I Solved it! Using the Rubik's Cube to Support Mental Rotation in a Middle School Science Classroom

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Abstract: Increasing demand for educational methods that can improve spatial skills is driven by research showing that it can help students to succeed in STEM fields. This short paper describes a study that looks at the effectiveness of learning to solve the Rubik's Cube to improve middle school students' spatial skills, specifically mental rotation. We also examine the overall dynamic of the classroom and the ways that students were interacting with the cubes through observational notes taken during each session. Middle school students participated in four sessions of Rubik's Cube training designed by the lead researcher and a partner middle school teacher. Results indicate that students improved in their ability to execute two and three-dimensional mental rotation tests. Our findings provide promising evidence that instruction with the Rubik's Cube can improve mental rotation performance of middle school students.

Introduction

Spatial skills are universally applicable to numerous domains of learning. Students need spatial skills to develop conceptual understanding of abstract concepts required in science, technology, engineering, and mathematics (STEM) learning. For example, drawing representations of molecules in chemistry (Stieff et al., 2014) and learning the layers of the earth in geology (Gagnier et al., 2016). In mathematics, Wekbacher and Okamoto (2014) found a positive correlation between students' mental rotation test scores and their geometric scores. Gunderson et al. (2012) found that spatial skills are a good predictor for students' improved understanding of the linear number line.

Despite the critical role of spatial skills in STEM learning, spatial skills have yet to be fully recognized in the STEM curriculum. Education researchers and learning scientists have highlighted the need for more emphasis on spatial skills training in education standards and learning objectives. Multiple studies have shown that spatial skills were a better predictor of students' performance in STEM fields than mathematical cognition and verbal reasoning (Shea et al., 2001; Stieff & Uttal, 2015; Wai, et al., 2009). These findings suggest that researchers look for more ways to improve spatial skills as a mechanism to enhance STEM learning. A meta-analysis by Uttal et al. (2013) showed that spatial skills could be trained and improved. Multiple research studies have demonstrated that spatial skills are trainable through games and game-like experiences. For example, a study with young children showed that puzzle play was effective in improving spatial skills (Levine et al., 2012). Students engaged in Tangram play also demonstrated a similar effect (Lin et al., 2011). In addition, undergraduate students who played the video game Tetris (an hour a week for 12 weeks) showed significant improvement in their mental rotation performance. They also showed long-term retention of the mental rotation improvement across several months (Terlecki et al., 2008).

To follow up on these findings, we developed four sessions of the Rubik's Cube training intervention that offered 8^{th}-grade students the opportunity to play and learn to solve the Rubik's Cube in their science class. One of our research team members is an experienced middle school science teacher who helped with the design and enactment of the training. The teacher ensured that the study materials and instructions were developmentally appropriate. When possible, connections were made between spatial skills to real-world contexts where students would need the skills they were practicing with the Rubik's Cube.

Linn and Petersen (1985) acknowledged three categories of spatial skills: spatial perception, spatial visualization, and mental rotation. Mental rotation is the ability to rotate figures mentally. The goal of the present study is to identify whether the Rubik's Cube can be used to improve the two-dimensional mental rotation (2D-MRT) and three-dimensional mental rotation (3D-MRT) performance of middle school students. Our study uses *mental rotation* as the measurement of construct because it is one of the most commonly used measures of spatial skills (Caissie et al., 2009; Hegarty, 2018). It is hypothesized that participating in the Rubik's Cube training intervention can improve both 2D-MRT and 3D-MRT performance.

Methodology

Research design

This research employed a quasi-experimental design. Students in the experimental group participated in the spring semester while students in the comparison group participated in the fall semester. This design decision was made based on the availability of students to serve as a comparison group. Students in the experimental group participated in four sessions of the Rubik' Cube training where the researcher came to the school once every two weeks. Students in the comparison group engaged in their usual science curriculum during the duration of the study. The comparison group received the Rubik's Cube training intervention after the study was completed. Study sessions were carried out across six, 46 minutes class periods. Both groups had an eight-week period between their pretest and posttest. The timeline of the study is presented in Figure 1.

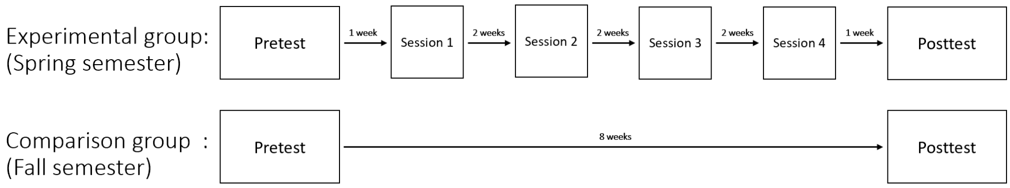

Figure 1. Timeline of the study.

