers demonstrated that preschoolers asked to reenact an 8-minute television segment were able to follow the plot line and include important parts in their reenactments. The children's reenactments, although not as detailed and complete as adult's reenactments, showed that the children had similar comprehension of the story's meaning as adults did (Pingree et al., 1984).

Given that preschool children show adequate comprehension of video and studies show that children's understanding of video representation improves with age, I anticipate that 6- and

7-year-old children will be able to learn sufficiently from video sources. To give children the best chance at learning, the video used takes advantage of two strategies that have been demonstrated to facilitate learning during live interaction: explanation and comparison (Chi et al., 1994; Christie & Gentner, 2010; Gentner et al., 2007; Gentner et al., 2009; Hoyos & Gentner, 2017; Legare & Lombrozo, 2014; Walker et al., 2014). These strategies have been shown to help children learn, so my study makes use of both explanation and comparison.

Explanation and Learning

One important way that explanation aids with learning is that it helps learners to integrate new knowledge with their existing knowledge (Chi et al., 1994). In one study, Chi et al. had 8th graders self-explain (generate explanations to themselves) while reading a passage about how the human circulatory system functions. In comparison to the students who were not prompted to explain, the students who were prompted to explain showed a deeper understanding of the material, largely because the process of self-explaining supported the integration of new information with existing knowledge.

Legare and Lombrozo (2014) also demonstrated the positive influence of self-explanation for 3- to 6-year-old children. Children were shown toy machines made from various parts (gears, crank, fan, non-functional peripheral parts) and assigned to groups where they were prompted to explain or observe the machine. The causal task required the child to choose from five parts which would make the machine (with one missing part) work. Children also completed a task where they had to select the correct color gear to test their memory for non-casual properties of the original machine. The researchers found that explainers (children who provided a mechanistic or functional explanation) performed better on causal learning measures than non-explainers (children who gave any other verbal responses), but higher scores were not seen on non-causal measures. They also found that the content of the explanation prompt influenced the types of responses given such that explanations were greater when a directed prompt (explain how the machine works) versus undirected prompt (explain the machine) was used by the experimenter (Legare & Lombrozo, 2014).

Similarly, Walker et al. (2014) found that prompting preschool aged children to explain allowed them to move beyond matching perceptual properties in favor of shared internal causal features. Children were assigned to either the explain or control condition, and they saw a toy and four sets of blocks each containing a target object, a perceptual match, and a causal match that were placed on top of the toy. The target object appeared to make the toy play music (it was actually activated by the experimenter with a remote control), the perceptual match was identical to the target object but would not make the music play, and the causal match did not look like the target object but made the music play. After seeing what each block did to the toy, children in the explain condition were asked to explain what had happened when the blocks touched the toy, and children in the control condition were asked to say yes or no to report if the blocks caused the toy to play music.

The experimenter then showed the child that the blocks had doors on them and opened the door on the target object to reveal a red map pin inside. The child was then asked to look at the other two objects (perceptual match and causal match) and point to the other block they thought also had something inside the door. Children in the explain condition were more likely to select the causal match, suggesting that explaining helped them move beyond shared perceptual features to notice the shared internal causes (both made the toy play music despite looking different) between the target object and causal match.

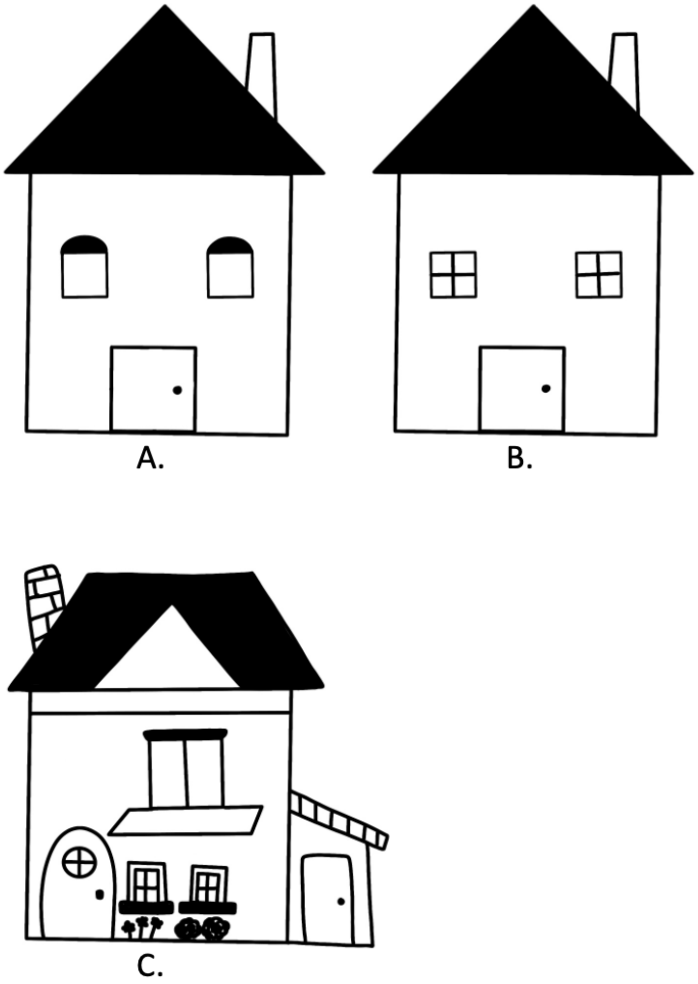
Comparison and Learning

Like explanation prompts, opportunities to compare can be useful in drawing attention to certain aspects of new information. According to Gentner and Medina (1997), comparison helps children “to learn about abstract commonalities and to make relational inferences” (p. 122). Comparing between two exemplars helps children notice important relational similarities that can then be used to take knowledge from a familiar situation and apply it to an unfamiliar one. Thus, comparison facilitates learning new information.

Using Genter’s structure-mapping theory, “the process of comparison is one of alignment and mapping between representational structures” (Markman & Gentner, 1997, p. 363). This theory states that “analogy is characterized by the mapping of relations between objects, rather than attributes of objects” (Gentner, 1983, p. 168). When two exemplars in an aligned structure have high similarity, it is easier to notice differences that play the same role in each structure. These alignable differences (differences “related to the commonalities of a pair”) make the comparison process more effective (Markman & Gentner, 1993). Figure 1 shows an example of highly alignable and less alignable pairs.

