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Coordinate Axes and Mental Rotation Tasks: A Solomon Four Group Design

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ABSTRACT

During the 1998 fall semester at North Carolina State University, a study was conducted to determine the effectiveness of adding coordinate axes to a mental rotations task. This study was a follow-up to a study conducted in the 1997 fall semester (Branoff, 1998). Undergraduate students enrolled in introductory graphic communications courses completed a computer version of the Purdue Spatial Visualization Test - Visualization of Rotations (Guay, 1980). 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. Coordinate axes were added to portions of the Purdue Spatial Visualization Test for three of the four treatment groups to determine if the axes provided contextual cues necessary to improve scores and response times. It was hypothesized that coordinate axes would provide verbal cues that could be coded along with nonverbal information to improve mental rotation efficiency. A Solomon Four Group Design was used to assess the effect of the coordinate axes, determine the effect of pretest sensitization, and assess interaction between the pretest and posttest conditions.

Introduction

This study was a follow-up on a study conducted during the 1997 fall semester at North Carolina State University (Branoff, 1998). The sample from the initial study included 81 students enrolled in introductory graphic communications courses. The intent of the study was to examine the effects of coordinate axes on a mental rotations task. Coordinate axes were added to items on the Purdue Spatial Visualization Test - Visualization of Rotations (PSVT) for the experimental group to examine how the axes influenced scores and response times (Guay, 1980). A pretest-posttest, control group design was used in the first study where both the control and experimental groups completed the 30 items on the PSVT (Part 1). After a short break period, both groups completed an equivalent form of the PSVT (Part 2) with coordinate axes added to the 30 items for the experimental group. The following conclusions were drawn from the initial study:

1. When examining differences between the experimental and control groups, the coordinate axes had only a small influence on scores. The mean score for the experimental group was greater than the mean score for the control group, but the difference was not significant.
2. The coordinate axes had a significant effect on response times. Analyses of response times indicated that more time was required to process the additional information present with the coordinate axes.
3. The addition of the axes eliminated gender differences on the PSVT.
4. There was a learning factor that appeared during the first study. Scores increased for both the control and experimental groups between Part 1 and Part 2.

Response times decreased for both groups.

The follow-up study was designed to verify some of the conclusions from the first study and to eliminate some of the problems that resulted from the research design. What follows is a description of the methodology, conclusions and recommendations of a study that was conducted during the 1998 fall semester at North Carolina State University.

Methodology

Purpose of the Study

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 introductory engineering graphics classes. Coordinate axes were added to the PSVT to determine whether the presence of the axes was a sufficient contextual cue for improving scores and response times.

Research Design

The study was conducted using a Solomon Four-Group Design (Gall, Borg, & Gall, 1996). The purpose of selecting this design was to assess the effect of the coordinate axes, determine the effect of pretest sensitization, and assess interaction between the pretest and posttest conditions (*see Table 1*).

Research Question and Hypotheses

The major research question for this study was: ***Does the contribution of frames of reference (coordinate axes) to mental rotations tasks affect scores and response times on tests of spatial visualization ability?***

Based on the review of literature and the conclusions from the 1997 study, 16 research hypotheses were developed relative to scores and response times on the PSVT:

1. There will be no difference in Part 1 mean scores between Groups 1 & 2.
2. There will be no difference in Part 1 mean response times between Groups 1 & 2.
3. There will be no difference in Part 1 mean scores between Groups 3 & 4.
4. There will be no difference in Part 1 mean response times between Groups 3 & 4.
5. There will be a significant difference in mean scores on Part 1 between Groups 1 & 2 (no coordinate axes present) and Groups 3 & 4 (coordinate axes present)-combined Group 3 & 4 will have a higher mean.
6. There will be a significant difference in mean response times on Part 1 between Groups 1 & 2 (no coordinate axes present) and Groups 3 & 4 (coordinate axes present)-combined Group 3 & 4 will have a higher mean.
7. Mean scores for males will be higher than mean scores for females on Part 1 for Groups 1 & 2 (no coordinate axes present).

Group	Pretest (Part 1)	Posttest (Part 2)
Group 1	No Axes Present	No Axes Present
Group 2	No Axes Present	Coordinate Axes Present
Group 3	Coordinate Axes Present	Coordinate Axes Present
Group 4	Coordinate Axes Present	No Axes Present

Table 1 *- Research design.*

8. There will be no significant difference in mean scores between males and females on Part 1 for Groups 3 & 4 (coordinate axes present).
9. There will be no significant difference between the mean score on Part 1 and the mean score on Part 2 for Groups 1 and 3 (same treatment on both parts of the PSVT).
10. The score on Part 2 of the PSVT will be significantly higher than the score on Part 1 for Group 2.
11. There will be no significant difference between the mean score on Part 1 and the mean score on Part 2 for Group 4.
12. There will be a significant difference between the mean response time on Part 1 and the mean response time on Part 2 for all Groups.
13. Mean response times for Groups 2 & 3 will be higher than mean response times for Groups 1 & 4 on Part 2-axes will require more processing time.