Participants and context

Participants were 8th-grade students recruited from a large, diverse, urban middle school in a midwestern city of the United States. All activities took place in a middle school science classroom where we have developed our research partnership for over a decade. All students who participated in the study had no prior knowledge of solving the Rubik's Cube based on self-reported data gathered through a questionnaire administered at the beginning of the study. Data from students who missed one or more practice sessions, had prior knowledge on solving the Rubik's Cube, and those who did not completed the pretest and posttest measures were excluded. After the exclusion criteria was implemented, a total of 137 students (M_{age} = 13.39 years) participated in the study. The experimental group included 68 students (M_{age} = 13.69 years) and the comparison group included 69 students (M_{age} =13.09 years).

Measures and analysis

Quantitative and qualitative data were gathered in this study. Quantitative data was collected via a two-dimensional mental rotation test (Figure 2) and the revised Vandenburg and Kuse three-dimensional mental rotation test (Figure 3). Both tests have been extensively used in research on mental rotation and are valid measures of the skills we targeted (Hoyek et al., 2012; Peters et al., 1995). Students completed the pretest and posttest measures prior to and following participation in the four sessions of the Rubik's Cube training intervention.

Each question in the 2D-MRT and 3D-MRT 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. 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). The order of the pretest and posttest were counterbalanced to control for any testing order effects.

Qualitative data was collected through observation notes taken by the researcher during each session. This data served to capture the overall dynamic of the classroom and the ways that students were interacting with the cubes.

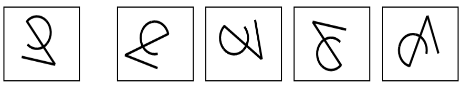

Figure 2. Two-dimensional mental rotation test (Hoyek et al., 2012).

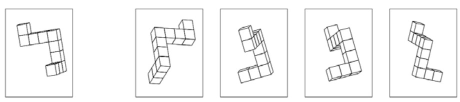

Figure 3. Three-dimensional mental rotation test (Peters et al., 1995).

Procedures

There were a total of four Rubik's Cube training sessions. The goal of the first session was to introduce students to learning angular and directional rotations (i.e., a 270° turn clockwise is equal to a 90° turn counterclockwise). The goal of the second session was to teach students how to solve the 1st layer (one side) of the Rubik's Cube. Students were given 10 minutes to solve it on their own. After 10 minutes passed, they could ask for help from their peers, science teacher, and the researcher. Students who successfully solved one side of the cube could freely explore other approaches and discuss strategies with their peers. Many algorithms exist that could be employed to solve the Rubik's Cube and students were encouraged to find the optimal solution.

The goal of the third session was to solve the 2nd layer of the Rubik's Cube, followed by creating a cross on the 3rd layer of the cube. The goal of the fourth session was to solve the Rubik's Cube entirely. Of the four sessions students experienced, the final was the least structured because students could practice at their own pace. Any students who were struggling to complete solves from prior sessions were able to continue where they had previously left off. Students who could successfully solve the Rubik's Cube were able to provide help to their peers still learning previous steps.

Findings

Pre-post findings

No significant differences were found in the 2D-MRT and 3D-MRT pretest scores across the comparison and experimental groups. Mean scores for the 2D-MRT and 3D-MRT (left and right figures respectively) are presented in Figure 4.

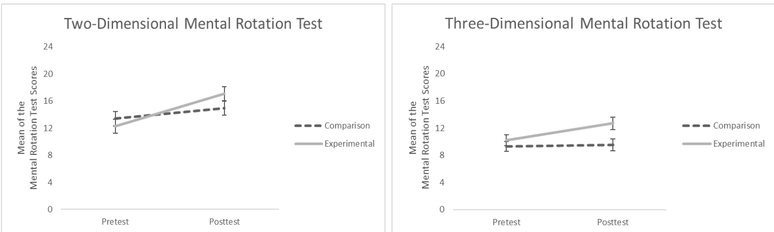

Figure 4. The change in the 2D-MRT and 3D-MRT scores from pretest to posttest.

The research question of this study is whether the Rubik's Cube training intervention can improve the 2D-MRT and 3D-MRT performance of middle school students. The research question was addressed through conducting a t-test using difference scores (posttest minus pretest = difference score). A significant main effect of the 2D-MRT ($t(135) = -3.44$, $p < 0.01$, $d = 0.59$) and 3D-MRT ($t(135) = -3.07$, $p < 0.01$, $d = 0.52$) was found. We also found moderate effect sizes. We can interpret the Cohen's d to indicate that the mean score of the 2D-MRT is 0.59 and 3D-MRT is 0.52 standard deviations greater for the experimental group than the mean score for the comparison group. These results suggest that the Rubik's Cube training intervention shows promising evidence of improvement in middle school students' two and three-dimensional mental rotation performance.

Qualitative findings

We examined the observation notes taken during each session. These notes focused on the overall dynamic of the classroom and the ways that students were interacting with the cubes. Future studies have plans for finer grained, qualitative data collection methods (i.e., audio and video recordings of students' discussions and gestures).