Figure 1

Example of High and Low Alignability

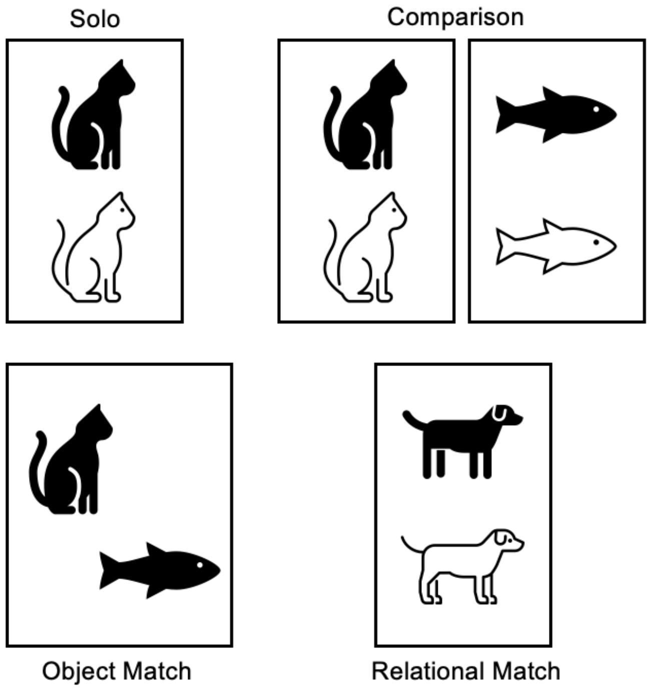


Note. A and B are a highly alignable pair. Because the two houses have high similarity, it is easier to notice differences between the two, whereas it would be more difficult to identify differences (low alignability) between A and C or B and C because they are dissimilar.

One example of the power of comparison is seen in a study by Christie and Gentner (2010) where the opportunity to compare two object cards simultaneously allowed children to move beyond object matches to notice relational matches. As shown in Figure 2, children saw a single card (solo) with a drawing of a pair of animals or two cards with two pairs of different animals (comparison) which all had the same relational structure (e.g., black animal on top of white animal). The pair of items was given a novel name (e.g., jiggy). The cards were then taken away, and two new cards that had not been seen by either group were presented. Children were asked to identify which of the new cards was also a jiggy, and the children in the comparison group were significantly more likely to pick the correct (relational) match instead of the object match. The researchers also had a group of children who saw multiple cards sequentially instead of simultaneously, and the same effect was not found. This difference shows that seeing multiple exemplars at different times does not have the same result as seeing multiple exemplars simultaneously thus allowing for comparison.

Figure 2

Example Cards From Christie and Gentner (2010)



In another study with preschool children, Gentner et al. (2007) found that by age 4 years, comparison helped children learn names for novel parts of animals. As predicted, children were more successful at noticing the part that differed between animal drawings when the animals shown were highly similar, which facilitated comparison. This similarity allowed the children to focus on the difference in the identifiable part rather than the color, shape, and other irrelevant features of the animal.

These findings informed another study by Gentner et al. (2009) where children participated in a brief analogical training activity at a children's museum related to engineering. The activity was meant to promote comparison to help children learn that a diagonal brace provides stability in a structure. As in the previously mentioned comparison studies, comparison of exemplars was used to draw children's attention to the diagonal brace on the towers, thus, helping them move past surface similarities and discover what purpose the diagonal brace serves in the structure. Children were assigned to the High Alignment (HA) condition, Low Alignment (LA) condition, or No Training (NT) condition and shown various model skyscrapers. The HA children saw two towers that were identical aside from the placement of a diagonal brace versus a horizontal crosspiece, whereas the LA children saw two towers that differed in width and placement of pieces as well as whether they had a diagonal brace or horizontal crosspiece. Children wiggled the towers and saw that the structure with the horizontal crosspiece could be distorted, but the structure with the diagonal brace remained stable. Although the availability of two towers allowed children in both the HA and LA groups to compare, the nearly identical surface similarity of the towers in the HA group was meant to help direct children's attention to the difference in bracing between the two towers (alignable difference) in hopes of facilitating their learning of the diagonal brace principle.

After training, children participated in a construction activity (building a strong, tall tower) with their families and then an individual brace placement (fixing an unstable building with a brace) task. As predicted given the high similarity of the towers in the HA group and the highlighting of the diagonal brace, the children in the HA group benefited most from the training activity. On the brace placement task, children in the HA training group performed better (produced more diagonal braces) than those in the LA and NT groups. This study demonstrated that comparison could facilitate learning of an engineering principle.

Explanation and Comparison

In another study in this series of skyscraper studies, Hoyos and Genter (2017) had children participate in a comparison activity with the added aspect of explanation to investigate "whether and how young children use comparison to inform their explanations" (p. 1366). As previously discussed, generating explanations has been demonstrated to effectively facilitate children's learning, but it is unclear what processes they use to generate explanations. Lombrozo (2012) hypothesized that explanation could utilize many processes, such as inductive reasoning, deductive reasoning, categorization, causal reasoning, and analogical reasoning. Because many comparison and explanation studies have included adult participants (e.g., Edwards et al., 2013; Edwards et al., 2019; Sidney et al, 2015), children's abilities to use these processes may differ. Hoyos and Gentner (2017) suspected that children do not use all of these complicated processes, but they hypothesized that comparison is one subprocess children likely use in generating explanations.

Hoyos and Gentner assigned children to one of four groups: High Alignability (HA), Low Alignability (LA), Single Model (SM), and No Training (NT). The HA, LA, and SM groups participated in a training activity where they saw various model skyscrapers. The HA and LA groups were shown two towers, and the SM group was shown one tower. In the HA group, the two towers were identical in shape and size except that one had two diagonal braces and the other had two horizontal cross beams. This difference in bracing resulted in one tower (diagonal brace) being sturdy when pushed and the other tower (horizontal) becoming distorted when pushed. The similarity of these two towers was meant to highlight the difference in bracing to make it easier for children to notice those pieces were doing something within the structure. In the LA group, the two towers differed in shape and whether they had diagonal or horizontal bracing. As in the HA group, the diagonal brace tower remained strong when pushed on, but the other tower was able to be distorted when pushed. In this group, the children still saw a strong tower with a diagonal brace, but this brace was not highlighted because it was not the sole difference between the two towers. In the SM group, the children were only shown the strong diagonal brace tower with no comparison tower.

