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THE EFFECT OF STRATEGY INSTRUCTION AND SPATIAL ABILITY ON SPATIAL PROBLEM SOLVING

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THE EFFECT OF STRATEGY INSTRUCTION AND SPATIAL ABILITY ON SPATIAL PROBLEM SOLVING

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ABSTRACT

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High spatial skills tend to be a strong indicator for predicting STEM success. There are varying abilities when it comes to spatial skills, despite that spatial skills are adaptable and can develop with proper training. The aim of this experiment was to investigate the role of strategy instruction on spatial thinking performance. More specifically whether or not a response elimination strategy (count the number of folds and multiply by two) or a visualization strategy (imagining unfolding the paper) would be more beneficial in terms of improving Paper folding task score. Students participating in this experiment were undergraduate students from St. John's University (n=108 age mean = 20.794, SD= 3.325, female= 463, male= 149. We found that strategy instruction does not impact overall performance in paper folding task score, in either the response elimination condition or visualization condition. The relationship between spatial skill level and strategy instruction was also investigated. Based on the scores of the Mental Rotation task students were divided into three groups (Low, Moderate, High) which determined their spatial thinking skill level. It was through these analyses we also discovered difference in paper folding score between the visualization condition and the response elimination conditions for participants in both the low and moderate spatial skill level groups. However, for participants in the high spatial thinking skill level group,

paper folding scores were lower in the response elimination strategy condition compared to the visualization strategy condition. These results suggest that we must consider individual differences when it comes to strategy instruction.

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Introduction

STEM Crisis

The United States is currently facing a “STEM Crisis” in that there are not enough Science, Technology, Engineering and Mathematics qualified professionals to meet economic demands (Stevenson, 2014). Data consistently points to a trend that students in the US are not performing as well as students in several other countries in STEM disciplines (Stevenson, 2014). With this in mind, there has been an increased interest in working to support student achievement and persistence in STEM domains (Hossain & Robinson, 2012).

Many students find STEM concepts challenging and one approach to solving the STEM crisis is to begin to understand the factors that contribute to successful learning in STEM. Learning in science is challenging for many students because it often requires understanding complex phenomena that occur at imperceptible scales (i.e., too fast/slow/large/small to perceive). Being able to successfully understand these concepts may rely on the ability of the learner to visualize or manipulate spatial information and to understand visual representations.

And in fact, previous research has demonstrated a robust relationship between spatial thinking skills and achievement and persistence in STEM domains (Wai et al., 2009). Spatial thinking refers to a set of skills related to generating, manipulating, retaining, and interpreting visual images. These skills are necessary for everyday functioning, like when we try to plan the easiest route to someone’s house or trace back our steps after losing something but are also critical for developing mental models of important science phenomena. For example, research has shown that students with high spatial skills are better able to solve human anatomy problems (involving cross-sections, mental rotations, and intersecting planes) than those with low spatial skills (Hegarty, 2010). Research has also demonstrated the link between spatial skills and mathematics proficiency. For example, research has indicated that spatial skill relates to mathematical reasoning skills in middle school students (Delgado & Prieto, 2004; Lombardi, Casey, Pezaris, & Shadmehr, 2019) and mathematical aptitude in undergraduates (Casey et al., 1995). Spatial visualization skill has been shown to be related to improved STEM text comprehension (Jaeger, Taylor, & Wiley, 2016).

Spatial Skills Training

Although this robust relationship exists between spatial skills and STEM performance, some evidence has shown that spatial thinking skills are malleable and can be improved, with long-lasting impacts, through training (Uttal et al., 2013). Considering these findings, researchers have suggested that if spatial skills can be improved, then perhaps that will result in improved stem performance and greater persistence in stem domains. Research has shown that performance on tests of spatial ability and laboratory tasks such as mental rotation can be improved with targeted instruction (Gerson, Sorby, Wysocki, & Baartmans, 2001), repeated task exposure (Stieff et al., 2020), strategy intervention courses (Sorby Casey, Veurink, & Dulaney, 2013), or by providing students with visual grouping strategies, also known as “chunking” (Stieff et al., 2020). Some work suggests that performance on spatial tasks may improve when employing different strategies (Gardony, Eddy, Brunyé & Taylor, 2017). Furthermore, the outcome of such training carries over to alternative spatial ability tasks that have not been practiced prior (Wright, 2008). For instance, training in origami folding was shown to transfer to the mental rotation task (Boakes, 2009) and it persists for months after the initial training session (Terlicki et al., 2008).

