Supporting Middle School Students' Spatial Skills Through Rubik's Cube Play

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Jesslyn Valerie

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Abstract

Spatial skills are a strong predictor of students' science, technology, engineering, and mathematics (STEM) achievement. The present study uses a quasi-experimental design to address three research objectives focusing on the development of spatial skills; specifically, mental rotation. This study's first research objective examines if learning to solve the Rubik's Cube improves eighth-grade students' two- and three-dimensional mental rotation performance. The second objective explores if there are differences between male students' and female students' mental rotation performance. Finally, the Need for Cognition Scale is utilized to determine whether motivation, enjoyment, and effort in cognitive endeavors can predict the change in students' mental rotation performance from pretest to posttest. This study's findings show that eighth-grade students' who participated in the Rubik's Cube training interventions significantly improved on measures of two- and three-dimensional mental rotation. Students' scores on the Need for Cognition Scale predicted the degree to which their two-dimensional mental rotation skills improved. This study's results suggest that students' motivation for critical thinking and reasoning predicts their capacity to learn from spatial training experiences. Overall, these findings contribute to the literature that spatial skills are malleable.

Keywords: spatial skills, spatial cognition, mental rotation, cognitive development.

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Chapter 1: Introduction

Spatial skills are helpful in everyday tasks whether a person is navigating spaces or understanding the relationship between objects. In 2015, Newcombe and Shipley defined spatial skills as “spatial information concerns shapes, locations, paths, relations among entities and relations between entities and frames of reference” (p.180). Spatial skills include but are not limited to one’s ability to conceptualize space, visualize relationships, problem solve, recognize the relationship between two- and three-dimensional constructs, and utilize tools of representation (Ness et al., 2017).

Spatial Skills in Science, Technology, Engineering, and Mathematics (STEM)

Spatial skills are universally used in multiple domains of science, technology, engineering, and mathematics (STEM). Spatial skills are useful in STEM learning because STEM problem solving requires reasoning of spatial information (Stieff & Uttal, 2015). For example, in chemistry, students use spatial skills to make judgements about whether pairs of molecular representations are the same or a mirror image of the molecular structure (Stieff et al., 2018). In physics, study by Kozhevnikov et al. (2007) showed that students with high spatial skills are better at solving kinematics problems because they are able to use mental imagery to predict the trajectory of a hockey puck. In geology, a study done by Gagnier et al. (2017) found that sketching a three-dimensional geologic block diagram of rock layers helped develop students' spatial skills. Findings from a mathematics study by Weckbacher and Okamoto (2014) found that spatial skills are significantly and positively correlated with high school students' geometry achievement. Students who scored high on the three-dimensional mental rotation test tended to achieve higher geometry course grades.

Furthermore, research studies suggest conducting spatial training at an early age. For example, studies with kindergarten and early primary school students showed that spatial skills are good predictors of how well students will perform on linear number line tasks (Gunderson et al., 2012) and basic calculation problems (Cheng & Mix, 2014). Additionally, a longitudinal study showed that engaging in spatial tasks, such as deconstructing building blocks, with preschoolers led to stronger sense of arithmetic in elementary school (Verdine et al., 2014). A study by Gilligan et al. (2017) with over 12,000 participants further demonstrated that spatial skills account for a significant proportion of variance in elementary school students' mathematical achievement. Time spent on practicing and refining spatial skills are also significant. A study by Levine et al. (2012) found that students who spent more time playing with spatial toys performed better in spatial tasks.

Similar relationships are found with older students. A longitudinal study done by Shea et al. (2001) found that high school students with higher spatial skills were more likely to pursue STEM majors in higher education and go into

STEM careers tracks. Another longitudinal study suggest that spatial skills were better predictors of high school students' performance in STEM classes compared to mathematical reasoning and verbal reasoning measures (Wai et al., 2009).

Following the National Research Council's (2006) research on *Learning to think spatially: GIS as a support system in the K-12 curriculum*, increasing emphasis has been placed upon the integration of spatial skills into STEM education national standards and curricula. In 2010, the Common Core State Standards Initiative included spatial reasoning into its mathematical components which addresses geometric transformation and learning symmetry. In 2012, the National Council for Geographic Education drew attention to spatial thinking as an essential topic in their geography curriculum. In 2013, the Next Generation Science Standards added spatial constructs into the middle school (MS-ESS2-2) and high school (HS-ESS2-1) earth science standards (National Research Council, 2013).

Although these new national standards have pinpointed spatial skills as crucial aspects of their respective subject matter, further research is needed to better understand the ways in which spatial skills can be used as educational tools and integrated into curricula. Previously, according to Newcombe (2014) "the inclination and ability to think spatially were widely regarded as fixed rather than learned, as difficult to change, and hence not as targets for intervention and education" (p. 323). Fortunately, a meta-analysis has shown that spatial skills are trainable for individuals of all ages (Uttal et al., 2013). It is important to continue to develop and expand upon students' spatial skills in deliberate ways that promote deeper learning and meaning. Ness et al. (2017) noted that "young children's spatial skills are often automatic and spontaneous; for this reason, the curriculum needs to present spatial skills in a more deliberate manner" (p. 173). There is a need to emphasize the connection of spatial skills to the task at hand in order to recognize the interrelationship between the concepts. For example, a student might refer to a Rubik's Cube as a square to which their instructor could redirect the student, referring to the object as a cube. Ideally, the introduction of this new scientific concept would not stop there; the instructor could then make deliberate connections explaining the concept of a cube. These concepts might include what differentiates a square from a cube, characteristics of a cube, and real-world examples of cubes. Utilizing this teaching practice could help students to develop a conceptual knowledge and draw connections between scientific and spatial concepts (Ness et al., 2017, pp. 173-174). If spatial skills are not stated in the curriculum in a deliberate manner, it could be assumed that students are developing these skills, but this is not necessarily the case. Ensuring that teaching models coincide with spatial constructs in curricula to best facilitate learning is crucial as is continued research surrounding various spatial tools.

Given the significance of spatial skills in STEM learning, students in K-12 education need to be given adequate opportunity to train, learn, and demonstrate their spatial skills in science classrooms. Deliberate connections between scientific and spatial concepts needs to be drawn to facilitate advancement in children’s scientific knowledge and spatial development. It is important to continue studying the ways in which spatial skills are learned, taught, and integrated into everyday life and the classroom.

Chapter 2: Literature Review

Biological Sex Differences in Spatial Skills

This study is concerned with differences between the performance of male and female students on spatial skills tasks. Meta-analyses of several studies consistently showed robust biological sex differences in which men outperform women in a wide variety of spatial tasks including: the Mental Rotation Test (MRT), the Cards Rotation Test, and the Spatial Relations subtest of the Primary Mental Abilities Test (Linn & Petersen, 1985; Voyer et al., 1995). Despite efforts to narrow biological sex differences in spatial skills through training, results remained ambiguous whether training was effective in decreasing biological sex differences seen in spatial skills. A study by Terlecki et al. (2008) where students participated in 12 weeks of spatial training by playing the video game Tetris, resulted in men outperforming women on spatial tasks. In the posttest taken 12 weeks after the training, biological sex differences narrowed. This finding illustrates that there is a potential to decrease biological sex differences with longer spatial interventions. A year-long longitudinal study by Miller and Halpern (2013) trained undergraduate students on spatial skills through workbook exercises for 12 hours (divided into 6 two-hour spatial training sessions distributed across six weeks). Students completed a spatial skills pretest prior to training and a posttest a week after their final training session. Posttest results revealed a decrease in biological sex differences. However, a posttest completed by students eight months after training showed the loss of spatial skills gained by women. Large biological sex differences persisted. The present study investigates whether biological sex differences exist in eighth-grade students' spatial skills, measured through students' mental rotation performance, before and after their participation in the Rubik's Cube training interventions.

Training Spatial Skills

Although people often think that spatial skills are innate, evidence suggests that spatial skills are malleable. Learners of all age groups and biological sexes can improve their spatial skills (Uttal et al., 2013). For example, a study done by Yang and Chen (2010) showed that playing with a digital Pentominoes game is beneficial and significantly improves students' spatial skills because it requires students to select, rotate, flip, mirror, and fit the Pentomino pieces onto the game board to complete the Pentomino puzzle. These multi-step manipulations of geometric shapes are effective in enhancing students' geometric learning. Yang and Chen's study also found significant biological sex differences in the pretest, but not the posttest. These results demonstrated a reduction in biological sex differences following the students' training interventions. Similarly, Terlecki et al. (2008) Tetris video game study found that undergraduate students who played Tetris over the course of 12 weeks demonstrated improvements in their spatial skills. Tetris is a one player game where a geometric form falls from the top to the bottom of the game screen. Players need to rotate each geometric shape to create as many horizontal lines as possible as pieces fall to the bottom at increasing speed. Players receive points for completing each horizontal line. These studies which involve game play that requires rotations and manipulations of an object showed promising evidence of improving people's spatial skills. These studies served as a catalyst for the present study's interest investigation of whether the Rubik's Cube can be used to train students' spatial skills.