In the three training groups, children were asked to guess which tower was stronger (HA and LA) or if the tower was strong (SM) before being invited to wiggle the towers. When wiggling the towers, the children saw that the diagonal brace towers remained upright and strong, but the other towers changed shaped. After seeing the effects of pushing on the towers, children were either asked to explain why the building was strong (SM group), or they were asked to identify which building was stronger and then explain why it was strong (HA and LA groups). Before moving to the transfer tasks, all four groups completed two filler tasks. One filler task involved choosing which pattern was different from the others out of four possible patterns, and the other task was a modified version of Raven's matrices.

All four groups of children then completed near and far transfer tasks to see whether the information learned during the training activity transferred to different situations. In the near transfer task, children were presented with an unbraced cube that was wobbly and could be distorted. They were then given a single beam and asked to place it on the cube to fix it and make it strong. In the far transfer task, children were shown a toy motorcycle with a square part that was unbraced and could be distorted. Again, children were given a single beam and asked to fix the motorcycle.

Children in the HA group produced the most correct (brace-based) explanations of all groups, but children in the LA group utilized comparison as well by mentioning either the diagonal brace or using comparisons between the two towers they saw during training in their explanations. The HA group also performed better than the LA and NT groups on both transfer tasks. As the HA training materials were designed to facilitate comparison with an alignable difference, Hoyos and Gentner (2017) concluded that these children successfully used comparison to inform their explanations.

Current Study

The goal of the current study was to examine the effectiveness of a video comparison activity in teaching an engineering principle to 6- and 7-year-old children by adapting the demonstration used in the Hoyos and Gentner (2017) study to a video format. Hoyos and Gentner examined whether children could learn the engineering principle that diagonal bracing provides structural stability through various interventions that used a brief comparison and explanation activity using physical materials. In the present study, children were randomly assigned to one of three groups: Comparison, Single Model, and No Training. The children in the Comparison and Single Model groups participated in the training activity used by Hoyos and Gentner, but they saw the various tower(s) in a video. Children in the Comparison group saw two towers, and a researcher pushed on the towers to demonstrate that one was stable (diagonal brace tower), and one was unstable (horizontal crosspiece tower). Children in the Single Model group only saw the stable tower in their video, and the researcher pushed on the tower to demonstrate that it was stable. Children in the No Training control group did not see any training videos. Children in the Comparison and Single Model groups were asked to explain why the towers they saw in the training videos were strong, and their explanations were audio recorded. The near transfer task was adapted to a computer format, asking children to place a brace to make a cube strong. Children completed two additional computer-based spatial tasks. The Relational Reasoning task was used to measure children's ability to notice patterns, and the Mental Transformation task was used to measure children's spatial transformation ability. Additionally, information on children's STEM interest/exposure levels and spatial language use was collected from parents, and these responses were correlated with performance on the transfer, Relational Reasoning and Mental Transformation tasks.

The following hypotheses were tested in the current study:

Hypothesis 1: There would be differences between the types of explanations provided by children in the Comparison and Single Model groups. I expected that children in the Comparison group would produce more brace-based explanations than children in the Single Model group after watching the training videos based on the results of Hoyos and Gentner (2017).

Hypothesis 2: The knowledge children gained from the training videos would transfer to another situation. On the transfer task, I predicted that children in the Comparison group would perform better than both the Single Model and No Training groups.

Hypothesis 3: There would be a correlation between parent-reported STEM interest and child performance on the spatial tasks. I predicted that children's performance on the transfer, Relational Reasoning, and Mental Transformation tasks would be positively correlated with STEM interest.

Hypothesis 4: There would be a correlation between parent-reported spatial language use and child performance on the spatial tasks. I predicted that children's performance on the transfer, Relational Reasoning, and Mental Transformation tasks would be positively correlated with spatial language.

CHAPTER II: METHOD

Participants

Forty-four 6- and 7-year-old children (*M* = 6 years 11.84 months, *SD* = 7.10 months) participated in the study along with one parent per child. Of the 39 children who completed all child tasks, 13 were randomly assigned to the Comparison group, 15 were randomly assigned to the No Training group, and 11 to the Single Model group. The remaining five children were assigned to the No Training group and only completed the Relational Reasoning task, so their performance on the transfer task and explanations were not collected. Additionally, seven parents completed all parent measures, but their children (*M* = 6 years 10.85 months, *SD* = 7.73 months) did not complete any child tasks. Parents and children had the opportunity to receive one $5 electronic Amazon gift card at the conclusion of the study by providing a valid email address.

The target sample size was 54 children, with 18 children per training group. This sample size was based on Hoyos and Gentner (2017) where each training group had 18 children. An a priori power analysis conducted using G*Power3 indicated a sample of 52 would be needed to detect a medium effect size (.50) using a Chi square test, and a sample of 46 would be needed to detect a medium effect size using correlations (Faul et al., 2007). The target sample size was not obtained due to recruitment difficulties and time constraints. School-based recruitment was no longer possible once the school year ended. Six-and seven-year-olds were selected as the target age because Hoyos and Gentner demonstrated that the tower training activity and transfer task were an appropriate difficulty level for use with this age group.

Nineteen of the 44 child participants were girls and 24 were boys based on parent report. English was the reported first language of 41 children. Parent reports indicated that one child identified as Asian (2.3%), three as Black (6.8%), six as Other/Multiple (13.6%), and 33 as

White (75.0%). One parent did not report any demographic data for their child. Two parents reported having a high school diploma or equivalent (4.7%), three reported having an Associate degree (7.0%), twenty reported having a Bachelor's degree (46.5%), eight reported having a Master's degree (18.6%), four reported having a Doctorate (9.3%), and six reported having a professional degree (14%). Fourteen parents (32.6%) reported having a STEM occupation.