During the training sessions, students discussed different ways in which they solved the Rubik's Cube. Students also discussed the applied knowledge learned through the Rubik's Cube training to understand science concepts and phenomena. For example, some students inquired about utilizing spatial skills to imagine layer of the earth, beyond what is visible to the eye. Students also discussed the usage of mental rotation to help think about the size of stars in comparison to the moon and how the spatial distance between objects affects judgement as to which one is larger.

In addition, some students were more engaged in the activities when they practiced solving the Rubik's Cube in a collaborative manner. During the time where students could play and explore with the cube at their own pace, students tended to group themselves into dyads and discussed the steps that they suspected were required to advance in solving the Rubik's Cube. For example, some students encouraged their friends to take on the risk of 'messing up' the one completed side of the Rubik's Cube in order to solve more sides.

Discussion

Our results suggest that the Rubik's Cube training intervention is effective in improving the 2D-MRT and 3D-MRT performance. The results of our experiment add evidence that engaging in puzzle play, such as the Rubik's Cube, can be a promising methodology for mental rotation training in middle school students.

The current study introduces a short-term training intervention designed to improve spatial skills, specifically mental rotation through students' participation in the Rubik's Cube training. It would be beneficial for a future study to look at the long-term retention rate of the training effect. Our qualitative data found that some students were able to draw connections and build conversations around usage of spatial skills to describe the science phenomena learned in their science class. Future studies could specifically focus on building explicit and deliberate connections between spatial skills training and students' science curriculum.

In collaboration with our lead middle school science teacher, we are currently working on follow-up study in which we seek to better understand the dynamic interactions between students through video-based data collection and conversation analysis. The focus of our follow-up study is to look at the effectiveness of the productive failure framework in improving students' mental rotation performance. We are also expanding our study to determine the extent to which these skills transfer to the 8th-grade science curriculum and students' overall perception of science concepts that involve spatial skills.

References

Caissie, A. F., Vigneau, F., & Bors, D. A. (2009). What does the Mental Rotation Test Measure? An Analysis of Item Difficulty and Item Characteristics. *The Open Psychology Journal, 2*(1), 94–102.

Gagnier, K. M., Atit, K., Ormand, C. J., & Shipley, T. F. (2016). Comprehending 3D Diagrams: Sketching to Support Spatial Reasoning. *Topics in Cognitive Science, 9*(4), 883–901.

Gunderson, E. A., Ramirez, G., Beilock, S. L., & Levine, S. C. (2012). The relation between spatial skill and early number knowledge: The role of the linear number line. *Developmental Psychology, 48*(5), 1229–1241.

Hegarty, M. (2018). Ability and sex differences in spatial thinking: What does the mental rotation test really measure? *Psychonomic Bulletin & Review, 25*(3), 1212–1219.

Hoyek, N., Collet, C., Fargier, P., & Guillot, A. (2012). The Use of the Vandenberg and Kuse Mental Rotation Test in Children. *Journal of Individual Differences, 33*(1), 62–67.

Levine, S. C., Ratliff, K. R., Huttenlocher, J., & Cannon, J. (2012). Early Puzzle Play: A Predictor of Preschoolers' Spatial Transformation Skill, *Developmental Psychology, 48*(2), 530–542.

Lin, C. P., Shao, Y. J., Wong, L. H., Li, Y. J., & Niramitranon, J. (2011). The impact of using synchronous collaborative virtual tangram in children's geometric. *Turkish Online Journal of Educational Technology, 10*(2), 250–258.

Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: a meta-analysis. *Child Development, 56*, 1479–1498

Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A redrawn vandenberg and kuse mental rotations test - different versions and factors that affect performance. *Brain and Cognition. 28*(1), 39-58.

Shea, D. L., Lubinski, D., & Benbow, C. P. (2001). Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study. *Journal of Educational Psychology, 93*(3), 604–614.

Stieff, M., Lira, M., & DeSutter, D. (2014). Representational competence and spatial thinking in STEM. *Proceedings of International Conference of the Learning Sciences, ICLS*.

Stieff, M., & Uttal, D. (2015). How Much Can Spatial Training Improve STEM Achievement? *Educational Psychology Review, 27*(4), 607–615.

Terlecki, M. S., Newcombe, N. S., & Little, M. (2008). Durable and Generalized Effects of Spatial Experience on Mental Rotation: Gender Differences in Growth Patterns. *Applied Cognitive Psychology, 22*, 996–1013.

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin*, *139*(2), 352–402.

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial Ability for STEM Domains: Aligning Over 50 Years of Cumulative Psychological Knowledge Solidifies Its Importance. *Journal of Educational Psychology, 101*(4), 817-835.

Weckbacher, L. M., & Okamoto, Y. (2014). Mental rotation ability in relation to self-perceptions of high school geometry. *Learning and Individual Differences, 30*, 58–63.