This paper examines the effectiveness of spatial training with the Rubik's Cube. This study measures eighth-grade students' ability to perform two- and three-dimensional mental rotation. Rubik's Cube was chosen for the present study because it was hypothesized that the complexity involved in solving the Rubik's Cube requires significant spatial skills, specifically, mental rotation.

Mental Rotation as a Measure for Spatial Skills

In this study, mental rotation is an indicator of a specific set of spatial skills. Mental rotation involves the ability to rotate figures mentally (Linn & Petersen, 1985) and is one of the most commonly used measures of spatial skills (Caissie et al., 2009; Hegarty, 2018). There are two types of mental rotation that are commonly explored: two-dimensional mental rotation (Cooper, 1975; Hoyek et al., 2012) and three-dimensional mental rotation (Shepard & Metzler, 1971; Vandenberg & Kuse, 1978). To measure two-dimensional mental rotation, students are presented with 4 two-dimensional target figures (two correct target figures and two distractors) where they must identify which two figures could be mentally rotated to match the reference figure. Similarly, to measure three-dimensional mental rotation, students are presented with 4 three-dimensional target figures (two correct target figures and two distractors) where they must identify which two figures could be mentally rotated to match the reference figure. The present study focuses on investigating students' growth trajectory in two- and three-dimensional mental rotation performance prior and following students' participation in the Rubik's Cube training interventions.

Measuring Motivation

In order to solve the Rubik's Cube, individuals must be willing to try multiple solution methods, reflect on what works and what does not work, and modify their approach and strategies. In this study, students must also be willing to learn Rubik's Cube notations and algorithms. These aspects of the study increase the cognitive challenges that students encounter. Therefore, the study is interested in determining how students' motivation, enjoyment, and effort predict the change in their mental rotation performance. The Need for Cognition Scale (Cacioppo et al., 1984) includes 18 items which measure whether individuals engage in and enjoy tasks that require critical thinking such as solving puzzles and solving ill structured problems. The full scale is presented in Appendix A. Prior studies have demonstrated positive relationships between students' need for cognition and their academic performance (Sadowski & Gulgoz, 1992, 1996; Tolentino et al., 1990).

Chapter 3: Research Objectives

The present study has three main research objectives. The first objective examines whether learning to solve the Rubik's Cube improves eighth-grade students' two- and three-dimensional mental rotation performance. It is hypothesized that participating in the Rubik's Cube training interventions can improve both two- and three-dimensional mental rotation performance. This hypothesis was formulated in accordance with existing research showing spatial skills are trainable through a variety of tasks including: puzzle play (Levine et al., 2012), digital Pentominoes (Yang & Chen, 2010), Tangram (Lin et al., 2011), and Tetris (Terlecki et al., 2008).

The second objective explores whether there are differences between male students' and female students' mental rotation performance. The third research objective utilizes the Need for Cognition Scale in order to determine if motivation, enjoyment, and effort in cognitive endeavors can predict the change in students' mental rotation performance. The current study expects the Rubik's Cube training interventions to contribute evidence to literature that puzzle games can be utilized to improve the design of spatial training interventions for K-12 students.

Chapter 4: Methods

Participants

Two hundred sixty eighth-grade students from a diverse, urban, middle school participated in the study. School demographics are included in Table 1 (Department of Education, 2019). The experimental group consisted of 132 students and the control group consisted of 128 students. All students completed a demographic questionnaire concerning their prior experience. Four students (two from the control group and two from the experimental group) who indicated they knew how to solve the Rubik's Cube were excluded from this study. Students who did not complete the pretest and posttest as well as students who did not attend all the training sessions were also excluded. In total, 62 students from the experimental group and 57 students from the control group were excluded due to missing a test or training session. These students were excluded because their incomplete test data did not allow change to be measured.

After implementing the exclusion criteria, this study included a total of 137 eighth-grade students (74 male students, 63 female students, *M* = 13.39 years old, *SD* = 0.49, Range = 13-14). The experimental group included 68 eighth-grade students (40 male students, 28 female students, *M* = 13.69 years old, *SD* = 0.47) and the control group included 69 eighth-grade students (34 male students, 35 female students, *M* = 13.09 years old, *SD* = 0.28). The participant flowchart is presented in Figure 1.

Figure 1

Exclusion process for study participants

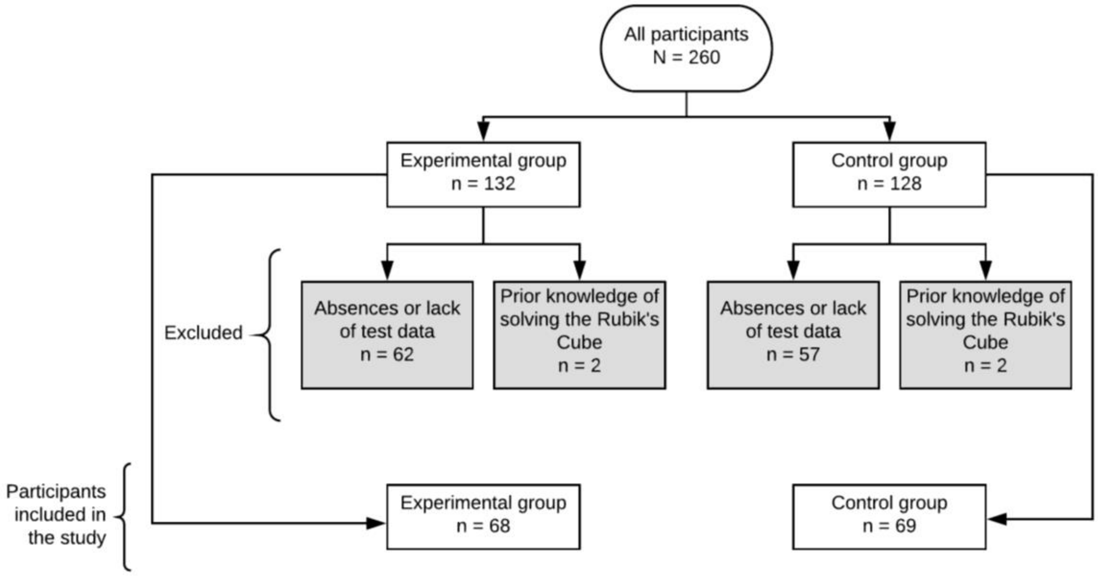


Table 1

Middle School Demographics, 2019

Race or Ethnicity	Percent
Hispanic or Latino	43.90%
American Indian or Alaska Native	0.70%
Asian	4.40%
Black or African-America	14.60%
Native Hawaiian or other Pacific Islander	0.10%
White	27.00%
Two or more races	9.30%

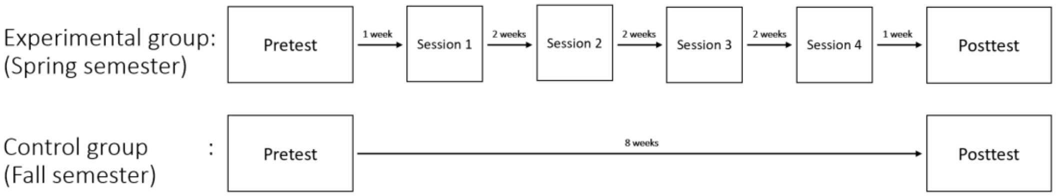
Note. Data are from “the Minnesota Report Card,” by the Department of Education, 2019 (https://rc.education.state.mn.me/#demographics/orgId--10280037000__p--5). In the public domain.

Study Design

This study uses a quasi-experimental design. Students were not randomly assigned to the control group or the experimental group. Students in the experimental group participated in this study during the spring semester. Students in the control group participated during the fall semester. The control group was included in the study to increase the validity of the research. The timeline for the study is presented in Figure 2. There was an eight-week period between the pretest and posttest for both the experimental and control groups. This design decision was made based on the availability of students to serve as a control group. Students in both groups had the same classroom teacher and similar demographics. The classroom teacher confirmed that in both cases, students did not receive instruction that could interfere with the study objectives. Students in the experimental group participated in four Rubik's Cube training interventions. Each of the students in the experimental group were given a Rubik' Cube at the end of the first session. Students in the control group participated in their typical science curriculum lessons during the duration of the study and were given the Rubik's Cube training at the end of the study.

Figure 2

Study timeline



Measures

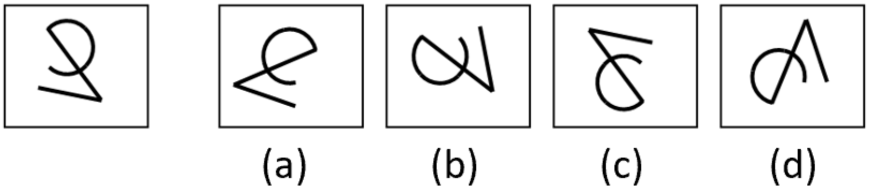
Demographics. Students completed a demographic questionnaire asking them to share their biological sex, age, and whether they know how to solve the Rubik's Cube. Only two options for biological sexes were presented (male and female).

