# Coloring Strategy Combined with Three-Dimensional Animation: Does the Mental Strategy Fits Everyone?

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**Abstract:** Spatial thinking is considered an important influence to learn Science, Technology, Engineering and Math (STEM) domains. The way to improve the spatial thinking ability drawn attention in the education. This study investigated a way in terms of multimedia environment combined with intervention on mental rotation strategy to train the spatial skill. 410 undergraduates recruited in the experiment revealed that the strategy intervention assisted with designed 3-D learning tool is a promising way to improve mental rotation ability of those who are not good at it.

**Keywords:** spatial thinking; multimedia learning; strategy intervention; 3-D animation and rotation

## 1. Introduction

Spatial thinking is a fundamental cognitive skill that has been recognized as a key ability to the performance in geography (Orion, Ben-Chaim & Kali, 1997), music (Hetland, 2000), visual arts (Goldsmith et al., 2013) and physical education (Pietsch & Jansen, 2012) as well as STEM disciplines (Newcombe, 2010). Given the importance of this ability, how to improve spatial thinking ability and evaluate the effectiveness of training has been a significant concern of educators. Some previous study shows that the spatial rotation in particular has been the object of training (Uttal et al., 2013), and even the spatial rotation strategy was found to be a key factor capable of improving the efficiency of mental rotation ability training. So what kind of strategy can be used in mental rotation testing? Does it fit everyone? This study focus on whether a mental rotation strategy which as an intervention in the multimedia environment combining with 3-D animation and manipulation could improve the mental rotation ability of young adults. Especially the divergence comparison of young adults between the United State and China.

## 2. Literature Review

According to numerous researches, the importance of spatial ability is beyond doubt, but the approach to enhance the ability still an unconquered aspect of educational practice.
Some of them uncovered that computer games or augmented reality technology may enhance this ability. Lee (2016) combined augmented reality technology with 3-D holography in his experiment and found it is an effective way to reduce participants' cognitive load and improve their sense of spatial direction compared to the traditional 2-D form.

The use of strategies is another way that influences the spatial ability learning. The researches (Gluck & Fitting, 2003; Linn & Petersen, 1985) adopted self-reported measures on exploring the strategies employed in the mental rotation. The research result indicated there were two strategies been utilized when people solving the mental rotation problems. They include: 1) Holistic strategy. A kind of strategy based on the rotation of the whole figure. 2) Analytical strategy. A kind of strategy that mentally rotating a stimulus piece by piece or labeling parts of an object. Nonetheless, in general, both strategies will be involved during the mental rotation test.

Some research revealed that both spatial ability and spatial strategy were the factors affecting the effectiveness of spatial learning (Meneghetti et al., 2014; Stieff, Dixon, Ryu, Kumi, & Hegarty, 2014). Meanwhile, Geiser (2008) found that strategy intervention was useful to students who have good skills on mental rotation rather than those who have poor skills.

Therefore, this study aims to explore:

1) The effectiveness of the combination of strategy intervention with 3-D animation and manipulation.
2) Whether the level of mental rotation ability influences the effectiveness of the strategy intervention.

## 3. Methods

### *3.1 Participants*

410 undergraduates (218 American and 192 Chinese) have enrolled in this experiment. The age of the participants varied between 17 and 23 (26.3% aged 17-18 years, 33.4% aged 19 years and 40.3% aged 20-23 years). During the experiment, participants were randomly divided into a control group (n=217) and an experimental group (n=193) to compare the differences of their test improvements after learning with different intervention strategies.

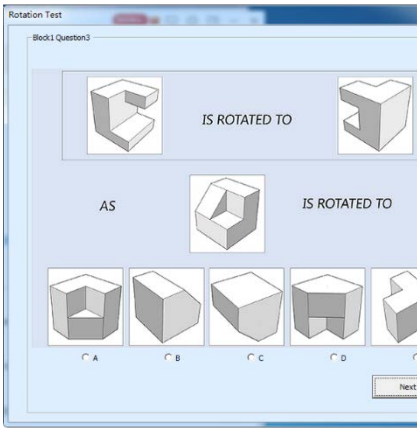
### *3.2 Materials*

Questions required participants to finish is extended version of the Revised Purdue Spatial Visualization Tests: Visualization of Rotations (Revised PSTV: R). To make sure participants got enough training before post-test, researchers developed 10 new questions, the new questions are based on the shape of the original title with different rotation angles. The reliability of the extend version was evaluated by Cronbach alpha and the internal reliability coefficient is 0.905, which shows the question consistency in measurement.