Numerous strategy training models have been found to improve spatial thinking. One group of researchers investigated this theory by observing pre/post changes in spatial performance after completing a semester long spatial training course (Sorby et al., 2013). They took a group of freshmen from Michigan Tech that had failed a mental rotation test. They then required each student to undergo a spatial intervention course for the semester in an effort to enhance their spatial skills. Ultimately, they found that students who completed the semester long spatial training course demonstrated improved spatial task performance, and importantly, improved STEM course performance (Sorby Casey, Veurink, & Dulaney, 2013). Past research has also demonstrated that different strategies are employed by students with differing abilities when completing spatial thinking tasks (Kyllonen, 1984). When considering the Mental Rotation Task some students used mental imagery strategies such as perspective taking (imagining looking at the figure from another viewpoint), While others used more orientation strategies such as global shape (eliminated answer choices based on the figures arms being perpendicular or parallel) (Kyllonen, 1984).

The evidence in this study suggests that there are differences in the degree to which skills impact problem completion. These differences depend on both the person and the item within the spatial measure (Kyllonen, 1984). Similarly, Hegarty and their colleagues found that different strategies result in a higher accuracy in the Mental Rotation Task. Less successful solvers waste time using encoding or using “counting cube” strategies while more successful solvers used strategies such as the holistic rotation strategy (rotating figure as a whole) (Hegarty, 2018). This emphasizes the notion that low and high spatial problem solvers tend to complete these tasks differently.

One crucial takeaway from these studies is the importance of identifying low spatial students early on to bridge the gap between students with high spatial skills. It is evident that low spatial students may need more time to develop and practice their spatial skills, however with proper training it can be achieved. Considering these findings, we used these works to guide the development of the present study. In the present study we investigated what would take place if students were given a specific strategy for completing the paper folding task. More specifically, we were interested in examining whether instructing participants to use the response elimination strategy (count the number of folds and multiply by two) or a mental visualization strategy (imagining unfolding the paper) would affect performance on a spatial visualization task. Since analytic reasoning frequently corresponds with high spatial ability, we hypothesized that performance amongst the low spatial skill level would improve when directed to use the response elimination strategy because this strategy does not rely on one's ability to generate and transform a mental image, which may be especially challenging for low spatial individuals. We anticipated that students with high spatial skills could easily alternate between the strategies they were given, thus seeing improvement across the board however we assumed we would see a greater difference in performance among low spatial students that employed the analytic strategy.

Research Method

Participants

A total of 115 undergraduates (83 females; M_{age} = 19.79 years, *SD*= 2.26) from a large private university in the northeastern US participated in the experiment as part of their statistics lab course. Participants were recruited from four undergraduate statistics courses required for psychology majors. Data from 7 students were not included in the analyses because they did not complete the study either because they were absent or late and missed one or more tasks. The final sample was 108 undergraduate participants. Approximately half of the participants (n = 59) were in the visualization instruction condition and half were in the response elimination strategy condition (n = 49).

Materials

This experiment involved the completion of four tasks: two measures of spatial thinking skill, one measure of working memory capacity, and one demographic survey. This next section lays out materials given to participant in sequential order.

Mental Rotation Test (MRT). One measure of spatial thinking skill used in the present study was a redrawn version of the Mental Rotation Task (Peters & Battista, 2008) that was originally developed by Vandenberg and Kuse (1978). Participants completed this task using paper and pencil. In each item, participants are shown a target geometric cube figure on the left of a vertical line and four alternative answer option figures to the right of the line. Of those four possible response options, two show the target figure in a rotated position and two show a mirror image of the target object. Thus, two of the response options can be mentally rotated to match the target figure and two of the options cannot be rotated to match the target figure. The task of the participant is to identify both response options that show the target figure from a rotated perspective. There are 12 items on the test which participants were asked to complete within a 3-minute time limit. The original test has two forms (12 items on form A, 12 items on form B). Participants only completed one form and were given 3 minutes to complete it. Form order was counter-balanced so that half of the participants completed form A and half of the participants completed form B. Credit for correctness was only given if both correct rotated answer options were chosen. Thus, for this task, the maximum score one could receive was 12.