Need for Cognition Scale. The Need for Cognition Scale consists of 18 Likert scale items. Sample statements include: "I prefer complex to simple problems” and “I like to have the responsibility of handling a situation that requires a lot of thinking” (Cacioppo et al., 1984). Students rated using a Likert scale (1 = *strongly disagree* to 5 = *strongly agree*). Items 3, 4, 5, 7, 8, 9, 12, 16, and 17 were reverse coded. The full scale is presented in Appendix A. This study utilized students’ need for cognition average scores for data analysis.

Mental Rotation. A two-dimensional mental rotation test (Hoyek et al., 2012) and a revised version of the Vandenburg and Kuse three-dimensional mental rotation test (Peters et al., 1995) were used as pretest and posttest measures of students’ mental rotation performance. Each mental rotation task includes 24 items. See Figure 3 for an example of the two-dimensional mental rotation test and Figure 4 for an example of the three-dimensional mental rotation test.

Figure 3

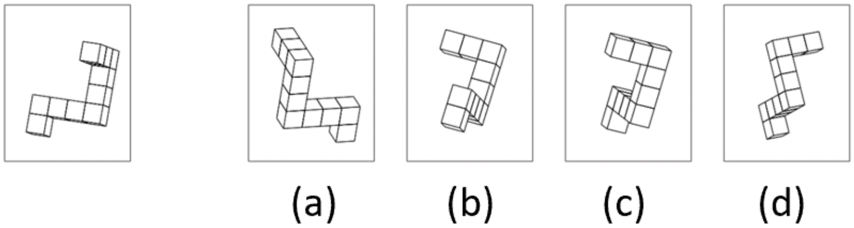
Example item of the two-dimensional mental rotation test



Note. The correct answers: c, d. Adapted from “The Use of the Vandenberg and Kuse Mental Rotation Test in Children,” by N. Hoyek, C. Collet, P. Fargier and A. Guillot, 2012, *Journal of Individual Differences, 33*(1), 62–67. (https://doi.org/10.1006/brcg.1995.1032).

Figure 4

Example item of the three-dimensional mental rotation test



Note. The correct answers: a, c. Adapted from “A redrawn Vandenberg and Kuse Mental Rotations Test: Different versions and factors that affect performance,” by M. Peters, B. Laeng, K. Latham, M. Jackson, R. Zaiyouna and C. Richardson, 1995, *Brain Cognition*, *28*(1), 39–58. (https://doi.org/10.1006/brcg.1995.1032).

Each question in the two- and three-dimensional mental rotation tests consisted of one reference figure and four target figures (two correct target figures and two distractors). The directions instructed students to mentally rotate each figure and identify which two target figures could be mentally rotated to match the reference figure. A question was scored as correct (one point) if both correct answers were identified and scored as zero if one or none of the correct figures were identified. This scoring method was employed to minimize guessing. Students did not get half points for identifying at least one of the correct target figures. This scoring method is in concurrence with the studies of Hoyek et al. (2012) and Peters et al. (1995). Possible scores ranged from zero (*no correct answers identified*) to 24 (*a perfect total score*).

Instructions emphasized that there were only two correct answers to each question. The time limit for the mental rotation tests was substantially different from the guidelines given by Peters et al. (1995) which provided six minutes. In this study, there was no time limit for students to finish their mental rotation tests. Students were expected to finish all the given measures within one class period (46 minutes). Therefore, the results of the mental rotation tests focused on accuracy rather than speed. This adjustment is more inclusive for students who may need more time to read and comprehend the instructions or may need to revisit them during the task.

Procedures

Overall Participation Schedule. Study sessions were carried out across six, 46 minutes class periods. The timeline of the study is presented in Figure 2. The order of pretest and posttest of the two- and three-dimensional mental rotation tests were counterbalanced to control for any testing order effects. The two- and three-dimensional mental rotation tests were counterbalanced by alternating the tests given to each classroom. Students in the first, third, and fifth hour classes completed the two-dimensional mental rotation test followed by the three-dimensional mental rotation test. Students in the second, and fourth hour classes completed the three-dimensional mental rotation test followed by the two-dimensional mental rotation test.

The demographic questionnaire and the Need for Cognition Scale were given using Google forms (https://www.google.com/forms/about/). The two- and three-dimensional mental rotation tests were given using Qualtrics (https://www.qualtrics.com). The participating school had a one-to-one digital device program so that each student has their own laptop for school related work. The majority of students completed all measures using a laptop. Students who did not have a laptop were provided paper copies.

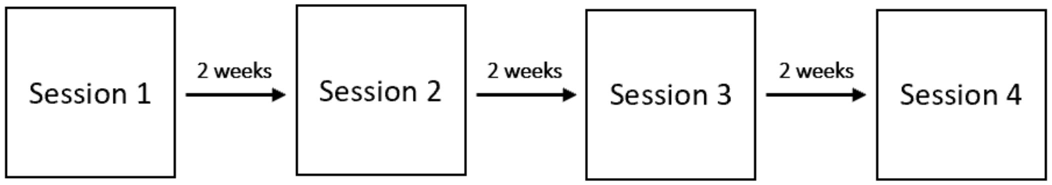
Pretests and Posttests. Students were instructed to complete the demographic questionnaire followed by the Need for Cognition Scale. After completing these two measures, students completed the two- and three-dimensional mental rotation pretests, counterbalanced. Eight weeks later, students completed the two- and three-dimensional mental rotation posttests. The two-dimensional mental rotation pretest and posttest are identical. However, the three-dimensional mental rotation test differs between pretest and posttest. Students received version A on the pretest and version B on the posttest.

Rubik's Cube Training Sessions

The Rubik's Cube training interventions included four training sessions where the researcher came to the middle school once every two weeks. The researcher and the science classroom teacher delivered all the instruction through whole class presentations and discussions. Students also had access to the presentation slides through their individual laptops via the online platform site used by their science teacher. The timeline of the training sessions is shown in Figure 5.

Figure 5

Timeline of the four training sessions



Training Session One. The first training session included three activities: understanding rotations, colors and pieces, and learning Rubik's Cube notation. The order of activities in session one is presented in Figure 6.

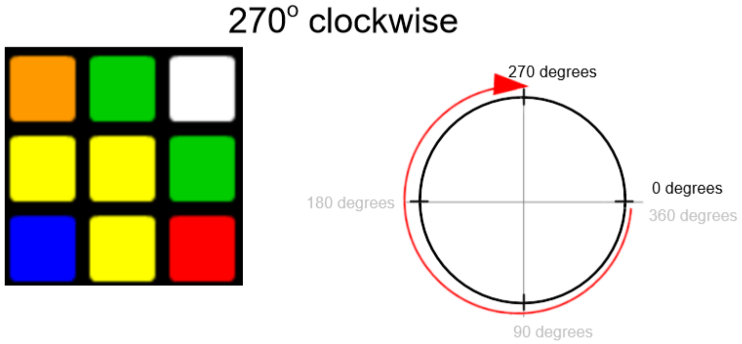
Figure 6

Three activities that were completed in session one

The first activity introduced students to directional rotations (clockwise and counterclockwise) and angular rotations (i.e., a 270° turn counterclockwise, to the left, is equal to a 90° turn, clockwise, to the right). An example from one of the instructions given to students is presented in Figure 7. This process is crucial because it provided the foundation for students' understanding of the rotations that are happening within the Rubik's Cube as it is manipulated.

Figure 7

First activity in session one: understanding rotations

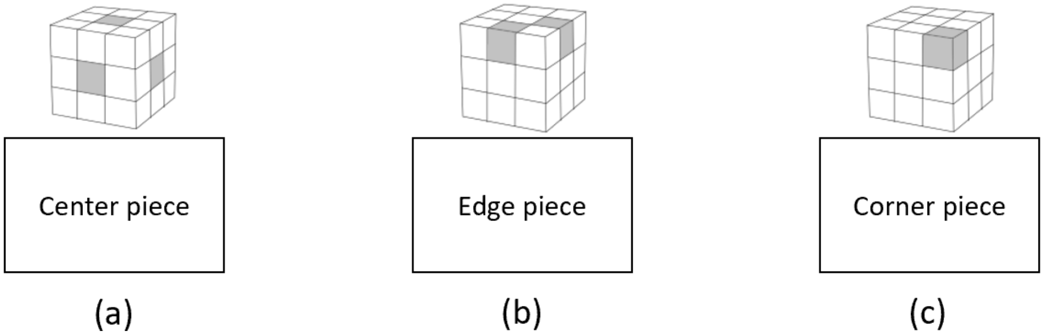


In the second activity, students were introduced to the relationship between different colors and pieces within the 3x3x3 Rubik’s Cube. There are three distinct locations of the pieces that make up the cube: center piece (Figure 8a), edge piece (Figure 8b), and corner piece (Figure 8c). There are six sides to a cube which consist of six different colors. Hence, there are six center pieces within the Rubik’s Cube where each center piece belongs to a color. Edge pieces have two colors of which there are a total of twelve. Corner pieces have three colors; within the 3x3x3 Rubik’s Cube, there are a total of eight corner pieces.