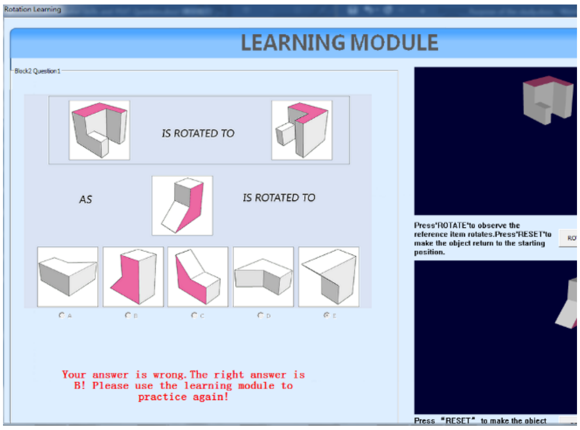
In the pre- and post-test, images of a reference 3-D object before and after rotation is presented and then a testing 3-D object is presented with initial status and 5 images after different rotation. Participants are required to determine which of the five images is the correct one in terms of the equivalent rotation process as the reference object.

### *3.3 Strategy Intervention Tool*

Between the pre- and post-test, a 3-D learning tool was provided to the participants, and specially, testing 3-D object presented to experimental group was with one face colored in the both initial states image and 5 rotated status images, the interface of learning process was showed in the right of figure 1. The colored face of the 3-D object could be a rotating stick to help participants imagine the image of rotated status. The intervention was designed to train participants' strategies on mental rotation ability. Combined the strategy intervention with the 3-D learning tool, participants could manipulate and rotate the object manually to execute their thinking after known the answer of the question.




The testing interface




The learning interface

Figure 1. The interfaces of testing process and learning process

### *3.4 Procedure*

Participants were required to take the experiment on the computer, for the technical can trace the process data. The experiment in both groups consisted of three phases:

- A pre-test with 10 questions without feedback of correct answers to assess the participants' initial space rotation ability. Participants would get 1 point for each correct answer.
- Intervention phase consisted of two blocks. Each block consisted of 10 questions with feedback of question. Both control group and experimental group could play with the 3-D learning tool when the experimental group had strategy intervention.
- A post-test with 10 questions to determine, to what extent, the space rotation ability of both group has been improved.

## 4. Results

To examine the intervention effect of the 3-D learning tool to improve participants' mental rotation ability and the influence caused by intervention strategies, the testing scores from the pre-test and the post-test, and a survey about attitude towards the experiment was collected. Data was analyzed with R, Microsoft Excel and IBM SPSS 22.

### *4.1 Learning outcomes*

A paired-sample t-test was conducted to compare the scores of pre-test and post-test, Table 1 sets out the descriptive statistics for each group. control group shows significant difference in the scores for pre-test(M=7.30, SD=1.81) and post-test(M=7.53, SD=1.79), t (216)=-1.99 p =0.048, experimental group have a better performance in post-test(M=7.25, SD=1.79) than pre-test(M=7.01, SD=2.10), but there is not significant difference, t (192)=-1.62, p=0.106. These results suggest that the 3-D learning tool without strategy intervention has significant intervention effect, participants in the control group made a better performance in test after intervention.

Table 1: Descriptive statistics of pre-test scores and post-test scores.

| Group | Pre-test | Post-test |
|---|---|---|
| | M±SD | M±SD |
| No strategy intervention (n=217) | 7.30±1.81 | 7.53±1.79 |
| Strategy intervention (n=193) | 7.01±2.10 | 7.25±1.79 |

### 4.2 *Effect of Strategy Intervention for Different Initial Rotation Ability Level*

In the previous study, we found initial levels of the mental rotation ability have some influence to learners' learning improvement. Therefore, factors could influence the performance included: 1) the strategy intervention provided by 3-D learning tool, 2) the initial levels of mental rotation ability. Therefore, next step is to examine whether the strategy intervention makes different influence for different level of initial ability. Participants were divided into three levels according to the pre-test scores. The mark of a low level is 60% accuracy, and the mark of a high level is 80% accuracy. The difference of post-test scores from pre-test scores was as an indicator to examine the improvement. Three one-way ANOVAs were conducted to compare the improvement of strategy intervention made at three levels. Table 2 sets out the descriptive statistics for each group in separate levels.