Five of the seven children with only parent measures reported were girls, and English was the first language of six of the children. One child identified as American Indian or Alaska Native (14.3%), one identified as Asian (14.3%), one identified as Black (14.3%), and four identified as White (57.1%). One parent reported their education as less than high school (14.3%), one reported having a high school diploma or equivalent (14.3%), three reported having a Bachelor's degree (42.9%), one reported having a Master's degree (14.3%), and one reported having a Doctorate (14.3%). One parent (14.3%) reported having a STEM occupation.

Materials

The towers used in the training videos were built from metal pieces and measured 7.38 inches long, 7.38 inches wide, and 13.63 inches tall. The Gorilla Experiment Builder (www.gorilla.sc) was used to create and host the experiment. Data was collected between October 19, 2022 and June 20, 2023. The Relational Reasoning and Mental Transformation tasks were cloned from Gorilla Open Materials using item sets from Chierchia et al. (2019) and Erlich et al. (2006). The remaining tasks were created for this experiment using Gorilla Task Builder. The Transfer Task utilized Gorilla's Drag and Drop Zone and Audio Recording features.

Measures

Training

In the training phase, children in the Comparison group were shown a brief video including two towers. One tower was braced diagonally, and the other tower had a horizontal cross piece. The experimenter pushed on the towers to demonstrate that the horizontal tower was unstable and could be distorted, but the diagonally braced tower remained upright and stable. The Single Model group was shown a brief video including only one tower that was identical to the diagonally braced model the Comparison group saw. The experimenter pushed on the tower to demonstrate that it was stable. The No Training group did not see any tower training videos.

On the next screen, children in the Comparison group were shown a picture of the diagonally braced tower and a picture of the tower with the horizontal cross piece. They were asked to choose which one was stronger, and they indicated their choice by clicking on the image. Children were then asked to explain why they thought their choice was stronger than the other tower, and their answer was audio recorded. Children in the single model group were shown a picture of the single braced tower they saw during training, and they were asked to explain why the tower was strong. The answers were audio recorded.

Explanation Coding

A trained research team member listened to the recorded explanations from this portion of the task and coded them into five categories based on common explanation content. Categories of explanations were adapted from Hoyos and Gentner (2017) and included Non-Diagnostic Parts (explanations mentioning materials the towers are made of), Shape/Spatial (explanations using non-diagonal spatial words to describe the towers), Brace (explanations referencing the diagonal brace), Movement/Action (explanations that mention the towers moving or being moved by the experimenter), and Other. The shape category was extended to include all non-diagonal spatial descriptors of the towers. The Movement/Action category was added in the current study to accommodate explanations participants gave that mentioned the experimenter pushing on the tower or the tower otherwise moving (leaning, bending, etc.). Another trained research team member independently coded 20% of the responses to determine inter-rater reliability. Percent agreement for the 20 explanations across the five categories was 85% and 100% on diagonal vs. non diagonal explanation distinction used in analyses, demonstrating adequate inter-rater reliability.

Relational Reasoning

Children completed a Relational Reasoning task from Gorilla. The task was cloned from Gorilla Open Materials and used item sets taken from Chierchia et al. (2019). The initial screen of this task informed participants to select an image that best completes the puzzle, and it indicated that participants had 20 seconds to complete each puzzle. An example of the format and answer for a puzzle like the ones included in the test trials was displayed below the instructions. Children then moved on to the test trials.

On each test trial, a fixation cross appeared for half a second followed by 8 objects of different colors displayed in a 3 x 3 matrix. The ninth object (bottom right) was missing, and children were directed to click the correct object out of four choices to complete the pattern established with the first eight objects. No feedback was given, and the experiment automatically advanced to a fixation cross and the next puzzle after an answer was chosen. If no item was clicked within the first 5 seconds, a prompt to “Go Faster!” appeared above the item choices. A countdown timer appeared in for the last 5 seconds, and if no item had been clicked after the 20 second total time limit, the experiment automatically advanced to a fixation cross and new puzzle. Children completed seven trials of this task.

Gorilla recorded data for each participant in a downloadable spreadsheet. Responses were coded as 1 for correct and 0 for incorrect, and the correct responses for each participant were summed for a total score on the Relational Reasoning task.

Transfer Task

After completing the Relational Reasoning task, children continued with the transfer task, where they were shown a video of an unbraced cube that needed to be repaired. The experimenter pushed on the cube to demonstrate that it bends out of shape. The participants then advanced to a new screen where they were shown a picture of the cube and asked to drag a single beam onto the picture to fix the cube and make it stable. Children were asked to choose from a beam that was oriented horizontally, a beam oriented vertically, or a beam oriented diagonally and then drag their chosen piece onto the picture of the cube in the center of the screen. After dragging the beam onto the image, the child was prompted to explain why they picked their chosen beam. The explanation was audio recorded, and Gorilla automatically started recording after the child was given directions.

Children then moved on to the next screen where they were asked to choose which cube was strongest from three images. Images shown included one cube with a horizontal piece, one with a vertical piece, and one with a diagonal brace. Children indicated their choice by clicking on the image of the cube they thought was strongest. After clicking on an image, the child was prompted to explain why they chose that image. The explanation was audio recorded. Then, the experiment automatically continued to the Mental Transformation task.

Gorilla recorded participants’ responses in a downloadable spreadsheet. For the click and drag beam task, participants received a 1 for dragging the diagonal beam and a 0 for dragging the horizontal or vertical beam. For the second portion of the transfer task, the participant received a 1 if they clicked the image with the diagonal brace or 0 if they clicked the incorrect image with the horizontal or vertical piece. Coding for the explanations from both portions of the transfer task was identical to that described in the training phase explanation category.

Mental Transformation

The Mental Transformation task was cloned from an existing task in Gorilla Open using procedure taken from Erlich et al. (2006). Children were shown a screen titled “Shape Game!” and then clicked to advance to the next screen for practice trials. On the first practice trial screen, an example was shown, and recorded verbal instructions played to tell the child to click on the image that is made when the two shapes in the box at the bottom of the screen are combined. The instructions told the child the correct shape to click on. In the next two practice trials, children were not told which shape to click on, but they received feedback and were able to choose again until they clicked the correct shape.

