Coordinate Axes and Mental Rotation Tasks: A Dual-Coding Approach

Ted Branoff
North Carolina State University

Abstract

During the 1997 Fall semester at North Carolina State University, a study was conducted to determine the effectiveness of adding coordinate axes to a mental rotations task. Eighty-one undergraduate students enrolled in introductory graphic communications courses completed a computer version of the Purdue Spatial Visualization Test - Visualization of Rotations (PSVT). The instrument was used to record student responses and response times as well as information on gender, current major, number of previous graphics courses completed, and method used to solve the test items. The theoretical framework of the study is based on Paivio's dual-coding theory [1]. Coordinate axes were added to a portion of the PSVT for the experimental group to determine if the axes provided contextual cues necessary to improve scores and response times. The researcher hypothesized that coordinate axes would provide verbal cues that could be coded along with nonverbal information to improve mental rotation efficiency. The additional coordinate axes slightly (but not significantly) improved scores on the PSVT, but not response times.

Introduction

Spatial ability has been of interest to people in many disciplines. It has been shown to be related to success in chemistry [2], geometry [3], and technical graphics [4]. Researchers in these fields have been concerned with devising ways to increase the spatial abilities of their students. The problem is spatial ability has been defined many different ways. McGee [5] defines spatial ability in terms of two factors: *spatial visualization* and *spatial orientation*. Spatial visualization requires the individual to mentally transform a perceived object (mentally rotate, twist, or invert). Spatial orientation requires the individual to remain unconfused when a pattern of objects has been rearranged. Since spatial ability is defined in many ways, it is also true that tests designed to measure spatial ability are equally as diverse. Research has shown that the Purdue Spatial Visualization Test - Visualization of Rotations [6] measures spatial visualization ability.

Information-processing theory provides an explanation for how spatial information is processed. The dual-coding model [7] offers some explanation for differences in processing strategies. Humans process information mentally through two systems. The verbal system handles abstract information and processes it in a sequential, successive manner. The nonverbal system handles concrete information and processes it in a synchronous, simultaneous manner. The nonverbal system handles mental rotation tasks more efficiently than the verbal system, however, the main emphasis of Paivio's theory is that information processed or coded in both systems can be retrieved and manipulated more readily.

The purpose of the study was to determine whether the presence of coordinate axes in a test of spatial visualization ability affects scores and response times on a mental rotations task for students enrolled in undergraduate introductory graphic communications classes. Coordinate axes were added to the Purdue Spatial Visualization Test - Visualization of Rotations (PSVT) to determine whether the presence of the axes was a sufficient contextual cue for improving scores and response times.

The major research question set up for this study was: *Does the contribution of frames of reference (coordinate axes) to mental rotations tasks affect scores on tests of spatial visualization ability?* The following nine research hypotheses guided the modification of the testing instrument, the selection of the sample, additional data collected from the examinees, and analysis of the data:

1. For the experimental group, the mean score will be significantly higher on Part 2 of the PSVT (coordinate axes present) than on Part 1 (no axes).
2. There will be no significant difference between the mean scores on Parts 1 and 2 of the PSVT for students in the control group.
3. The mean score on Part 2 of the PSVT for the experimental group will be significantly higher than the mean score for the control group.
4. For the experimental group, the mean response time will be significantly lower on Part 2 of the Purdue Spatial Visualization Test-PSVT (coordinate axes present) than on Part 1 (no coordinate axes).
5. There will be no significant difference between the mean response times on Parts 1 and 2 of the PSVT for students in the control group.
6. The mean response time on Part 2 of the PSVT for the experimental group will be significantly lower than the mean response time for the control group.
7. The mean score for males will be higher than the mean score for females on Part 1 of the PSVT (Part 1 - no coordinate axes present - should favor a holistic approach).
8. There will be no difference in mean scores between males and females on Part 2 of the PSVT for the experimental group (the presence of coordinate axes should allow success for both holistic and analytical approaches).
9. The mean response time for males will be lower than the mean response time for females on Parts 1 and 2 of the PSVT (the analytic approach requires more processing time).

Procedures

During the summer of 1997, two computer versions of the Purdue Spatial Visualization Test - Visualization of Rotations were developed by the researcher using Macromedia's Authorware 3.5™ on Microsoft Windows95™ personal computers. One version was used by the subjects in the control group while the other version was used by subjects in the experimental group. The initial 30 items of each test were identical to the 30 items of the paper/pencil version of the PSVT. The second 30 items of the control group version of the test were identical to the first 30 items except for the random assignment of the correct solution. The second 30 items of the experimental group version of the test were identical to the second 30 items of the control group version except that coordinate axes were added to the first and second stimulus objects for each item (see Figure 1). The computerized PSVT was pilot tested during the second summer session of 1997 to check the reliability and smoothness of data collection procedures.