The result of one-way ANOVA showed a ladder by level increased. In level1 group, strategy intervention showed a significant effect of improvement, $F(1,139) = 4.70$, $p = 0.032 < 0.05$, Eta Squared $\eta^2 = 0.033$. In level2 group, there was no significant difference between control and experimental condition. In level3 group, participants in no strategy intervention condition showed better performance than those in strategy intervention strategy, $F(1,120) = 5.92$, $p = 0.016$, Squared $\eta^2 = 0.047$. The result indicates that strategy intervention has the opposite effect on groups with a low level of mental rotation ability and those with a high level.

Table 2: Descriptive statistics of improvement of different levels in both conditions.

| Group | | N | Mean | SD |
|---|---|---|---|---|
| Level 1 | No strategy intervention | 70 | 1.24 | 1.64 |
| | Strategy intervention | 71 | 1.87 | 1.81 |
| Level 2 | No strategy intervention | 77 | 0.00 | 1.73 |
| | Strategy intervention | 70 | -0.44 | 1.74 |
| Level 3 | No strategy intervention | 70 | -0.54 | 1.05 |
| | Strategy intervention | 52 | -1.06 | 1.29 |

### 4.3 *Effect of Strategy Intervention in Learning Process*

Figure 2 presents mean scores in the four blocks, for each condition in three level groups. As can be seen in the chart, the group in strategy intervention condition performed a little behind the group in control condition. But during the learning phases, that is block2 and block3, group in experimental condition got higher scores, and specially, result of independent t-test shown significant difference in the score of block2 for no strategy intervention condition ($M=8.60$, $SD=1.34$) and strategy intervention condition($M=8.98$, $SD=1.26$), $t(406.73)=-3.0$, $p=0.03<0.05$.

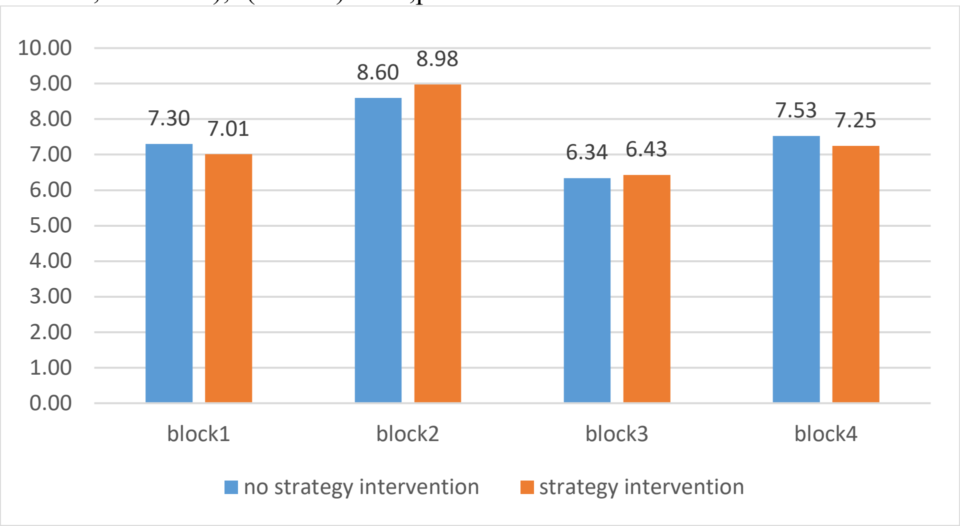



Figure 2. The mean scores of 4 blocks in control and experimental condition

Scores of group in strategy intervention condition fallen back to original state, which indicates that strategy intervention really provided a more effective strategy to deal with mental rotation questions, but this effect could not last after the support removed.

In order to understand how the strategy intervention influenced different level group, Figure 3 shows the mean of each block in a more detailed size.