In all test trials, children saw two separate halves of a black shape in a box at the bottom of the screen, and they chose which shape would be created when the halves were joined together. They indicated their answer by clicking on one of four shape choices. No feedback was given, and there was no time limit. After a response was clicked, the screen automatically advanced to a fixation cross for half a second before moving on to the next test trial.

After eight test trials, children reached a screen with the words “Nearly Finished” and an audio recording played that told them to click continue to move to the next part of the task.

Children then completed 8 more test trials. An audio recording then played telling children that they have reached the end of the game and to press finish to end the game.

Gorilla recorded data for each participant in a downloadable spreadsheet. Responses were coded as 1 for correct and 0 for incorrect, and the correct responses for each participant were summed for a total score on the Mental Transformation task.

Parent Measures

Demographic Survey

Parents completed a demographic survey designed for this study. Demographic data were used to describe the sample (see above). The demographic survey asked for the child's date of birth and gender identity, race/ethnicity, parental education level, and parental occupation.

STEM Interest Survey

Parents completed a STEM interest survey designed for this study. The survey included questions regarding their child's interest and performance in science and math classes. Other questions asked about toys and the type of games/apps the child plays, as well as questions about the child's science experiences outside the classroom. The 14 toy/game questions were adapted from Tõugu et al. (2017). The 10 science experiences questions were adapted from Christie (2020). Responses to the 24 items were summed to yield one STEM interest score, with higher scores indicating greater child STEM interest. Cronbach's alpha for the 24 items was .76, demonstrating adequate scale reliability.

Spatial Language Survey

Parents completed a survey regarding children's use of a variety of spatial terms (e.g., horizontal, vertical, angle, diagonal). The survey was created for this study and adapted from the spatial language survey used by Hund et al. (2021), which was based on a similar spatial language survey developed by Miller et al. (2017) and utilized by Miller and Simmering (2018). The spatial terms were derived from work by Fenson et al. (1994) and Cannon et al. (2007). Parents checked each word that their child says, and a total language score was determined from the number of spatial words the parent checked. Higher total scores indicated greater child spatial language usage.

Procedure

After the study was approved by Illinois State University's Institutional Review Board (IRB 2022-206) and the Minors Activity Compliance Committee, children were recruited from local elementary schools, online/social media postings, personal contacts and snowball sampling, and contacting families in the Department of Psychology database of families interested in research. School contact was the primary recruitment method. Our invitation flyer was distributed electronically or in paper format, depending on school requirements. Interested parents and children accessed the research materials online at a location of their choosing (likely home) using a computer to access the materials and Gorilla experiment.

First, parents read the informed consent/permission document and provided consent for their own participation and permission for their child to participate by clicking on the appropriate responses on the screen. Parents completed a demographic form and child STEM interest survey online. These instruments were designed for this study. Parents were also asked to allow Gorilla to have access to their computer microphone for audio recording later in the experiment. Parents were asked to be available while their child completed the assent process and completed the study in case questions arose; however, the details were designed to allow children to complete them independently. Children listened while an assent script was read aloud while appearing on the screen then clicked to provide assent. Twenty-eight children completed the online experiment in small groups of up to four participants at a local elementary school. Their parents completed paper versions of the permission, consent, and surveys and returned them to the school. Children sat at separate computers, and two trained members of the research team were nearby to help with recording and other technology issues, including enabling microphone settings to facilitate audio recording.

Children were randomly assigned to one of the three training groups: No Training, Single Model, or Comparison, replicating Hoyos and Gentner (2017) and extending by using video learning and testing. Children in the Single Model and Comparison groups watched the training task videos and provided their explanations. The explanations were audio recorded, and Gorilla automatically started recording after the child was given directions. All three groups of children then completed the Relational Reasoning task followed by the Transfer Task. The final task was Mental Transformation.

CHAPTER III: RESULTS

Hypothesis 1: I predicted there would be differences between the types of explanations provided by children in the Comparison and Single Model groups. For the training task, I planned to use a Chi square test to calculate the differences in diagonal explanation frequency between the two training groups. Each child received a 1 if they mentioned the diagonal brace in their explanation or a 0 if they did not mention it. I predicted that the children in the Comparison group would produce more brace-based explanations than the Single Model group. Table 1 shows the frequency of each explanation type by condition and task, and Table 2 shows examples of each explanation type. None of the children in either group gave an explanation referencing the diagonal brace after the training video, so the planned analysis was not completed. I had planned to explore potential age differences in brace-based explanations as an exploratory correlational analysis, but since no children provided a brace-based explanation during training, the analysis was not completed. Hypothesis 1 was not supported.

Hypothesis 2: I predicted that the knowledge children gained from the training videos would transfer to another situation. For the transfer task, I tested multiple 2 x 2 contingency tables of diagonal production and diagonal explanation frequencies for the three training groups. Children received a score of 1 if they produced a diagonal in either the click and drag portion of the transfer task or the picture selection portion, and they received a 0 if they did not produce a diagonal. For the explanation portion of the transfer task, children received a 1 if they referenced the diagonal brace in their explanation or a 0 if they did not mention it. I predicted the Comparison group would produce more diagonals in the transfer task than the Single Model and No Training groups for both the click and drag portion and the picture selection portion. I also predicted the Comparison group would produce more diagonal explanations than the other two groups.

Table 1

Number of Children Who Provided Each Explanation Type by Condition and Task

Category	Comparison	Single Model	No Training
	Training Task		
Brace	0	0	
Shape/Spatial	0	1	
Non-Diagnostic	2	8	
Movement/Action	8	0	
Other	3	2	
	Transfer Click and Drag		
Brace	1	2	0
Shape/Spatial	2	2	2
Non-Diagnostic	2	2	3
Movement/Action	3	1	0
Other	5	4	10
	Transfer Picture Selection		
Brace	2	5	1
Shape/Spatial	6	1	2
Non-Diagnostic	2	2	5
Movement/Action	0	0	2
Other	3	3	5

Table 2

Examples of Each Explanation Type

Category	Examples
Brace	“It has a diagonal line like a crate, and crates are strong.”
Shape/Spatial	“Because if it’s going up and down then that one will hold it straight up.”
Non-Diagnostic	“It looks metal.”
Movement/Action	“Because it is just so it won’t like bend over and backwards.”
Other	“I don’t know.”