During the second week of classes for the 1997 Fall semester, the class rolls for all introductory courses in Graphic Communications were used to select a random sample of 150 undergraduate students. The researcher visited each introductory class and invited the 150 students to participate in the study. One hundred thirty-three students signed up to participate in the study as a result of the researcher visiting the introductory classes.

Both the control and experimental groups were administered Part 1 of the PSVT. After a short rest period, Part 2 of the PSVT was administered. At the end of the test, students were asked to respond to several demographic questions.

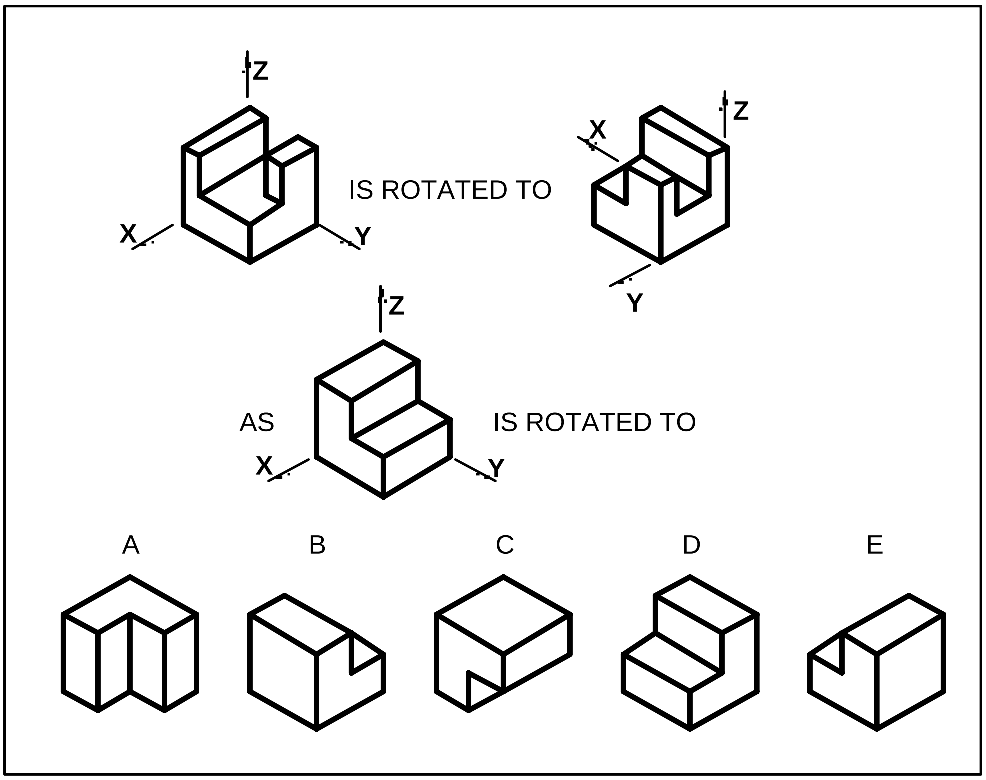

Figure 1. Visualization of Rotations Test with coordinate axes added.

Conclusions and Discussion

The Effects of Coordinate Axes on Scores - It appears that the addition of the axes had only a small influence on scores for the PSVT when examining differences between the two treatment groups. When examining only the experimental group (coordinate axes present for the 30 items on Part 2 of the PSVT), there was a significant increase in the mean score between parts 1 and 2 of the PSVT (mean increase of 2.098). Although the control group completed an equivalent form of the PSVT on Part 2, the mean score was significantly higher than the mean score on Part 1 (mean increase of 1.400). It appears that completing the items in Part 1 of the PSVT provided enough practice for students to slightly improve their scores on Part 2. Although both the experimental and control group mean scores increased on Part 2, the experimental group's mean score increased a small amount more than the control group's mean score. This difference was not significant, but it was enough for the researcher to feel that the addition of the coordinate axes influenced some of the test items. It is quite possible that the axes (verbal information) may have provided the extra cues necessary to verify particular rotations (nonverbal information) and aid in making correct responses.

The Effects of Coordinate Axes on Response Times - The presence of coordinate axes also appears to have influenced response times. When examining only the experimental group (coordinate axes present for the 30 items on Part 2 of the PSVT), there was a significant decrease in the mean response time between parts 1 and 2 of the PSVT (mean decrease of 95.74 seconds or 1.60 minutes). As with the analysis of mean scores, there was a significant difference in the mean response time between Parts 1 and 2 of the PSVT for the control group (mean decrease of 270.06 seconds or 4.50 minutes). Analyses of response times indicated more time was required to process the additional information present with the coordinate axes. This was evident when treatment group interaction was examined for response times. The mean response time for the control group decreased significantly more between parts 1 and 2 of the PSVT than the mean response time for the experimental group. The coordinate axes apparently demanded more processing time even for individuals who take a holistic approach to mentally rotating objects. It is possible that the addition of the coordinate axes caused some students to change from a holistic to an analytic strategy for processing the information.