The purpose of developing the computer versions of the PSVT was to provide accurate data on scores and response times.

14. There will be a significant difference in mean scores on Part 2 between Groups 1 & 4 (no coordinate axes present) and Groups 2 & 3 (coordinate axes present)-combined Group 2 & 3 will have a higher mean.
15. Mean scores for males will be higher than mean scores for females on Part 2 for Groups 1 & 4 (no coordinate axes present).
16. There will be no difference in mean scores between males and females on Part 2 for Groups 2 & 3 (coordinate axes present).

Instrumentation

Since the main construct of interest for the study was spatial visualization ability, the Purdue Spatial Visualization Test - Visualization of Rotations (PSVT) was used to assess this construct. The PSVT consists of 30 items of increasing level of difficulty. It is a 20 minute timed test appropriate for individuals 13 and older. Initial items require a rotation of 90° on one axis followed by items requiring 180° rotation about one axis, rotation of 90° about two axes, and concluding with items requiring rotation of 90°about one axis and 180° about another axis.

The first stimulus object used to specify the type of rotation is the same for all 30 items. The second stimulus object is different for each item. All objects are isometric pictorials of one of the following types of three-dimensional solids: truncated hexahedrons, right circular cylinders, right rectangular prisms, or right triangular prisms. Scoring the PSVT is simply a matter of adding the number of correctly answered items. Guay (1980) reports internal consistency coefficient results (KR-20) of .87, .89, and .92 from studies conducted on 217 university students, 51 skilled machinists, and 101 university students respectively. Sorby and Baartmans (1996) conducted a study involving 492 freshmen engineering students. They reported a KR-20 coefficient of .82. Battista, Wheatley and Talsma (1982) administered the PSVT to 82 preservice elementary teachers enrolled in an undergraduate geometry course. A KR-20 internal consistency coefficient of .80 was reported. For the study conducted at North Carolina State University during the 1997 fall semester on 81 undergraduate students, internal consistency coefficients of .82 and .80 were calculated for parts 1 and 2 of the computer-based PSVT respectively (Branoff, 1998). For the current study, coordinate axes were added to the first and second stimulus objects as part of the treatment condition (*see Figure 1*).