Familiarity with the pieces that make up the Rubik’s Cube is crucial in developing a conceptual understanding of the toy. Specifically, knowing each piece spatial location and the number of colors on each piece in addition to possible movement and rotations allows a student to develop strategies and more efficient moves to solve the Rubik’s Cube.

Figure 8

Session 1 training: Figure 8a (center piece), Figure 8b (edge piece), Figure 8c (corner piece).



In the third activity, students were introduced to the sides of the cube, shown in Figure 9, and the cube notations shown in Figure 10.

Figure 9

Session 1 training: sides of the cube

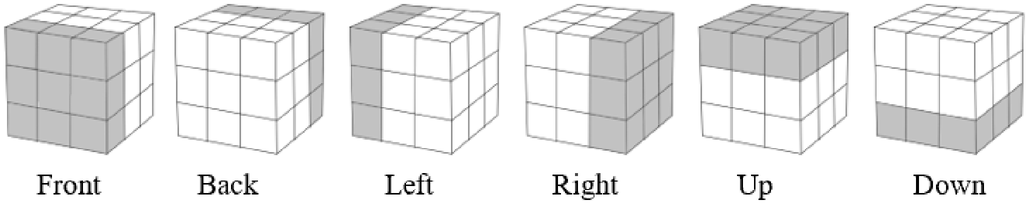
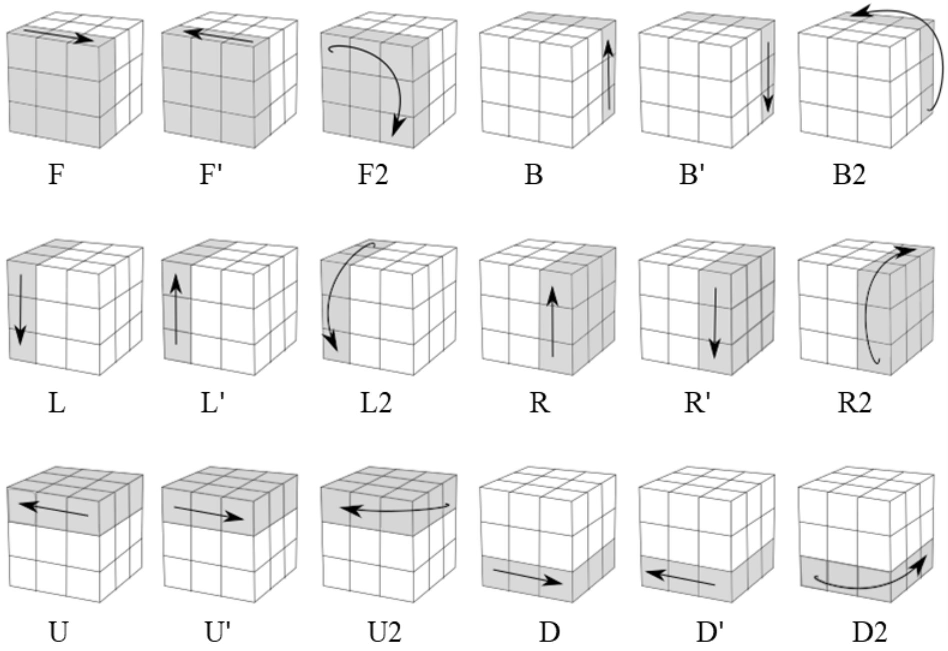


Figure 10

Session 1 training: cube notations



Cube notations were used to describe the rotations of the cube. There are six letters that are used to describe which sides of the cube will be rotated in reference to the sides that faces the students while holding the cube (Figure 9). These six letters are as follows:

- U stands for “up” side of the cube.
- D stands for “down” side of the cube.
- R stands for “right” side of the cube.
- L stands for “left” side of the cube.
- F stands for “front” side of the cube.
- B stands for “back” side of the cube.

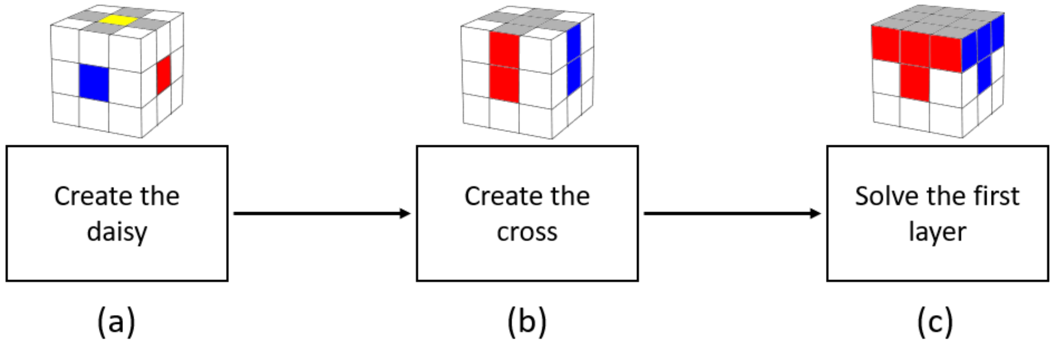
Additionally, each notation refers to a 90° turn clockwise (quarter of the way around the cube) unless otherwise noted by an apostrophe symbol ('). The apostrophe symbol (i.e., U’, D’, L’, R’, B’, and F’) indicates a 90° counterclockwise rotation, sometimes referred to as a prime or an inverse move. A combination of a letter and the numeral 2 (i.e., U2, D2, L2, R2, B2, and F2) indicates a 180° turn (half of the way around the Rubik’s Cube). Cube notations serve two important functions. First, cube notation was used as a language to convey the Rubik’s Cube algorithm. Second, notations were helpful for students’ navigation within the cube and synchronous classroom learning.

For example, if the algorithm written in cube notation is as follows: R, U, R', U2, one would read this as rotating the right side of the Rubik’s Cube 90° clockwise, followed by rotating the up side of the Rubik’s Cube 90° clockwise, followed by rotating the right side of the Rubik’s Cube 90° counterclockwise, and finally rotating the up side of the Rubik’s Cube 180° clockwise.

Training Session Two. The second session taught students to solve the first layer (one side) of the Rubik’s Cube. First, students created the *daisy* (Figure 11a), followed by the *cross* (Figure 11b), and finally completed the remainder of the first layer (one side) of the Rubik’s Cube (Figure 11c). The *daisy* is called as such because the color pattern resembles a daisy flower: yellow in the center piece and white in the edge pieces. Similarly, the *cross* is called as such because the pattern resembles the shape of a cross.

Figure 11

Session 2 training: Figure 11a (daisy), Figure 11b (cross), Figure 11c (first layer solved)



At the beginning of the session (creating the *daisy*), students were shown what the *daisy* looks like (Figure 11a) and allowed to work intuitively, alone or with a partner, to achieve the pattern. A majority of the students did not have trouble creating the *daisy*.

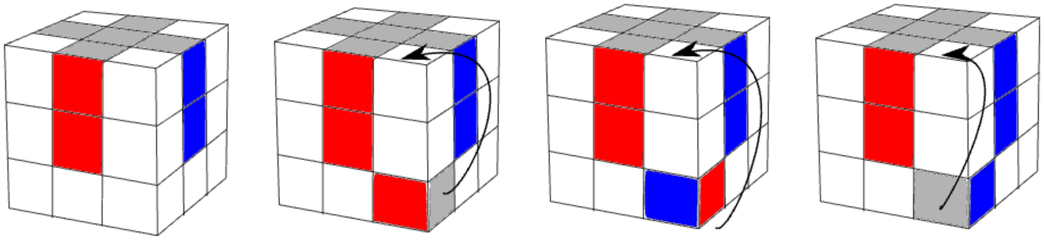
When students struggled, they were referred back to the first session where they learned about the relationship between the pieces of the cube. In order to create the *daisy*, students needed to think about the relationship between the center piece and the four edge pieces. Students needed to use the center piece as their point of reference because this piece never shifts on a 3x3x3 Rubik's Cube (Figure 8a). Only the edge pieces needed to be manipulated to successfully recreate the *daisy*.

Starting with the *daisy*, students matched the edge and the center piece colors followed by four, 180° rotations (Figure 11b). The sum of these movements creates the *cross*. Finally, in order to solve the first layer of the

Rubik’s Cube (Figure 11c), students were introduced to a Rubik’s Cube algorithm, presented in Figure 12.