Running Span. Running Span is a commonly used measure of working memory capacity (Broadway & Engle, 2010). In this task, participants are shown a series of letters one at a time but are asked to only remember the last few letters in the series. Therefore, they must keep track of the last letters but forget the first letters. On each trial, letter strings vary in length from three to nine letters. After the last letter in the string is presented, participants are asked to recall anywhere from the last 3 to 6 letters in the string. Participants are told how many letters they will need to recall before each series is presented. Typically, this task is conducted through a software called E-prime. However, to accommodate the classroom setting in which data was collected, this task was presented via PowerPoint and participants recorded their responses on paper response sheets. In order to prevent "cheating" during this task, the researcher would closely monitor students to ensure they weren't writing prior to response recording time. The response sheet given to each participant was numbered one through eighteen for each item. For each item, blank lines were provided where the participant would write the letters they recalled. There was a total of 18 trials, the first 6 served as practice trials and the last 12 served as the target trials. The letters were presented one at a time in size 88 font for 300 milliseconds. Each letter slide was followed by a blank, white slide to avoid carryover of stimuli. After the full string of letters were presented, participants had 15 seconds to record their response before the task moved on to the next letter string. This task took approximately 10 minutes to complete. Score is based on the sum of all accurate recorded letters (accurate letter and accurate spatial location of that letter).

Paper Folding Task. The present study used an adapted version of the original Paper Folding Task (Ekstrom, French & Harmon, 1976). The adapted version, developed by Burte, Taylor, and Hutton (2019) modified the original task to identify the cognitive strategies participants use more clearly on each item. In this task the participants were given a paper-and-pencil packet of mental paper folding problems. For each item, there is a vertical line that divides the left and right sides of the paper. On the left side there is a figure that depicts a paper being folded one, two, or three times in a step-by-step process. The last figure in the process is accompanied by a small circle which represents the location of a hole punch. Participants are told this hole has been punched through all layers of paper at that point. On the right side of the vertical division line there are five alternative answer option figures. One of these figures correctly portrays where the holes will be located once the paper is unfolded. Participants completed a total of 24 items divided across two parts (12 items in each part) See Figure 2. They were given 3 minutes to complete each part and order was counter-balanced across classrooms. Scores were calculated as the total items answered correctly making the maximum score possible a 24.

Importantly, for the sake of this experiment there were two conditions that varied based on the instruction provided for how to solve the problems. Half of the participants were given a visualization-based strategy instruction (Visualization Condition) and half were given a heuristic-based strategy instruction (Response Elimination Condition). Random assignment within each class was not possible, so two classes were randomly assigned to receive the visualization instructions and two classes were randomly assigned to receive the response elimination instruction.

Visualization Condition. In the visualization condition, participants were told to mentally visualize the paper going through each fold one at a time. They were also told to mentally visualize the hole being punched through all layers of paper and lastly to visualize what the paper would look like once unfolded. After the instruction on how to solve each problem, a sample question was provided before starting the task problems. In the sample question, the participants were asked to draw a picture of what they thought the answer would look like. This drawing procedure for the sample item was meant to reinforce a mental image generation strategy for solving the items.

Response Elimination Condition. In the response elimination condition, participants were told to focus on the figure that is on the left side of the vertical line. They were told to count the number of folds and then multiply that number by two. This procedure was used to calculate the number of holes that would be displayed in the final answer. After the calculation of the holes, the participants were told to locate where the original hole was punched and search for answers with the same punctured hole location.

The participants were told to utilize this strategy to eliminate incorrect answer options, and to help find the correct answer. After the instruction on how to use the response elimination strategy, participants were given the opportunity to practice their newly learned strategy in a sample problem before moving on to the formal task. In the sample problem participants were prompted to answer a series of questions meant to reinforce the response elimination strategy. Specifically, they were asked how many times the paper was folded in the item and what was the resulting number if the number of folds was multiplied by two. They were then asked to use that number to calculate the number of holes there will be at the end and use the final number to eliminate wrong answers.

Demographic Questionnaire. All participants completed a paper-and-pencil demographic survey that asked participants to report their age, gender, college major, year in school, and handedness. The demographic survey included a set of 7 items that assessed participants self-reported ability across a variety of spatial tasks (e.g., finding your way in a new city, packing the truck of a car). Participants responded to each item with a 10-point Likert scale (1 – Very poor, 10 – Excellent). Next, the demographic survey included 10 more items that asked participants to rate their agreement with whether they used a variety of problem-solving strategies on the paper folding test (e.g., counted folds in the problem to determine how many holes, determined the answer based on its similarity to previous problem). Participants answered using a 5-point Likert scale (1 – Strongly Disagree, 5 – Strongly Agree).