Multiple Chi square tests were planned to examine the association between condition and diagonal production as well as condition and explanation production. Several of the 2 x 2 tables had expected counts less than 5 in one or multiple cells, so Fisher’s exact test was used in these cases.

Tables 3, 4, 5, and 6 show the frequencies of diagonal production on the click and drag, picture selection, and two explanation portions of the transfer task for the Comparison and No Training groups. The result of Fisher’s exact test ($p = .10$) did not indicate a significant relation between condition and diagonal production for the click and drag portion. For the picture selection portion, a Chi square test indicated no significant relation between diagonal production and condition, $\chi^2(1, N = 28) = .001$, $p = .98$. Fisher’s exact test did not indicate a significant relation between condition for the explanation following the click and drag portion of the transfer task ($p = .46$) nor the explanation following the picture selection portion ($p = .58$). Exploratory correlational analyses of potential age differences in the production of diagonal explanations did not indicate significant relations for the click and drag explanation, *r* (36) = .06, *p* = .70, nor the picture selection explanation, *r* (36) = .00, *p* = .998.

Table 3

Diagonal and Non-Diagonal Frequencies for Transfer Task Click and Drag

	Comparison	No Training
Diagonal	6	2
Non-Diagonal	7	13

Table 4

Diagonal and Non-Diagonal Frequencies for Transfer Task Picture Selection

	Comparison	No Training
Diagonal	6	7
Non-Diagonal	7	8

Table 5

Diagonal and Non-Diagonal Frequencies for Click and Drag Explanation

	Comparison	No Training
Diagonal	1	0
Non-Diagonal	12	15

Table 6

Diagonal and Non-Diagonal Frequencies for Picture Selection Explanation

	Comparison	No Training
Diagonal	2	1
Non-Diagonal	11	14

Tables 7, 8, 9, and 10 show the frequencies of diagonal production on the click and drag, picture selection, and two explanation portions of the transfer task for the Comparison and Single Model groups. The result of Fisher's exact test (*p* = .42) did not indicate a significant relation between condition and diagonal production in the click and drag portion. For the picture selection portion, the result of Fisher's exact test (*p* = .24) did not indicate a significant relation between condition and diagonal production. Fisher's exact test did not indicate a significant relation between condition for the explanation following the click and drag portion of the transfer task (*p* = .58) nor the explanation following the picture selection portion (*p* = .18). Hypothesis 2 was not supported.

Table 7

Diagonal and Non-Diagonal Frequencies for Transfer Task Click and Drag

	Comparison	Single Model
Diagonal	6	3
Non-Diagonal	7	8

Table 8

Diagonal and Non-Diagonal Frequencies for Transfer Task Picture Selection

	Comparison	Single Model
Diagonal	6	8
Non-Diagonal	7	3

Table 9

Diagonal and Non-Diagonal Frequencies for Click and Drag Explanation

	Comparison	Single Model
Diagonal	1	2
Non-Diagonal	12	9

Table 10

Diagonal and Non-Diagonal Frequencies for Picture Selection Explanation

	Comparison	Single Model
Diagonal	2	5
Non-Diagonal	11	6

Hypothesis 3: I predicted that STEM interest scores would be positively correlated with spatial task performance. Table 11 shows the correlations between total STEM interest scores and task performance scores for the transfer task, Relational Reasoning task, and Mental Transformation task. No correlations between STEM Interest and spatial tasks reached

significance. The correlation between parent reported STEM interest and parent reported spatial language use was significant, r (46) = .29, $p < .05$. Hypothesis 3 was not supported.

Hypothesis 4: I predicted that spatial language scores would be positively correlated with spatial task performance. Table 11 shows the correlations between spatial language scores and task performance scores for the transfer task, Relational Reasoning task, and Mental Transformation task. The correlation between parent reported spatial language use and performance on transfer task click and drag explanation was significant, r (34) = .44, $p < .01$, indicating that Hypothesis 4 was partially supported.

Table 11

Correlations Between STEM and Language Scores and Spatial Task Performance

Variable	STEM Interest	Spatial Language	*M*	*SD*
1. STEM Interest	—		74.46	7.11
2. Spatial Language	.29*	—	28.00	9.27
3. Relational Reasoning	.01	.22	4.57	2.15
4. Mental Transformation	.06	.14	10.77	3.38
5. Transfer Click and Drag	-.16	.25		
6. Transfer Picture Selection	-.03	.10		
7. Transfer Click and Drag Explanation	.21	.44**		
8. Transfer Picture Selection Explanation	.11	.24		

*$p < .05$, **$p < .01$.

CHAPTER IV: DISCUSSION

The goal of the current study was to investigate the effectiveness of a video comparison activity for 6- and 7-year-old children’s learning of an engineering principle. Results were expected to replicate and extend findings from Hoyos and Gentner (2017) by showing that 6- and 7-year-old children can learn the importance of diagonal bracing using video-based comparison as well as they did via a live activity. The Comparison group was expected to produce more diagonal explanations after watching the two-tower video than the Single Model group after watching the single tower video. This hypothesis was not supported because no diagonal explanations were given by either group after the training videos.

Some children who watched training videos went on to give diagonal explanations later in the experiment, although none of them provided diagonal explanations immediately after watching the training videos. Additionally, some children who watched training videos but did not produce diagonal explanations after training went on to produce diagonals in the click and drag and picture selection portions of the transfer task. As suggested by Hoyos and Gentner (2017), it is possible that these children recognized the diagonal brace as important in the training videos, but they were not successful at verbalizing why.

The Comparison group was also expected to produce more diagonals than the other two groups in both portions of the transfer task, as well as more diagonal explanations than the other two groups during the transfer task. This hypothesis was not supported. Although more children in the Comparison group produced diagonals in the click and drag portion of the transfer task than children in both the No Training and Single Model groups, associations between condition and diagonal production were not significant. One possible reason for this could be the laptop computers used for in-person data collection. Some children expressed that they were struggling with using the laptop touchpad to click and drag the piece they wanted, and the experiment only gave them one chance to click and drag a piece. It is possible that more children intended to pick the diagonal piece than actually ended up doing so. It is also possible that watching the video of the tower was not as effective as physically interacting with the towers in person, and thus, children in the comparison group did not receive the full benefits of the comparison activity resulting in no greater diagonal production. It is also possible that limitations due to sample size precluded detecting subtle differences in performance.