Figure 12

Session 2 training: algorithm to orient the corner pieces



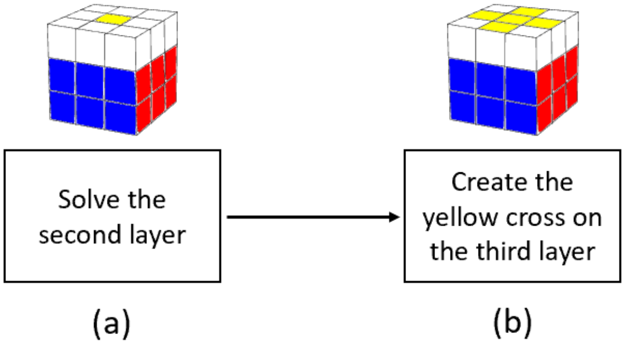
Repeat R’ D’ R D until the corners are solved

This step required students to orient the four corner pieces of the Rubik’s Cube in order to solve the first layer. Students needed to place the corner pieces on the bottom, right side of the cube. Students executed the algorithm: R', D', R, D. Written out the algorithm reads: rotate the right side of the Rubik’s Cube 90° counterclockwise, rotate the down side of the Rubik’s Cube 90° counterclockwise, rotate the right side of the Rubik’s Cube 90° clockwise, and rotate the down side of the Rubik’s Cube 90° clockwise. This step sometimes required several repetitions of the given algorithm in order to orient all four corners.

Training Session Three. The third session included two activities. In the first, students solved the second layer of the Rubik’s Cube, shown in Figure 13a. The second activity required students to create a cross on the third layer of the Rubik’s Cube, shown in Figure 13b.

Figure 13

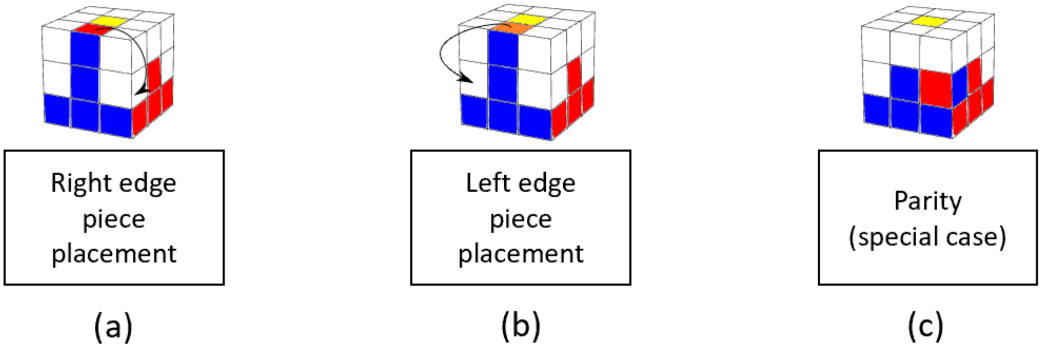
Session 3 training: Figure 13a (second layer of the Rubik's Cube solved), Figure 13b (cross on the third layer of the Rubik's Cube)



Solving the second layer of the Rubik's Cube was the goal of the first activity. There were three possible cases students could encounter (Figure 14).

Figure 14

Session 3 training: solving the second layer of the Rubik's Cube

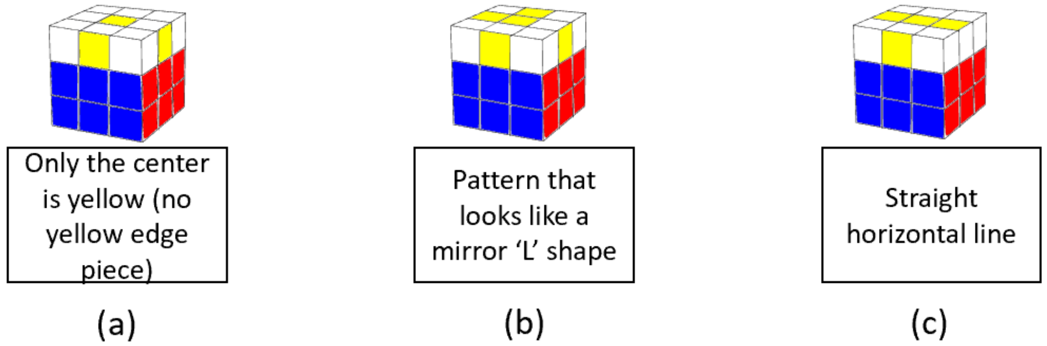


If students encountered the case as presented in Figure 14a, it meant the edge piece located on the third layer needed to be placed on the second row, third column of the cube. This algorithm written in cube notation is: U, R, U', R', U', F', U, F. If students encountered the case as presented in Figure 14b, it meant the edge piece located on the third layer needed to be placed on the first row, second column of the cube. This algorithm written in cube notation is: U', L', U, L, U, F, U', F'. Students were not expected to memorize any of the algorithm. Instead, they were encouraged to rotate each side of the cube slowly and analyze how each rotation affects the colors and pieces of the cube. One special case that some students encountered while performing this activity found the piece in the correct location, but the colors were flipped (Figure 14c). In this case, students had to follow the algorithm for Figure 14a and then re-orient the piece to its respective location resulting in correct color orientation.

The second activity's goal was creating a cross on the third layer of the Rubik's Cube without disrupting the rest of the cube (Figure 13b). Based upon the first activity, a student's cube could appear as any of the three options displayed in Figure 15. Depending upon which case a student encountered, they would repeat the following algorithm once, twice, or thrice. This algorithm written in cube notation is: F, R, U, R', U', F'. When the color of the cube's center did not match with the edges (Figure 15a), students needed to utilize the algorithm thrice. Similarly, students needed to repeat the algorithm twice if their cube displayed a pattern that looked like a mirror of an L shape (Figure 15b). Lastly, students needed to execute the algorithm once when a straight horizontal line was encountered (Figure 15c).

Figure 15

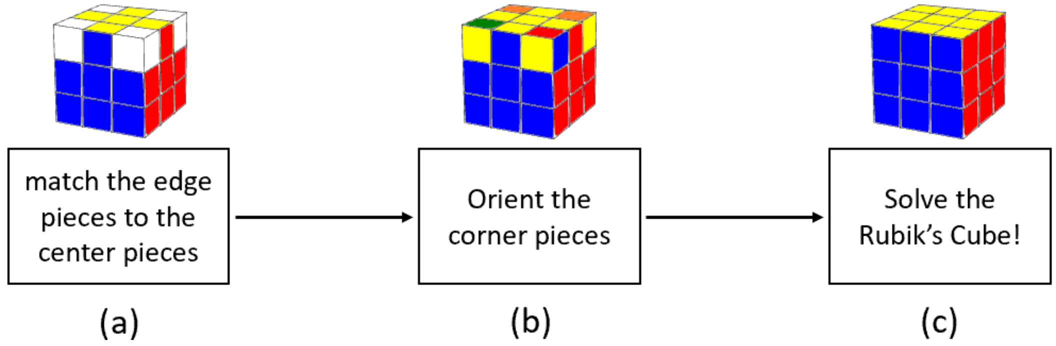
Session 3 training: creating a cross on the third layer of the Rubik's Cube



Training Session Four. There were three activities in the final session (Figure 16). The first activity matched the edges of the cross on the third layer of the Rubik's Cube, shown in Figure 16a. The second activity oriented the last four corners of the cube into their respective locations, shown in Figure 16b. The third activity was solving the rest of the Rubik's Cube, shown in Figure 16c. Of the four sessions students experience, the final was the least structured. Students could practice at their own pace. Any students who were struggling to complete solves from prior sessions were able to continue where they left off. Students who could successfully solve the Rubik's Cube were able to provide help to their peers still learning previous steps.

Figure 16

Session 4 training: *Figure 16a (match the edge pieces to the center pieces), Figure 16b (orient the corner pieces), Figure 16c (solve the whole Rubik's Cube)*



In the first activity of the fourth session, the goal was to match the color of the edge pieces of the cross on the third layer of the Rubik's Cube to their respective center pieces. Students first needed to check if any of the edge pieces were in the correct places in relation to their respective center pieces. At least one color of the edge pieces should have matched the center piece's color. If none of the colors match, the third layer had to be rotated until at least one of the edge colors matched the center's color. From there on, the side that had the matching edge pieces was placed at the "Front" side of the cube. This algorithm written in cube notation is: R, U, R', U, R, U2, R' and had to be executed twice to achieve the pattern shown in Figure 16a.

The goal of the second activity was orienting the last four corner pieces in the third layer of the Rubik's Cube to their respective places without disrupting the rest of the cube (Figure 16b). This algorithm written in cube notation is: U, R, U', L', U, R', U', L.

The goal of the third activity was solving the Rubik’s Cube (Figure 16c). This algorithm written in cube notation is: R', D', R, D. Written out the algorithm reads: rotate the right side of the Rubik’s Cube 90° counterclockwise, rotate the down side of the Rubik’s Cube 90° counterclockwise, rotate the right side of the Rubik’s Cube 90° clockwise, and rotate the down side of the Rubik’s Cube 90° clockwise. The activities in this session were mostly procedural. All the activities in this session required students executing the Rubik’s Cube algorithm correctly.

Chapter 5: Results

Three research objectives were investigated in this study. The first research objective explored whether the Rubik's Cube training interventions could be used to train spatial skills, specifically the two- and three-dimensional mental rotation performance of eighth-grade students. The second, investigated whether there were biological sex differences between male students' and female students' mental rotation performance. From pretest to posttest, the third objective explored whether students' average scores on the Need for Cognition Scale could predict the change in their mental rotation performance.