Procedure

A research assistant went into four statistics recitations to conduct this experiment. Prior to beginning the experiment, the research assistant introduced themselves to the class, gave a brief overview of what the experiment entailed, and collected informed consent from each student. Next the researcher gave each student a PIN number to deidentify them from their data. Participants were told that the experiment would take 45 minutes total to complete and that their answers would be confidential. The participants were then instructed to put their phones and computers in their backpacks to minimize distraction during the experiment.

The first task administered was the MRT. The researcher read the instructions aloud and asked the students to follow along. Prior to starting the target problems, all participants completed a set of 4 examples items and were shown the correct answers. Participants were given 4 minutes to complete the task, and a stopwatch was used to ensure timing accuracy. When time was up the researcher collected all the worksheets. Next participants completed the Running Span task (Broadway and Engle, 2010). The researcher read the instructions aloud and provided time for participants to ask clarifying questions to guarantee instructions were understood. After going through the instructions (both read aloud and displayed on the power point), the participant began the task. Timing of the task was automatically built into the presentation to ensure accurate timing. When the task was complete, the researcher collected all response sheets.

The Paper Folding Task (Burte, Taylor, Hutton 2019) was administered next. This task had two different versions that varied in the instructions provided to the participants (Visualization and Response Elimination). The actual task items did not differ across conditions. In both conditions, the researcher read the task instructions aloud and asked the participants to follow along with the worksheet in front of them. After reading the task and strategy instructions, participants in all classes and conditions completed the practice item. Participants were given 3 minutes to complete each form within the task, and a stopwatch was used to ensure timing accuracy. When time was up the researcher collected all the worksheets.

The final task was a demographics questionnaire. Once the participant received the questionnaire they could begin immediately. This task was self-paced, but no participant took longer than 5 minutes to complete it. The researcher gathered all the materials, thanked the classes for their time, and left. After this, students resumed to their regularly scheduled statistics recitation section activities. The experiment took approximately 45 minutes to complete.

Results

The goal of the present study was to investigate the impact of the response elimination instruction of spatial task performance. It was hypothesized that performance for low spatial students would be improved when instructed to use a response elimination strategy to solve the task.

Before running all the primary analyses, we wanted to be sure that our conditions were matched on several variables. A series of independent samples t-tests were run comparing the Visualization and Response Elimination conditions on several demographic and individual differences measures (see Table 1). In terms of demographics, we found no difference in gender or year in school across condition, all were *t*s < 1, ns. We also found there to be a difference in Running Span score across conditions, $t(106) = 1.78$, $p = .04$, however, we are skeptical of this difference being meaningful due to the fact that a few students did not adequately follow task instructions; e.g. writing down letters prior to the response recording time. Importantly, there was no difference across conditions in Mental Rotation score, $t < 1$.

Table 1

Demographic and Individual Difference Variables as a Function of Instruction Condition

	Visualization	Response Elimination
	M (*SD*)	*M* (*SD*)
Age	19.41 (1.09)	20.24 (3.09)
Year in School	2.46 (.63)	2.54 (.71)
Running Span	32.41 (7.90)	29.76 (6.62)
Mental Rotation	4.22 (2.45)	4.55 (2.75)