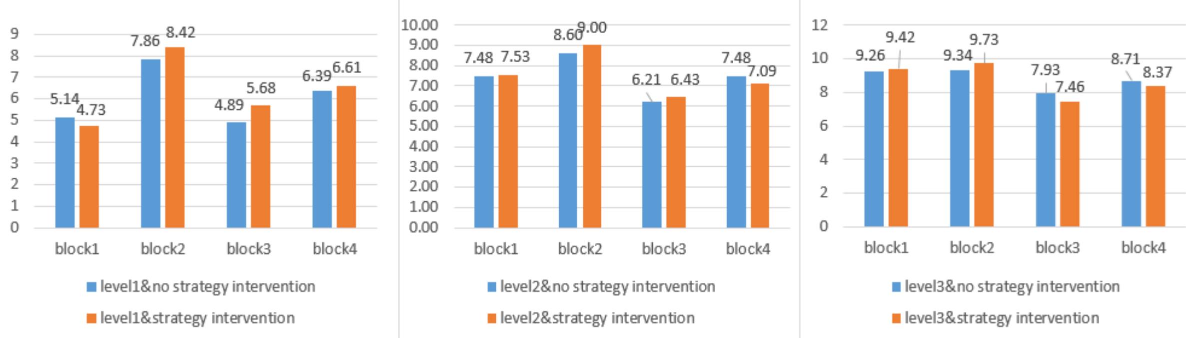



Figure 3. The mean scores of 4 blocks in control and experimental condition

For level1 group, participants showed great improvement during and after intervention phases, level2 group only performed better during the learning phase, and for level3 group, the participants in experimental condition had high initial level than those in control condition, but scored lower in the block3 and block4.

## 5. Discussion and Conclusion

The strategy is considered as a fundamental factor influence the performance of mental rotation ability and the effect of the train which has been verified in our study again. And further, we found that effective strategy support can increase the efficiency of mental rotation ability training. This study intends to compare the improvement of learning with or without strategy intervention. Though the tool involved in this experiment was examined in our previous research, we examined the effect of tool in both condition, and got the unexpected result that the group with strategy intervention showed no significant improve after learning when the control group had a great performance. Then the initial level of mental rotation ability has been used for the further analysis. The extraordinary findings shows that strategy intervention has a different effect to the participants with different initial levels. The members in the level 1 group may not be aware of using the strategy to solve this type questions, they would have developed the consciousness to use an effective strategy, and have been trained during the learning phase through 20 questions. Therefore, this group showed significant improvement in the following three blocks. Analysis of level 2 group showed no significant difference between two conditions, members in strategy intervention condition performed better than those in control condition until the strategy support was taken. They were divided into level 2 for scoring more than 6 points in the pre-test, which indicate they had ability to solve this type question. The intervention of tool may not provide a new strategy for them, but support their immature strategy as scaffoldings. Therefore, those in experimental condition got a more effective support than those in control condition, not surprisingly, there was a drop in performance. As for level 3 group, they got more than 8 points in the pre-test, which required talent or full-blown strategy to deal with the mental rotation. The strategy intervention seems like interference for them, it is hard to figure out whether strategy intervention influence their original strategy or not.

The result verified that there is not an effective strategy which could be used commonly. Aimed at students of different types or levels, different strategy and methods are needed. As for the learning tool designed by our team, it is suitable to be an assistant for the beginners or backward students rather than for those who have mastered techniques about mental rotation. In other hands, the learning tool may be beneficial to develop a normative mode of thinking to handle mental rotation questions.

In this study, we proposed a strategy intervention in the multimedia learning environment of combining 3-D animation and manipulation to support mental rotation ability development. The experimental study reveals that strategy intervention is a promising way to improve those with a low level of mental rotation ability, but this way may not provide enough help for the group with a certain level ability. The results indicate that there is no such a mental strategy fit everyone; different learners need different support strategies.

## 6. Limitation and Future Work

This research has a few limitation. First, the question in the survey to investigate the strategy preferred by participants was not designed the well, the data could not provide reliable circumstantial evidence. Second, the amount of the question may be a little large, cognitive load may be an unobservable interference factor in the experiment. In the next version, we will optimize these parts of the learning tool, and future research might take account strategy in a more detailed aspect, to investigate its influence on the mental rotation ability improvement.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