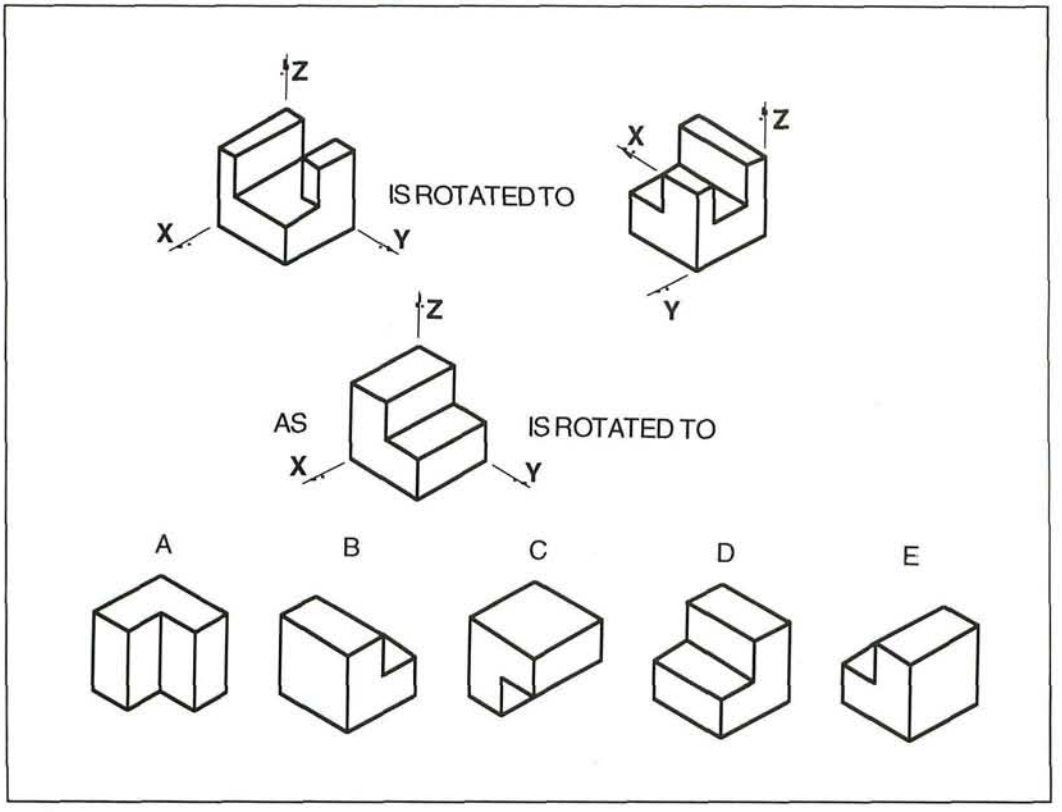


Figure 1 *- Visualization of rotations test with coordinate axes added.*

Sample

Students enrolled in introductory engineering graphics courses at North Carolina State University during the 1998 fall semester were asked to participate in the study as part of the requirements for their course. Of the 361 students enrolled in GC101, GC120, GC210, and GC211, 249 students completed the study.

Procedures

During the summer of 1998, four computer versions of the PSVT were developed by the researcher. All four versions of the instrument consisted of 60 items. The first 30 items were identical to the 30 items on the paper/pencil version of the PSVT. The second 30 items were an equivalent form of the PSVT. Coordinate axes were added to the following sections: the first 30 items for Groups 3 and 4; the second 30 items for Groups 2 and 3.

The purpose of developing the computer versions of the PSVT was to provide accurate data on scores and response times. The researcher designed the tests such that data was gathered in a spreadsheet format. The tests were also used to collect data on gender, age, current major, number of previous graphics courses taken, and questions on the approach taken to solve the problems (holistic or analytic). Students completed the computer-based PSVT during the first 6 weeks of classes.

Presentation of Data

Description of the Participants

A majority of the students were male, freshman, engineering students enrolled in GC120-Foundations of Graphics. *Table 2* provides data on the participants in the study by gender, classification, major, and graphic communications course in which currently

enrolled. Most students were enrolled in his/her first graphics course. *Table 3* describes the historical experience of the participants in graphics courses. Students were randomly assigned to one of four treatment groups. *Table 4* describes the distribution of participants in the four treatment groups. The mean ages of the participants in the four treatment groups are shown in *Table 5*.

Gender	**Frequency**	**Percent**
Female	61	24.5
Male	188	75.5
Total	**249**	**100.0**
Class	**Frequency**	**Percent**
Freshman	59	23.7
Sophomore	139	55.8
Junior	34	13.7
Senior	14	5.6
Undergraduate Special	3	1.2
Total	**249**	**100.0**
Major	**Frequency**	**Percent**
Design	11	4.4
Education	6	2.4
Engineering	185	74.3
First Year College	28	11.2
Other	19	7.6
Total	**249**	**100.0**
Course	**Frequency**	**Percent**
GC101-Engineering Graphics I	27	10.8
GC120-Foundations of Graphics	130	52.2
GC210-Intro to Engineering Graphics for IE	42	16.9
GC211-Intro to Engineering Graphics for MAE	50	20.1
Total	**249**	**100.0**

***Table 2** - Demographics of the participants.*

Number of High School Courses	Frequency	Percent
No High School Courses	144	57.8
1 High School Course	62	24.9
2 High School Courses	26	10.4
3 High School Courses	13	5.2
4 or more High School Courses	4	1.6
Total	**249**	**100.0**
Number of Post-Secondary Courses	**Frequency**	**Percent**
No Courses since High School	224	90.0
1 Course since High School	23	9.2
2 Courses since High School	0	0.0
3 Courses since High School	1	0.4
4 or more Courses since High School	1	0.4
Total	**249**	**100.0**

Table 3 *- Previous graphics courses taken.*

Group	Frequency	Percent
Group 1	63	25.3
Group 2	63	25.3
Group 3	62	24.9
Group 4	61	24.5
Total	**249**	**100.0**

Table 4 *- Treatment groups.*

Group	N	Mean	Std Dev	Min	Max
Group 1	63	19.75	1.97	18	27
Group 2	63	19.60	1.70	18	29
Group 3	62	19.81	2.76	18	39
Group 4	61	20.08	2.72	18	35
Total	**249**	**19.81**	**2.32**	**18**	**39**

Table 5 *- Mean age of the participants.*

Group	Part 1 Mean	Std Dev	Part 2 Mean	Std Dev
Group 1	21.381	5.338	22.190	4.935
Group 2	23.063	4.645	24.571	3.762
Group 3	23.097	4.911	23.952	4.685
Group 4	23.593	5.655	23.0998	5.715
Total	**22.775**	**5.186**	**23.453**	**4.872**

***Table 6** - Scores for PSVT Part 1 and Part 2 by treatment group.*

Analysis of Scores

Table 6 examines the scores obtained on the PSVT for all treatment groups.