Spatial Skill Level

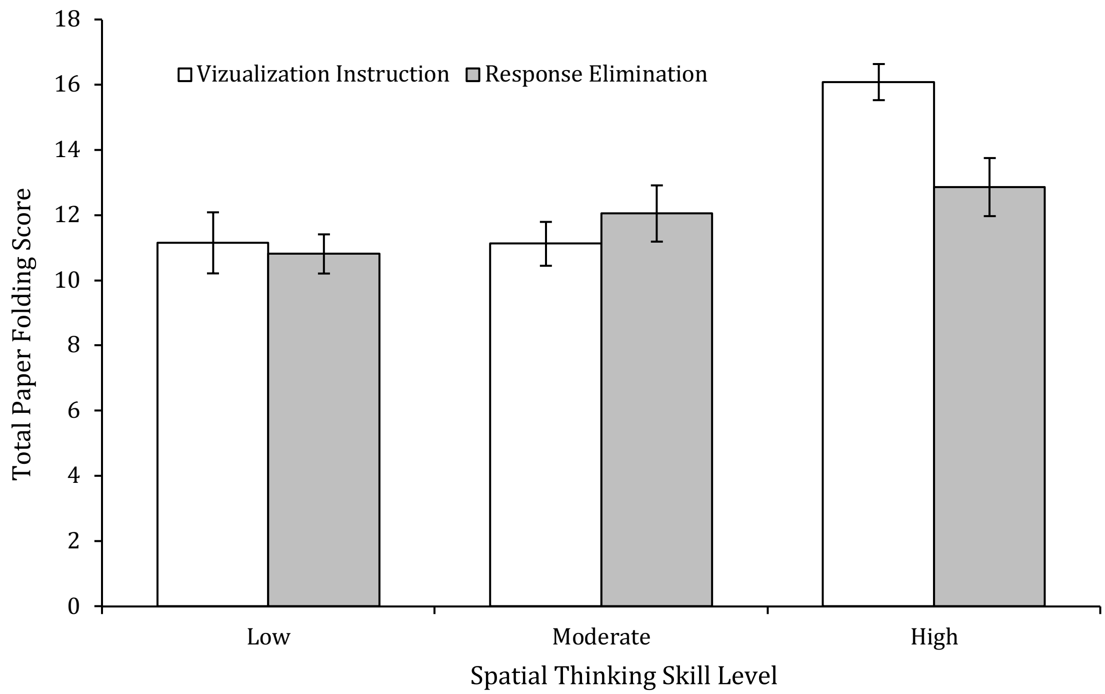
To examine differences in performance as a function of spatial skill level, we used performance on the mental rotation task as an independent measure of spatial thinking skill. All raw scores were transformed into z-scores and participants were categorized as high, moderate and low based on their scores on this task. Participants with mental rotation Z-scores that were more than a half of a standard deviation above the mean were categorized as high spatial. Participants with a mental rotation z-score lower than a half of a standard deviation below the mean were categorized as low spatial. All remaining participants with Z-scores ranging from a half a standard deviation above to a half standard deviation below the mean were categorized as moderate. This resulted in 27 students ($M = 7.59$, $SD = 1.74$) in the high spatial group, 45 students ($M = 4.24$, $SD = 1.68$) in the moderate spatial group, and 36 students ($M = 2.11$, $SD = 1.11$) in the low spatial group.

Instruction Condition and Skill Level

To test our two primary hypotheses, that performance would be higher in the analytic condition than the visual condition, and that low spatial students would especially benefit from the response elimination strategy instruction, a 2 (Instruction condition: Visualization, Response Elimination) x 3 (Spatial Skill Level: High, Moderate, Low) between-subjects analysis of variance (ANOVA) was conducted. As shown in Figure 1, contrary to our prediction, there was no overall main effect of instruction/strategy condition on paper folding score, $F(1, 102) = 1.88$, *ns*, $\eta_p^2 = .018$. There was a significant main effect of spatial skill level, $F(2, 102) = 9.98$, $p < .001$, $\eta_p^2 = .164$. A post hoc Tukey HSD test revealed that there was no difference in paper folding score between the low and moderate spatial skill participants (*ns*), but the high spatial participants scored significantly better than both the low spatial ($p < .001$) and moderate spatial participants ($p = .001$). These effects were qualified by a significant interaction between instruction condition and spatial skill level, $F(2, 102) = 3.50$, $p = .03$, $\eta_p^2 = .064$.

Figure 1

Paper Folding Score as a Function of Spatial Skill Level and Instruction Condition



Note. Error bars represent standard error of the mean.

To follow up the significant interaction between instruction condition and spatial skill level, two one-way ANOVAs were conducted. The first one-way ANOVA examined paper folding score as a function of spatial skill level for participants in the visualization condition and revealed a significant effect, $F(2, 56) = 12.67$, $p < .001$, $f = 1.17$. Planned contrasts revealed that there was no difference in paper folding score between the low and moderate skill groups ($t(56) = .04$, *ns*), but the high skill group performed better than both the low ($t(56) = 4.42$, $p < .001$, $f = 1.02$) and moderate ($t(56) = 4.67$, $p < .001$, $f = 1.08$) groups. The second one-way ANOVA examined paper folding score as a function of spatial skill level for participants in the response elimination condition and revealed to overall effect, $F(2, 46) = 1.45$, *ns*. This result indicates that in the response elimination condition, all spatial skill level groups performed equally.