The research objectives of this study were addressed through conducting analysis of covariance (ANCOVA) with type III sum of squares due to unbalanced design. The two independent variables were biological sexes (male and female students) and conditions (control and experimental groups). Difference scores were used for the data analyses. It was obtained through calculating the change in the two- and three-dimensional mental rotation test scores from pretest to posttest. Prior to conducting the ANCOVA, two-sample t-tests were conducted to check for preexisting significant differences between the control and experimental groups. The mean difference scores of the two-dimensional pretests were not statistically significant, $t(135) = 0.74$, $p = .46$, $d =$

0.13. Additionally, the mean difference scores of the three-dimensional pretests were not statistically significant, *t*(135) = -0.83, *p* = .41, *d* = 0.14.

What Works Clearinghouse (2013) recommends researchers measure the effect sizes of the differences between the control and experimental groups prior to further analyses. This is done so that proper statistical adjustments can be made if necessary. For an effect size larger than 0.05, pretest scores need to be included as a covariate in the ANCOVA model to account for statistical adjustment in order to meet the baseline equivalence requirement set by the What Works Clearinghouse. The effect size of the two-dimensional mental rotation pretest scores was 0.13 and the effect size of the three-dimensional mental rotation pretest scores was 0.14. Since both effect sizes were larger than 0.05, pretest scores of the two- and three-dimensional mental rotations were included in the ANCOVA model as covariates to account for statistical adjustment.

In the two-dimensional ANCOVA model, the dependent variable was the two-dimensional mental rotation difference scores (the change in the two-dimensional mental rotation test scores from pretest to posttest). Covariates included both two-dimensional pretest scores and the need for cognition average scores. An interaction between biological sexes (male and female students) and conditions (control and experimental groups) was also included in the model. In the three-dimensional ANCOVA model, the dependent variable was the three-dimensional mental rotation difference scores (the change in the three-dimensional mental rotation test scores from pretest to posttest). Covariates included both three-dimensional pretest scores and the need for cognition average scores. An interaction between biological sexes (male and female students) and conditions (control and experimental groups) was also included in the model.

The need for cognition average scores were included as covariates in both the two- and three-dimensional ANCOVA models. This was done to determine whether students' average scores on the Need for Cognition Scale could predict the change in students' two- and three-dimensional mental rotation performance from pretest to posttest after controlling for their mental rotation pretest scores, biological sexes, and conditions.

Two-dimensional results. Results from the ANCOVA model for the change in the two-dimensional mental rotation test scores from pretest to posttest are reported in Table 2.

Table 2

ANOVA table for the two-dimensional mental rotation test results

Variable	*SS*	*F*(1, 131)	*p*
Two-dimensional pretest scores	493.1	18.73	<.001
Need for cognition average scores	191.7	7.28	.008
Biological sexes	3.8	0.15	.704
Conditions	240.8	9.15	.003
Biological sexes x Conditions	0.00	0.00	.999
Residuals	3447.8	—	—

Note. Biological sexes = male and female students; Conditions = control and experimental groups; *SS* = sum of squares.

The response variable was the change in two-dimensional mental rotation test scores from pretest to posttest. A statistically significant main effect for conditions (control and experimental groups) was found (Cohen's *d* = 0.59). The moderate effect size indicates that the mean of the two-dimensional mental rotation test scores was 0.59 standard deviations greater for the experimental group than the mean for the control group. The mean differences and the standard deviations are presented in Table 3. The changes in mean between the control and experimental groups measured during pretest and posttest are presented in Figure 17. This graph shows that in the pretest, the control group scored higher than the experimental group. Following the training interventions, the experimental group scored higher than the control group. The ANCOVA model reflects a significant difference between the control and experimental groups two-dimensional mental rotation difference scores.

The main effect for biological sexes was not statistically significant (Cohen's *d* = 0.09). The mean changes of male and female students between the control and experimental groups measured during pretest and posttest are presented in Figure 18. The mean two-dimensional pretest scores of female students in the experimental group (*M* = 11.86), male students in the control group (*M* = 12.24), and male students in the experimental group (*M* = 12.58) were lower than the mean scores for female students in the control group (*M* = 14.49). Female students in the experimental group scored slightly lower in the pretest and posttest compared to male students in the experimental group. However, this difference was not statistically significant. Following participation in the Rubik's Cube training, both male and female students in the experimental group showed improvement on the two-dimensional mental rotation performance in a similar upward trend. The interaction effect between biological sexes and conditions was not statistically significant.

Figure 17

Mean differences of the two-dimensional mental rotation test scores

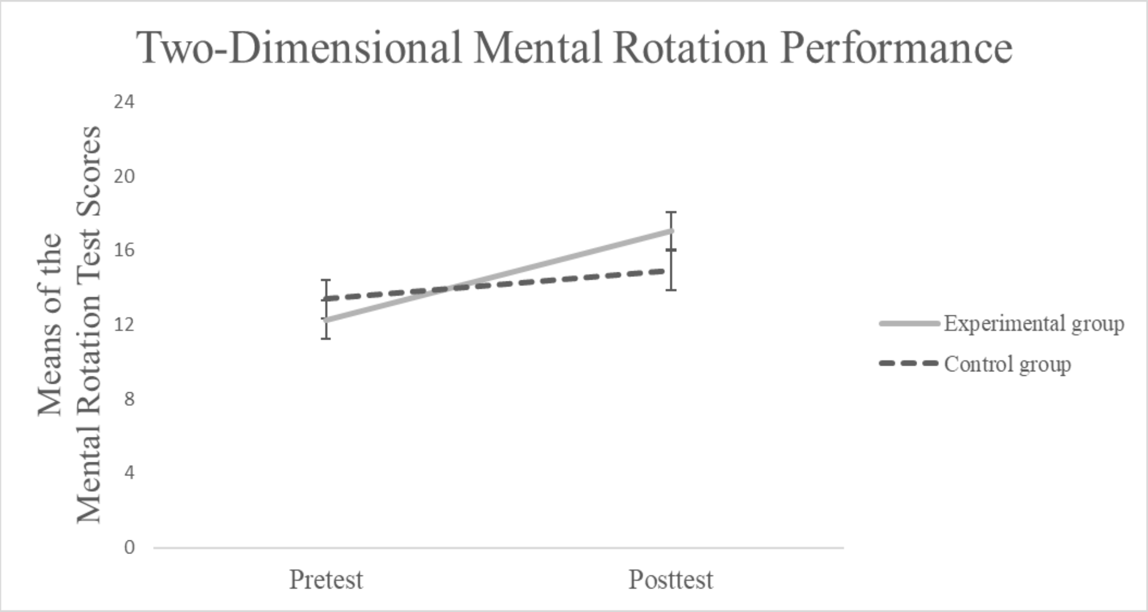


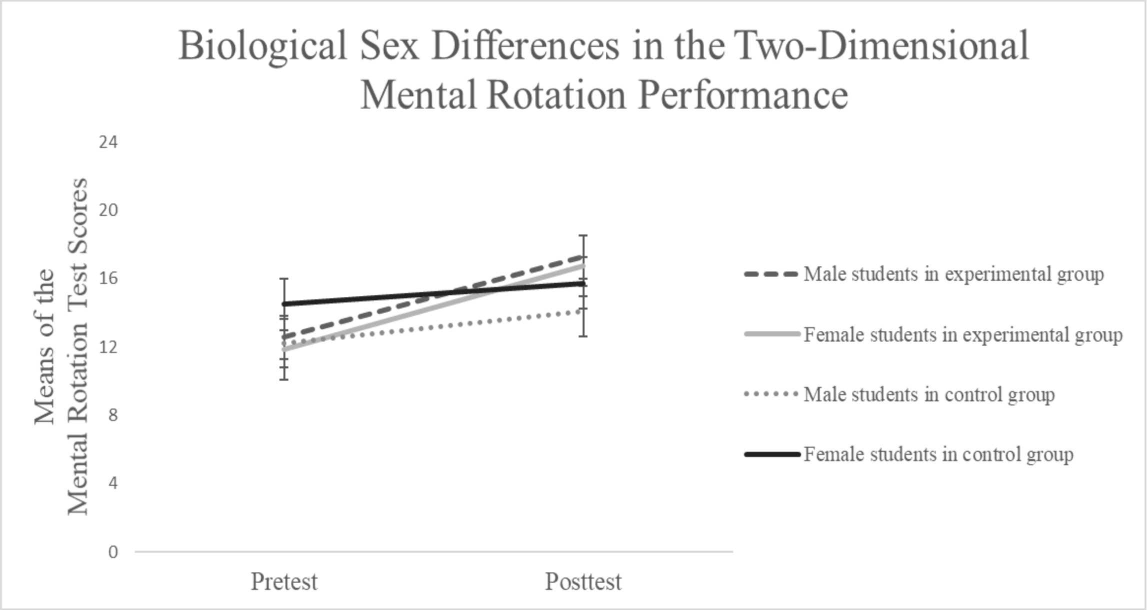
Table 3

Means, standard deviations, and standard errors of students' mental rotation performance

Mental Rotation Test	Experimental			Control		
	Pretest	Posttest	Difference	Pretest	Posttest	Difference
Two-dimensional						
M	12.27	17.06	4.78	13.38	14.93	1.55
SD	8.62	8.51	6.51	8.73	8.70	4.28
SE	1.04	1.03	0.79	1.05	1.05	0.52
Three-dimensional						
M	10.21	12.69	2.49	9.29	9.51	0.22
SD	6.75	7.52	4.98	6.14	7.13	3.56
SE	0.82	0.91	0.60	0.74	0.86	0.43

Figure 18

Means of the two-dimensional mental rotation test scores including biological sex differences



Three-dimensional results. Results from the ANCOVA model for the change in the three-dimensional mental rotation test scores from pretest to posttest are reported in Table 4.