The Effects of Coordinate Axes on Gender - As reported in previous research [8], males tend to score higher than females on the PSVT and on other tests of spatial visualization ability. This was verified when examining gender differences for scores on Part 1 of the PSVT. It appears, however, that the addition of the axes eliminated gender difference on Part 2 of the PSVT. There was no significant mean score difference between males and females on Part 2 of the PSVT for the experimental group. Males tend to score higher than females on the PSVT primarily because the test is designed to measure spatial visualization ability which requires holistic rotation. Males tend to take a holistic approach to mentally rotating objects while females tend to take an analytical approach. The addition of the coordinate axes appears to have eliminated biases based on method of rotation. It should be noted that only 17 females participated in the study. Therefore, generalizations based on gender should be carefully examined.

Another explanation for not finding gender differences for response times may reflect the type of students participating in the study. A majority of the students were enrolled in engineering programs. It may be that students in engineering, whether male or female, tend to take the same type of approach to solving mental rotation tasks.

Learning Factor - After examining the results, there appears to be a significant learning factor that occurred during the study. Mean scores increased significantly between parts 1 and 2 of the PSVT for both the experimental and control groups. Response times decreased significantly for both groups. The relatively short wait period (5 minutes) between parts 1 and 2 of the test probably contributed to this learning factor. After completing the first 30 items of the test, students appeared to feel more comfortable completing the second 30 items.

Implications for Teaching Methods in Graphics Education

Graphics educators, both secondary and post-secondary, should think seriously before adding coordinate axes to all objects in their curriculum materials. Since scores improved slightly but not significantly with the addition of the axes, the amount of time required to add coordinate axes to objects in existing materials may not be time effective. Educators, however, should consider adding the axes to sketches made during class on the chalkboard, whiteboard, or overhead projector. Some students may benefit significantly from the addition of the coordinate axes to sketches of objects. Depending upon the approach a student takes to mentally rotating objects (holistic or analytic), the axes may serve as a visual cue to improve rotation accuracy.

Graphic educators should note that the addition of axes to objects may not decrease the time required to perform mental rotation tasks. It is likely that the axes will require students to take more time to process the additional information.

As mentioned earlier, the addition of the coordinate axes seemed to eliminate gender differences for scores on the PSVT. If educators are aware of differences in spatial visualization ability between males and females within their classes, the addition of coordinate axes to objects may help to eliminate some of the differences.

Recommendations for Further Research

This study examined the effects of the addition of coordinate axes to a test measuring spatial visualization ability. The conclusions reached by the researcher suggest several areas of further research:

1. The learning factor that occurred in this study needs to be eliminated. A longer wait period between parts 1 and 2 of the PSVT might begin to reduce this factor. Care must be taken to ensure that other factors occurring during the wait period do not influence scores and response times on Part 2. Also, a Solomon Four-Group experimental design might help to eliminate pretest sensitization.
2. A larger sample that includes more females should be examined to confirmed gender differences revealed in this study.
3. The study needs to be replicated at other universities with similar populations to verify the generalizations made with regards to the influences of the coordinate axes.
4. The study needs to be replicated with different samples (non-engineering students, high school students, etc.) to verify the effects of the coordinate axes on gender differences.

Bibliography

1. Paivio, A. (1986). Mental representations: A dual coding approach. New York: Oxford University Press
2. Carter, C. S., LaRussa, M. A., & Bodner, G. M. (1987). A study of two measures of spatial ability as predictors of success in different levels of general chemistry. Journal of Research in Science Teaching, 24 (7), 645-657.
3. Battista, M. T., Wheatley, G. H., & Talsma, G. (1982). The importance of spatial visualization and cognitive development for geometry learning in preservice elementary teachers. Journal for Research in Mathematics Education, 13 (5), 332-340.
4. Deno, J. A. (1995). The relationship of previous experiences to spatial visualization ability. Engineering Design Graphics Journal, 59 (3), 5-17.

5. McGee, M. G. (1979). Human Spatial Abilities. New York: Praeger.
6. Guay, R. (1977). Purdue Spatial Visualization Test - Visualization of Rotations. W. Lafayette, IN. Purdue Research Foundation.
7. See Ref. 1.
8. Guay, R. B. (1980). Spatial ability measurement: A critique and an alternative. A paper presented at the 1980 Annual Meeting of the American Educational Research Association, April, Boston, MA. (ERIC Document Reproduction Service No. ED189166).

Biography

TED BRANOFF, Ph.D. has been a Lecturer in the Graphic Communications Program at NC State University since 1986. A member of ASEE-EDGD since 1987, Ted has presented papers at both Mid-year and Annual Conferences. His current academic interests include spatial visualization ability, information processing theory, geometric dimensioning and tolerancing, and descriptive geometry.