Item Type Analysis

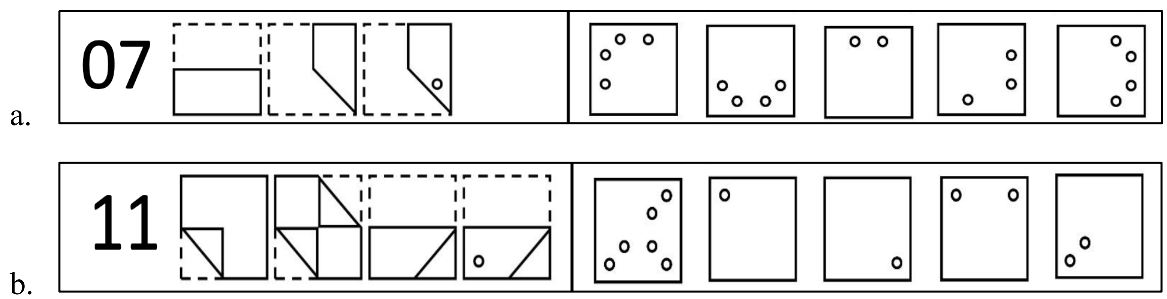
We were also interested in exploring if the instruction conditions had a differential effect on performance depending on the type of paper folding item. Paper folding items vary across several characteristics including the numbers of folds in the item (1, 2, or 3), whether the folds are symmetrical, whether previous folds obstruct following folds (visually blocks another fold), and whether the item contains folds that are irrelevant (do not impact the final answer).

Using these characteristics, we identified a set of 10 items that could be successfully solved using the response elimination strategy (i.e., Analytically Solvable) and 14 items that could not be solved with the response elimination strategy (i.e., Visualization Required). Figure 2 shows an example of one analytically solvable item and one item that requires visualization for solution. We analyzed the impact of instruction condition and spatial skill level on performance for these two subsets of paper folding items to see if perhaps the response elimination instruction was only beneficial for analytically solvable problems.

A 2 (instruction condition) X 3 (spatial skill level) X 2 (Item Type: Visualization Required, Analytically Solvable) repeated-measures ANOVA was conducted. As indicated in the previous set of analyses, there was no main effect of instruction condition, $F(1, 102) = 1.91$, *ns*, but there was a significant main effect of spatial skill level, $F(2, 102) = 9.69$, $p < .001$, $\eta_p^2 = .16$. There was a main effect of problem type such that performance was higher on items that could be successfully solved using the response elimination strategy compared to items that required a visualization strategy, $F(1, 102) = 127.99$, $p < .001$, $\eta_p^2 = .56$. There was a significant interaction between instruction condition and spatial skill level that aligned with the interaction found in the previous analyses, $F(2, 102) = 3.81$, $p = .03$, $\eta_p^2 = .07$. The interaction between item type and instruction condition was not significant, $F(1, 102) < 1$, *ns*. However, there was a significant interaction between item type and spatial skill level, $F(1, 102) = 4.68$, $p = .01$, $\eta_p^2 = .08$. Lastly, the three-way interaction between these variables was not significant, $F < 1$ (see Figure 3).

Figure 2

Analytically Solvable and Visualization Required Example Items



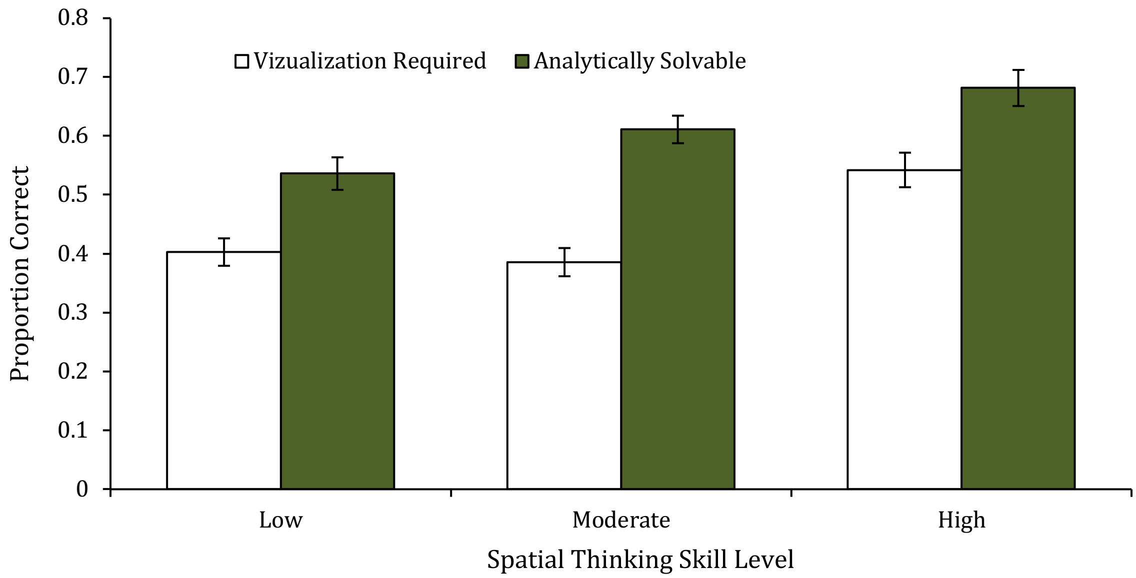
Note. (a) depicts an analytically solvable item, one in which the heuristic strategy can be used to solve the problem; (b) depicts an item that requires visualization for successful solution.