Table 4

ANOVA table for the three-dimensional mental rotation test results

Variable	*SS*	*F*(1, 131)	*p*
Three-dimensional pretest scores	34.41	0.02	.179
Need for cognition average scores	10.35	1.83	.460
Biological sexes	0.03	0.55	.969
Conditions	162.9	0.00	.004
Biological sexes x Conditions	12.88	0.68	.410
Residuals	2465.20	—	—

Note. Biological sexes = male and female students; Conditions = control and experimental groups; *SS* = sum of squares.

The response variable was the change in three-dimensional mental rotation test scores from pretest to posttest. A statistically significant main effect for the conditions (control and experimental groups) was found (Cohen's *d* = 0.52). The moderate effect size indicates that the mean of the three-dimensional mental rotation test scores was 0.52 standard deviations greater for the experimental group than the mean for the control group. The mean differences and the standard deviations are presented in Table 3. The changes in mean between the control and experimental groups measured during pretest and posttest is presented in Figure 19. The graph shows students in the control group scored lower in their three-dimensional mental rotation performance compared to students in the experimental group in both the pretest and posttest. The ANCOVA model reflects a significant difference between the control and experimental groups three-dimensional mental rotation difference scores. The main effect for biological sexes was not statistically significant (Cohen's *d* = 0.05). The mean changes between male and female students in the control and experimental groups measured during pretest and posttest is presented in Figure 20. Both male and female students in the experimental groups scored higher in the pretest and posttest compared to the control groups. Three-dimensional results showed that female students in the experimental group scored slightly lower in the pretest and posttest compare to male students in the experimental group. However, this difference was not statistically significant. Following participation in the Rubik's Cube training, both male and female students in the experimental group showed significant improvement in the three-dimensional mental rotation performance at a similar upward trend. The interaction effect between biological sexes and conditions was not statistically significant.

Figure 19

Mean differences of the three-dimensional mental rotation test scores

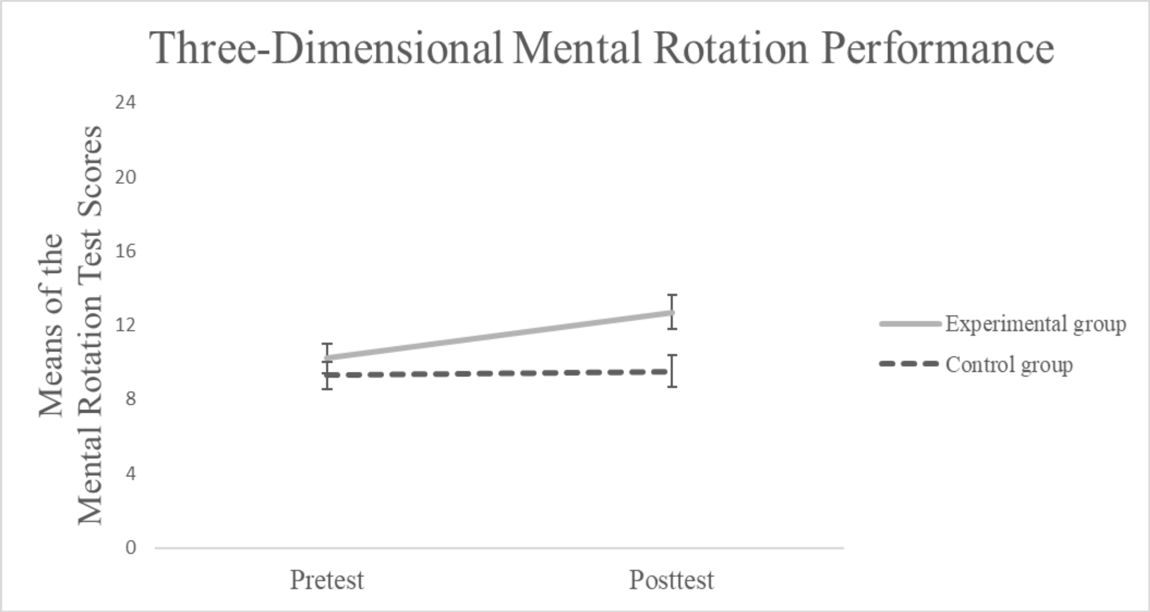
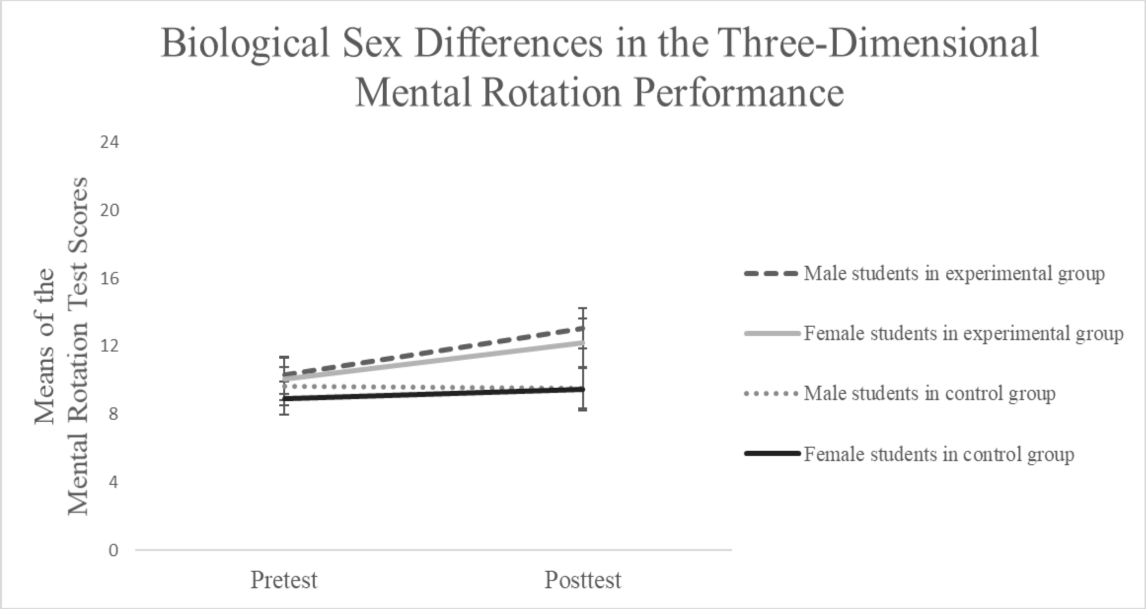


Figure 20

Means of the three-dimensional mental rotation test scores including biological sex differences



Need for Cognition Scale. The need for cognition average scores were used to conduct data analysis. For the two-dimensional findings, the need for cognition average scores showed very weak correlation with the two-dimensional mental rotation pretest scores. This shows that there is very little collinearity between the two variables. The correlation table is presented in Table 5. The study found a significant main effect of the need for cognition average scores (Table 2). The study also found that for every 1-point increase in the Need for Cognition Scale, students showed on average a 2.18 increase in their two-dimensional mental rotation test scores after controlling for two-dimensional pretest scores, biological sexes, and conditions.

Table 5

Correlation table of the Need for Cognition Scale and mental rotation test scores

Variable	Need for cognition average scores	Two-dimensional difference scores	Three-dimensional difference scores
Need for cognition average scores	—	.21	.09
Two-dimensional mental rotation pretest scores	.09	-.33	—
Three-dimensional mental rotation pretest scores	.02	—	-.10

For the three-dimensional findings, the need for cognition average scores showed a very weak correlation with the three-dimensional mental rotation pretest scores. The correlation table is presented in Table 5. The main effect of the need for cognition average scores was not statistically significant (Table 4). The study found that for every 1-point increase in the Need for Cognition Scale, students showed on average a 0.50 increase in their three-dimensional mental rotation test scores after controlling for three-dimensional pretest scores, biological sexes, and conditions. Although the partial regression coefficient showed an increasing trend, it was not statistically significant. Hence, generalization cannot be made to the larger population of students beyond what was represented by the sample.