Positive correlations were expected between parent reported STEM interest scores and children's performance on the transfer, Relational Reasoning, and Mental Transformation tasks. No correlations reached significance, so this hypothesis was not supported. Parent reported spatial language scores and children's performance on the transfer, Relational Reasoning, and Mental Transformation tasks were expected to be positively associated. This hypothesis was partially supported because the correlation between Spatial Language and diagonal explanation production after the transfer click and drag portion was significant. Additionally, STEM interest and spatial language scores were significantly positively correlated.

These findings are consistent with previous research demonstrating a positive association between children's production of spatial terms and performance on spatial tasks (Ankowski et al., 2012; Hund et al., 2021; Lowenstein & Gentner, 2005; Pruden et al., 2011; Simms & Gentner, 2019; Turan & De Smedt, 2022). Broadly speaking, relational language has been linked concurrently, longitudinally, and via intervention studies to children's STEM performance (Chan et al., 2022; Hornburg et al., 2018; Pupura et al., 2017; Purpura & Reid, 2016), demonstrating the vital importance of spatial relational language for STEM success. For example, Purpura et al. (2017) found that when 3- to 5-year-old children participated in a reading intervention including mathematical language (which included many spatial labels), they performed significantly better than a control group on posttest measures of both mathematical language and mathematical knowledge. The books used in the intervention centered mathematical/relational language rather than content knowledge such as numbers or counting. Exposure to relational language, such as through informal learning and play activities, can foster children's STEM success and should be the focus of continued research and practice.

The association between STEM interest and spatial language scores is consistent with existing findings showing that informal spatial activities can encourage greater spatial language use (Ferrara et al., 2011; Polinsky et al., 2023; Pruden et al., 2011). The STEM interest survey utilized in the present study includes many items that refer to spatial play (e.g., Lego, construction toys, board games) and other informal learning opportunities that include spatial activities (e.g., science museums, home science projects). Increased spatial language use during informal tasks is beneficial given the demonstrated links between relational language and later performance on spatial and other STEM tasks. It is important for future research to continue to explore the relation between spatial language, STEM interest, and performance to better understand the complexity of relations and to support formal and informal learning opportunities for children and families.

Strengths and Limitations

Ongoing research regarding learning in virtual settings is an important and timely pursuit given the widespread use of technology in schools (Gallup, 2019) and in informal learning contexts (Andre et al., 2017; Marcus et al., 2023, 2021; Polinsky et al., 2023). One strength of this study is that it was focused on advancing knowledge about virtual learning and comparison and explanation principles that may be utilized to help make virtual learning more effective. The accessibility of the experiment was also increased given the online format. This format allowed children and parents who were not local to participate in the study from their home, and it provided the opportunity to reach a more diverse group of learners than may have been available locally. The study also focused on early STEM interest, STEM learning, and spatial language and skills, which are vital topics for research and practice.

One limitation of the study was that the explanations were only audio recorded, not video recorded given technology constraints in Gorilla. The VideoCapture feature in Gorilla was in beta testing as this study was being designed, so video recordings were not yet fully established or compatible with all devices and browsers. In Hoyos and Gentner (2017), they accounted for gestures the children made that referenced the diagonal brace. Without video recording, we were unable to account for such gestures. Thus, some gesture references to the diagonal brace during the explanations may have been missed. Additionally, some children were not responding to the experiment prompt to talk without extra prompting from the parent or experimenter. Therefore, some children's explanations or parts of explanations may have been missed because of the time limits on the audio recording portions of the experiment (e.g., Gorilla automatically played the explanation prompt and started audio recording when the screen appeared for the transfer click and drag explanation portion, and it was programmed to move to the next screen after 35 seconds).

Another limitation is that we could not control if parents helped their child with the experiment at home. Although parents were directed to only help children with technical issues, we cannot be sure this direction was followed. Also, STEM interest and spatial language use were measured via parent report surveys. There is subjectivity in how parents interpret the questions asked and scale levels, as well as possible bias or dishonesty in answers due to selfreport. Recruiting the target sample size or greater would have been preferable to better detect effects. Future research should seek larger, more diverse samples. The study also was limited by the set of measures included. Future research should continue to explore STEM interest and learning and related spatial language and skills in greater detail to facilitate understanding important mechanisms of change, as well as avenues for practical implementation in formal and informal learning settings.

Future Directions

Future research should continue to examine learning principles, such as comparison and explanation, and their effectiveness in technology-based activities. It is important to test that these principles are effective in a virtual format before adapting learning activities to ensure children have the best chance at learning new information. It might be important to extend the video interactions to determine circumstances that facilitate learning STEM principles. Also, some activities are easier to adapt than others depending on complexity, and it is likely that certain types of activities will be more effective than others once adapted to a virtual format. For example, an app-based version of Christie and Gentner (2010) might be as effective as the live activity, whereas the more complex tower activity in the current study had added obstacles (e.g., switching between different tasks with different instructions, keeping children's attention for a longer activity) that could be accounted for and improved with further research.

It is also worthwhile to examine what types of activities might be more time efficient and cost effective in a virtual format. Children in the virtual condition in Klahr et al. (2007) were able to make and test mousetrap cars more quickly than children who constructed physical mousetrap cars. Teachers often have to purchase supplies for physical activities as well as spend time preparing the materials for the activities. The financial and time benefits are further reason to add virtual options when possible.

Adding a virtual option where effective is important because of the accessibility of technology as compared to in person activities such as science camps and museums. Rideout and Robb (2020) showed that children from lower SES backgrounds had higher overall screen time than children from higher SES backgrounds. Research should continue testing ways this higher screen time might be leveraged to help close the gaps in STEM exposure and experiences children from lower SES backgrounds might experience.

The lack of support for the first three hypotheses in this study demonstrate why testing is needed for virtual activities. It should not be assumed that children will learn just as well from virtual activities as they do from a live task. However, virtual learning should not be discounted as a possible effective option for the classroom even if a task is complex. The change of format may require some adjustments to reach the same level of effectiveness, but the results of testing and effectively adapting activities are beneficial to learners and educators.