To follow up the item type by spatial skill level interaction we ran two separate one-way ANOVAs with spatial skill level as the IV and item type as the DV. For items that require visualization for successful solution, there was an overall significant effect, $F(2, 105) = 9.86$, $p < .001$, $f = .17$. Post hoc Tukey HSD tests revealed that the high spatial participants solved more visualization-required items correctly than moderate ($p <$

.001) or low spatial participants (p = .001), who did not differ from each other (*ns*). For items that were solvable using the response elimination strategy, there was also an overall significant effect, $F(2, 105) = 6.40$, $p < .01$, $f = .14$. Post hoc Tukey HSD tests revealed that the high spatial participants solved more analytically solvable items correctly than low spatial participants (p = .002) but did not significantly differ from moderate spatial participant (p = .18). Moderate spatial skill level participants performed marginally better on the analytically solvable items compared to the low spatial participants (p = .097).

Figure 3

Proportion of Paper Folding Items Correct as a Function of Spatial Skill Level and Item



Type

Note. Errors bars represent standard error of the mea**n**

Discussion

The initial goal of this study was to examine how strategy instruction would impact paper folding task performance. Overall, instructing students to use a visualization strategy or a heuristic strategy did not result in a change in performance. We anticipated that by instructing students how to use a non-visual strategy, like response elimination, the low spatial skill students' scores would improve. This notion is consistent with past research indicating students who struggle to visualize or create a mental representation are at a disadvantage (Jaeger et al., 2016), but that spatial performance can be improved through strategy training (e.g., Gardony et al., 2017; Stieff et al., 2020). However, our findings did not align with our initial hypothesis. We found that the response elimination instructions did not support problem solving for the low spatial students and in fact hurt problem solving performance for those with high spatial skills. Performance scores amongst the high spatial students in the response elimination was nearly equivalent to those in both the low and moderate skill level groups.

In a study evaluating science text comprehension between low and high spatial students, researchers found that readers who have the abilities required for generating spatial mental models, are more successful when they are not given additional supports (Jaeger et al., 2016). A similar relationship can be seen with our research findings. This is important because it suggests that high spatial students perform better when using strategies that come naturally to them rather than being taught a new strategy.

The current study also examined the impact of strategy instruction and spatial skill levels on different types of paper folding items. In general, the results showed that students were more successful at solving analytically solvable items compared to visualization items. Interestingly, giving students a strategy that can be used to solve analytic items did not result in vastly better performance on these items.

The lack of expected outcomes in this study could be attributable to one of several limitations in the current study design. One limitation of our study is that students only received one practice session as well as only one exposure to instruction. To further understand strategy instruction and spatial skills training it would potentially be beneficial for students to undergo prolonged exposure to the response elimination strategy (Gerson, Sorby, Wysocki, & Baartmans, 2001). Similarly, a longitudinal version (continued practice/training throughout the semester) of this study could potentially result in better outcomes for low spatial skill level students. Another limitation of this study would be determining whether the students truly used the strategies given. It would be crucial to further analyze the data from the demographic questionnaires. More specifically we asked students to rate their strategy use on a 5-point Likert scale while solving the problems (e.g., "I figured out where one of the holes should be and then eliminated answer choices that did not have a hole in that location"). By examining this data, we can potentially determine if reported strategy use aligns with the data we have analyzed. This would give us more insight into the relationship between performance scores, strategy use, and instruction condition. In the same demographic survey, we additionally asked participants to rate their own spatial ability. It would also be worthwhile to explore this data to see if it coincides with our original data analysis.