Summative quantitative results. These results showed significant improvements in students' two- and three-dimensional mental rotation performance following participation in the Rubik's Cube training interventions. This study did not find any significant differences between the mental rotation performance of male and female students. The study found that students' average scores on the Need for Cognition Scale did predict the change in students' two-dimensional mental rotation performance from pretest to posttest after controlling for two-dimensional mental rotation pretest scores, biological sexes, and conditions. However, students' average scores on the Need for Cognition Scale could not predict their three-dimensional mental rotation performance from pretest to posttest after controlling for three-dimensional mental rotation pretest scores, biological sexes, and conditions.

Chapter 6: Discussion

Prior to the study, it was hypothesized that game play that requires rotations and manipulations of an object shows promising evidence of improving spatial skills. The hypothesis of the present study is supported by the findings. These findings are consistent with research demonstrating that spatial training involving three-dimensional tasks led to spatial improvements in two- and three-dimensional tasks. For example, a research study showed that students who engaged in a two-dimensional block videogame training for three weeks improved exclusively in two-dimensional mental rotation performance. However, students who engaged in a three-dimensional block videogame training improved on both their two- and three-dimensional mental rotation tests (Moreau, 2013).

In order to solve the Rubik's Cube, one must learn and develop knowledge of two-dimensional rotation. For example, in the first training session, students were introduced to angular rotations, directional rotations, and cube notations. This specific set of knowledge requires manipulation of two-dimensional space and is continuously used and refined as the training sessions progress. This study introduced three-dimensional rotation by way of teaching students Rubik's Cube algorithm in addition to the relationship between colors and pieces of the Rubik's Cube. For example, students need to first identify the correct color orientation that belongs to the target location within the three-dimensional space of a Rubik's

Cube. Second, students need to find the piece that goes into that specific target location. Third, students need to manipulate the three-dimensional cube to correctly orient the target piece into the target location. Figure 14 provides a good representation of this process.

This study found a larger increase in students' two-dimensional mental rotation performance compared to three-dimensional mental rotation performance. One of the reasons could be because the two-dimensional mental rotation test was the same for pretest and posttest. Some students could have received practice effect from completing the identical two-dimensional mental rotation test. However, the three-dimensional mental rotation test had two different versions between pretest and posttest which could have lowered the likelihood of a practice effect. Hence, it is important to include an interaction in the ANCOVA model (biological sexes and conditions) to understand the relationship between the differences in mental rotation performance of male and female students in the control and experimental groups.

The second research objective looks at biological sex differences. The findings of this experiment found no significant differences between the performance of male and female students. From the data provided by the World Cube Association (2020), 130,822 male competitors and 14,769 female competitors have participated in a Rubik's Cube competition. This means that male competitors made up around 86% of all competitors. This number is surprisingly high given the increasing access to better quality puzzles at a cheaper price point. The number of female competitors represented in the Rubik's Cube competition remains significantly low. Based on the findings of the current study, mental rotation performance is not a factor in the lack of participation by females in Rubik's Cube competitions. Thus, some driving factors of female competitors' low participation in Rubik's Cube competitions could be due to lack of motivation, enjoyment, and effort in cognitive endeavors. Beyond cognitive factors, opportunities to learn, marginalization in the social community, power imbalances, and the lack of interest in the competitive nature of Rubik's Cube competitions could also be driving factors influencing the underrepresentation of female competitors.

Although the present study does not suggest that there are biological sex differences, some studies did find biological sex differences in mental rotation performance (Linn & Petersen, 1985; Terlecki et al., 2008; Voyer et al., 1995; Yang & Chen, 2010). In addition to continuing the possibility that there are biological sex differences, broader research questions regarding these imbalances could be examined. For example, future studies could look at students' sense of belonging in the community, accessibility to spatial toys, confidence, and self-worth in their ability to perform mental rotation optimally.

The third research objective examines whether motivation, enjoyment, and effort in cognitive endeavors can predict the change in students' mental rotation performance from pretest to posttest measured by the Need for Cognition Scale. The two-dimensional findings suggest that students with higher need for cognition scores are more likely to improve upon their mental rotation performance compared to students with lower scores. This means the role of motivation and enjoyment in cognitive tasks has the potential to affect students' performance in spatial training. However, the three-dimensional findings were not statistically significant. This means that although the partial regression coefficient for the three-dimensional findings showed an increasing trend, the data cannot be generalized to a larger population of students beyond what was represented by the sample. It would be important for future studies to measure the degree to which motivation affects a student's mental rotation performance. Additionally, it would be beneficial to look at both the short- and long-term implications of motivation in relation to students' mental rotation performance.

Limitations

Despite these contributions, this study also has its limitations. In the pretest, a demographic questionnaire was the first measure given to students (prior to the students completing the Need for Cognition Scale and mental rotation tests). This study had a higher proportion of male students in the experimental group (40 male students, 28 female students), but nearly an even split in the control group (34 male students, 35 female students). The difference in proportion of male and female students could affect the change in pretest to posttest scores between the control and experimental groups. However, this study did not find any significant biological sex differences in students' mental rotation performance from pretest to posttest after controlling for biological sexes in the ANCOVA model. Additionally, this study did not find an interaction between biological sexes (male and female students) and conditions (control and experimental groups). Hence, it is unlikely that the difference in proportion could significantly alter the results.

The high number of students excluded in this study raises the possibility that this subset of excluded students could have included individuals with less pronounced mental rotation performance improvements, thus altering the findings of this study. Sixty-four students from the experimental group and 59 students from the control group were excluded from the study. Four of these students (two from the control group, two from the experimental group) were excluded due to prior knowledge of solving the Rubik's Cube. The remainder of the exclusions were individuals who did not complete the study in its entirety; only students who completed all of the training sessions and took both the pretest and posttest were included (68 experimental group, 69 control group). There are numbers of reasons why a student might not have completed the study in its entirety. These include absences from class due to health issues, students being pulled out of class for academic reasons, or lack of motivation to participate. Due to the voluntary nature of the study, there were no academic ramifications for missing training sessions which could have influenced students' motivation to participate. It could also be possible that some of the students who did not complete training sessions perceived themselves as unable to be successful in the training sessions, thus altering the findings of this study. Without knowing the exact reason behind a student's partial completion of the study, it cannot be said with a high degree of certainty that partial completion of the study could alter this study's findings.

Future Directions

The present study only investigates the short-term learning of the Rubik's Cube interventions. It would be beneficial to investigate the long-term implications of this study by conducting a follow up on students to measure the retention rates of their mental rotation improvements. Studying the long-term implications of the Rubik's Cube training effects would contribute crucial information to literature regarding the retention of trained spatial skills.

Future studies could also explore how spatial skills transfer to students' learning of science concepts in their eighth-grade science classrooms. It would be beneficial to know how spatial skills affect students' overall perception of science concepts. For example, an observational study could be conducted to investigate the conversation and classroom interaction between students and teachers. The study would examine the type of science inquiries posed by students in order to better understand a student's ability to make deeper relational and spatial connections with the science curriculum.

Future studies could also examine students' eye gaze patterns as they engaged in the Rubik's Cube training. There is a high possibility that there is an interaction between eye gaze (the perceptual input) and complementary cognitive internal processing. For example, instead of doing the full rotation of an object through mental imagery, students visualize the figure by tracing the lines of the object to execute the rotation. If such problem-solving strategies are used by students to execute mental rotation tasks, eye gaze data would provide evidence of these phenomena.

To conclude, this study has three main findings. First, engaging in Rubik’s Cube training interventions can be one of the methodologies for improving and training spatial skills in two- and three-dimensional mental rotation performance in educational settings, specifically through working with eighth-grade students in United States middle schools. This is consistent with previous research concerning the malleability of spatial skills. Second, this study found no evidence of biological sex differences in male and female students’ mental rotation performance. Finally, this study found students’ average scores on the Need for Cognition Scale were able to predict the degree to which students’ two-dimensional mental rotation skills improved following the Rubik’s Cube training interventions but were unable to predict improvements of three-dimensional mental rotation skills.

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Appendix A

Need for Cognition Scale (Cacioppo et al., 1984).

1. I would prefer complex to simple problems.

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

2. I like to have the responsibility of handling a situation that requires a lot of thinking.

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

3. Thinking is not my idea of fun.**

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

4. I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.**

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

5. I try to anticipate and avoid situations where there is likely chance I will have to think in depth about something.**

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

6. I find satisfaction in deliberating hard and for long hours.

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

7. I only think as hard as I have to.**

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

8. I prefer to think about small, daily projects to long-term ones.**

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

9. I like tasks that require little thought once I've learned them.**

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

10. The idea of relying on thought to make my way to the top appeals to me.

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

11. I really enjoy a task that involves coming up with new solutions to problems.

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

12. Learning new ways to think doesn't excite me very much.**

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

13. I prefer my life to be filled with puzzles that I must solve.

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

14. The notion of thinking abstractly is appealing to me.

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

15. I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

16. I feel relief rather than satisfaction after completing a task that required a lot of mental effort.**

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

17. It’s enough for me that something gets the job done; I don’t care how or why it works.**

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

18. I usually end up deliberating about issues even when they do not affect me personally.

1	2	3	4	5	6
Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree

Note. ** = reverse scored item.