The partial support for the last hypothesis highlights the connection between spatial language and spatial task performance. The relation between STEM interest and spatial language also provides support for the importance of early STEM exposure. STEM activities and spatial toys offer opportunities for children and parents to use spatial language, and they also allow children to explore their STEM interests. These results emphasize the benefits of spatial activities and early STEM exposure, and thus, the importance of continued research to make spatial training opportunities and early STEM exposure accessible to more learners.

Conclusion

The current study provides new details regarding the effectiveness of comparison and explanation in virtual learning settings. The learning of an engineering principle focusing on diagonal bracing through a live activity did not translate to the online experiment as expected. However, positive correlations were found between children's spatial language use and diagonal explanation production on the picture selection of the transfer task, as well as between children's spatial language and STEM interest. These findings provide support for the importance of spatial language in relation to spatial performance and STEM experiences, and they also highlight the need for research and testing of activities before switching from a physical to virtual format.

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APPENDIX A: DEMOGRAPHIC SURVEY

The questions below focus on you and your family. You may omit any questions you do not wish to answer.

Your Child's Race/Ethnicity

Please choose which race/ethnicity best represents your child and/or write in the space provided.

_____American Indian or Alaska Native

_____Asian

_____Black

_____Hispanic or Latino

_____Native Hawaiian or Other Pacific Islander

_____White

_____Other ______________________________

Your Child's Gender Identity

_____Female

_____Male

_____Transgender

_____Other ______________________________

Your Child's First Language

Is English your child's first language?

_____Yes

_____No

If not, what is your child’s first language? ______________________

Your Role

Please indicate your relationship with your child.

_____Mother

_____Father

_____Legal Guardian

Your Education

What is the highest grade (or year) of regular school you have completed? (Check one.)

Elementary School	High School	College	Graduate School
_____01	_____09	_____13	_____17
_____02	_____10	_____14	_____18
_____03	_____11	_____15	_____19
_____04	_____12	_____16	_____20+
_____05			
_____06			
_____07			
_____08			

Your Education Continued

What is the highest degree you earned? (Check one.)

_____Less than high school

_____High school diploma or equivalency (GED)

_____Associate degree (junior college)

_____Bachelor’s degree

_____Master’s degree

_____Doctorate

_____Professional (MD, JD, DDS, etc.)

_____Other (please specify) ______________________________

Family Income

Which of these categories best describes your total combined family income for the past 12 months? (Check one.)

_____Less than $25,000

_____$25,000 to $49,999

_____$50,000 to $74,999

_____$75,000 to $99,999

_____$100,000 to $124,999

_____$125,000 to $149,999

_____$150,000 to $174,999

_____$175,000 to $199,999

_____$200,000 and greater

_____No response

Occupation

Do you or any of your child’s other parent(s)/legal guardian(s) work in STEM (Science, Technology, Engineering, and Math)?

_____Yes

_____No

If yes, what is your/their occupation?

____

APPENDIX B: STEM INTEREST SURVEY

	Never	Rarely	Sometimes	Often	Always
My child enjoys learning about science	1	2	3	4	5
My child enjoys learning about math	1	2	3	4	5
My child likes to use computers	1	2	3	4	5
My child likes to use technology	1	2	3	4	5
My child plays with puzzles (e.g., jigsaws, tangrams, and Rubik's Cubes)	1	2	3	4	5
My child plays puzzle games (e.g., mazes, dot-to-dot)	1	2	3	4	5
My child plays Legos	1	2	3	4	5
My child plays with construction toys (e.g., Lincoln Logs)	1	2	3	4	5
My child creates art	1	2	3	4	5
My child plays board and card games	1	2	3	4	5
My child likes pretend play	1	2	3	4	5
My child plays math games	1	2	3	4	5
My child plays educational computer games	1	2	3	4	5
My child plays video games	1	2	3	4	5

My child's current grade in science class is ____

My child's current grade in math class is ____

For the following scale, we are interested in identifying specific experiences and activities that your child has been exposed to. For the 10 items listed below, please respond considering how often your child visits these places or engages in these activities.

1. Parks

    1- Almost never 2- Occasionally 3- Often 4- Almost always

2. Zoos

1- Almost never 2- Occasionally 3- Often 4- Almost always

3. Girl Scouts or Boy Scouts

1- Almost never 2- Occasionally 3- Often 4- Almost always

4. Aquariums

1- Almost never 2- Occasionally 3- Often 4- Almost always

5. Science Fairs

1- Almost never 2- Occasionally 3- Often 4- Almost always

6. Sports Games

1- Almost never 2- Occasionally 3- Often 4- Almost always

7. Art Galleries or Museums

1- Almost never 2- Occasionally 3- Often 4- Almost always

8. Home Science Projects

1- Almost never 2- Occasionally 3- Often 4- Almost always

9. Concerts

1- Almost never 2- Occasionally 3- Often 4- Almost always

10. Science Museums

1- Almost never 2- Occasionally 3- Often 4- Almost always

APPENDIX C: SPATIAL LANGUAGE SURVEY

Relationship to child

☐ Mother ☐ Father ☐ Guardian

Children understand many more words than they can say. <u>We are particularly interested in the SPATIAL WORDS that your child SAYS</u> (e.g., words that describe relationships between object sizes or locations, properties of objects, or object shapes). <u>Please go through this list and check the words that you have heard your child use appropriately.</u> Do not worry if your child says only a few of these words right now.

Words	**Says**	**Words**	**Says**	**Words**	**Says**	**Words**	**Says**
Center		Apart		Toward		Right side-up	
Corner		Together		Turn		Upside-down	
Right		Separate		Sideways		Somewhere	
Left		Flip		Opposite		Join	
Among		Away		Rotate		Through	
Within		Backward		Reverse		Throughout	
Across		Forward		Around			

Words	**Says**	**Words**	**Says**	**Words**	**Says**	**Words**	**Says**
Angle		Tilt		Side		Flat	
Horizontal		Brace		Zigzag		Line	
Vertical		Wide		Diagonal		Column	
Criss-cross		Curve		Edge		Length	