In conclusion, our findings provide insight into how spatial skill level and strategy instruction are entwined as latent factors students' achievement. Furthermore, this study highlights the idea that, sometimes providing additional support for those who need can undermine the performance of those who do not. In the present study, participants with high spatial skills performed better when given the more standard visualization instructions as opposed to providing them with instructions to use new strategies. These results suggest that future interventions should take individual differences into account and that there is likely not a one-size-fits-all approach to improving spatial thinking skills.

References

Boakes, N. J. (2009). Origami instruction in the middle school mathematics classroom: Its impact on spatial visualization and geometry knowledge of students. *Research in Middle Level Education Online, 32*(7), 1-12.

Broadway, J. M., & Engle, R. W. (2010). Validating running memory span: Measurement of working memory capacity and links with fluid intelligence. *Behavior Research Methods*, *42*(2), 563-570.

Burte, H., Gardony, A. L., Hutton, A., & Taylor, H. A. (2019). Knowing when to fold'em: Problem attributes and strategy differences in the paper folding test. *Personality and Individual Differences, 146*, 171-181.

Casey, M. B., Nuttall, R., Pezaris, E., & Benbow, C. P. (1995). The influence of spatial ability on gender differences in mathematics college entrance test scores across diverse samples. *Developmental Psychology*, 31(4), 697–705.

Delgado A. R., Prieto G. (2004). Cognitive mediators and sex-related differences in mathematics. *Intelligence*, 32(1), 25-32

Gardony, A. L., Eddy, M. D., Brunye, T. T., & Taylor, H. A. (2017). Cognitive strategies in the mental rotation task revealed by EEG spectral power. *Brain and Cognition*, *118*, 1-69.

Hegarty, M. (2010). Components of spatial intelligence. In B. H. Ross (Ed.), *The psychology of learning and motivation: Advances in research and theory* (pp. 265–297).

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

Hossain, M.M., & Robinson, M.G. (2012). How to Motivate US Students to Pursue STEM (Science, Technology, Engineering and Mathematics) Careers. *US-China education review, 2*, 442-451.

Gerson, H. B. P., Sorby, S. A., Wysocki, A., & Baartmans, B. J. (2001). The development and assessment of multimedia software for improving 3-D visualization skills*. Computer Applications in Engineering Education*, *9*, 105–113.

Jaeger, A. J., Taylor, A. R., & Wiley, J. (2016). When, and for whom, analogies help: The role of spatial skills and interleaved presentation. *Journal of Educational Psychology*, *108*(8), 1121–1139.

Kyllonen, P. C., Lohman, D. F., & Snow, R. E. (1984). Effects of aptitudes, strategy t training, and task facets on spatial task performance. *Journal of Educational Psychology, 76*(1), 130–145

Lombardi, C. M,. Casey B., Pezaris,E., Shadmehr, M.,(2019). Longitudinal analysis of associations between 3-D mental rotation and mathematics reasoning skills during middle school: Across and within genders. *Journal of Cognition and Development*, *20*(4), 1-13

Peters, M., & Battista, Ch. (2008). Application of mental rotation figures of the Shepard and Metzler type and description of a mental rotation stimulus library. *Brain and Cognition, 66,* 260–264

Sorby, S.A., Casey, B.M., Veurink, N., & Dulaney, A. (2013). The role of spatial training in improving spatial and calculus performance in engineering students. *Learning and Individual Differences, 26*, 20-29.

Stevenson, H. J. (2014). Myths and motives behind STEM (Science, Technology, Engineering, and Mathematics) education and the STEM-worker shortage narrative. *Issues in Teacher Education, 23*(1), 133-146.

Stieff, M., Werner, S., DeSutter, D., Franconeri, S., & Hegarty, M. (2020). Visual chunking as a strategy for spatial thinking in STEM. *Cognitive Research: Principles and Implications*, *5*(1), 1-15.

Terlecki, M.S., Newcombe, N.S., & Little, M. (2008). Durable and generalized effects of spatial experience on mental rotation: gender difference in growth patterns. *Applied Cognitive Psychology, 22(7),* 996-1013.

Uttal, D., Meadow, N., Tipton, E., Hand, L., Alden A., Warren C., Newcombe, N. (2012). The malleability of spatial skills: Meta-analysis of training studies. *Psychological Bulletin*, *139*(2), 352-402.

Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations, a group of three-dimensional spatial visualization. *Perceptual and Motor Skills, 47*, 599-604.

Wai, J., Luninski, 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.

Wright, R., Thompson, W. L., Ganis, G., Newcombe, N. S., & Kosslyn, S. M. (2008). Training generalized spatial skills. *Psychological Bulletin*, *15*(4), 763-771.

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