Hypothesis #1 - Since both Groups 1 and 2 completed the same version of the PSVT for Part 1 (no coordinate axes present), it was hypothesized that there would be no difference in Part 1 mean scores. No significant difference was found between the mean scores at α=.05 (F=3.56, df=125, p=0.0615). The findings support Research Hypothesis #1.

Hypothesis #3 - Since both Groups 3 and 4 completed the same version of the PSVT for Part 1 (coordinate axes present), it was hypothesized that there would be no difference in Part 1 mean scores. No significant difference was found between the mean scores at α=.05 (F=0.27, df=122, p=0.6062). The findings support Research Hypothesis #3.

Hypothesis #5 - It was hypothesized that the presence of coordinate axes would provide sufficient cues to increase the mean score for Groups 3 and 4. No significant mean score difference was found between combined Groups 1 & 2 and combined Groups 3 & 4 on Part 1 at α=.05 (F=2.92, df=248, p=0.0886). The findings do not support Research Hypothesis #5 *(see Table 7)*.

Hypothesis #7 - Traditionally, males have tended to score higher on the PSVT than females. It was hypothesized that males would score higher than females on Part 1 for Groups 1 and 2 (no coordinate axes present). The mean score for males was significantly higher than the mean score for females on Part 1 of the instrument for individuals in Groups 1 and 2 at α=.05 (F=8.68, df=125, p=0.0038). The findings support Research Hypothesis #7 *(see Table 8)*.

Hypothesis #8 - Research indicates that males tend to mentally transform objects holistically more often than females. The PSVT favors persons who take a holistic approach to solving the test items. It was hypothesized that the addition of coordinate axes would eliminate gender differences on the PSVT. No significant mean score difference was found between males and females on Part 1 of the PSVT for Groups 3 & 4 (coordinate axes present) at α=.05 (F=0.71, df=122, p=0.4002). The findings support Research Hypothesis #8 (see Table 8). Further analysis of mean scores on Part 1 did not yield a significant difference between combined Groups 1 & 2 (no axes present) and 3 & 4 (axes present) for females (F=3.10, df=60, p=0.0836).

Hypothesis #9 - Since Groups 1 and 3 received the same treatment on Parts 1 and 2 of the PSVT (Group 1 - no coordinate axes on either part, Group 3 - coordinate axes on both parts), it was hypothesized that there would be no difference in mean scores between the two parts. There was no signifi-

cant difference between the mean scores on Parts 1 and 2 for Group 1 at α=.05 (t=1.668, p=0.1003). The findings support Research Hypothesis #9. The mean score on Part 2 of the PSVT was significantly higher than the mean score on Part 1 for students in Group 3 at α=.05 (t=2.210, p=0.0308). The findings do not support Research Hypothesis #9.

Hypothesis #10 - Since the primary question of the study was to examine the effects of adding coordinate axes to a mental rotations task, it was hypothesized that coordinate axes would improve students' scores. The mean score on Part 2 of the PSVT was significantly higher than the mean score on Part 1 for students in Group 2 at α=.05 (t=4.012, p=0.0002). The findings support Research Hypothesis #10.

Hypothesis #11 - It was hypothesized that if coordinate axes were taken away from students on Part 2 of the PSVT, mean scores would not decrease significantly nor improve significantly. There was no significant difference between the mean scores on Parts 1 and 2 for Group 4 at α=.05 (t=-1.114, p=0.2697). The findings support Research Hypothesis #11.

Hypothesis #14 - It was hypothesized that the presence of coordinate axes would provide sufficient cues to increase the mean score for Groups 2 and 3. A significant mean score difference was found on Part 2 between combined Groups 1 & 4 and combined Groups 2 & 3 at α=.05 (F=7.11, df=248, p=0.0082). Combined Groups 2 & 3 had a significantly higher mean score than combined Groups 1 & 4. The findings support Research Hypothesis #14 (*see Table 7*).

Hypothesis #15 - The mean score for males was significantly higher than the mean score for females on Part 2 of the instrument for individuals in Groups 1 and 4 at α=.05 (F=6.86, df=123, p=0.0100). The findings support Research Hypothesis #15 (*see Table 8*).

Hypothesis #16 - No significant mean score difference was found between the males and females on Part 2 of the PSVT for Groups 2 & 3 (coordinate axes present) at α=.05 (F=1.92, df=124, p=0.1687). The findings support Research Hypothesis #16 (see Table 8). Further analysis of mean scores on Part 2 did yield a significant difference between combined Groups 1 & 4 (no axes present) and 2 & 3 (axes present) for females (F=4.24, df=60, p=0.0438).

Additional Analyses - A repeated measures analysis of variance procedure revealed significant score differences (F=10.22, df=245,

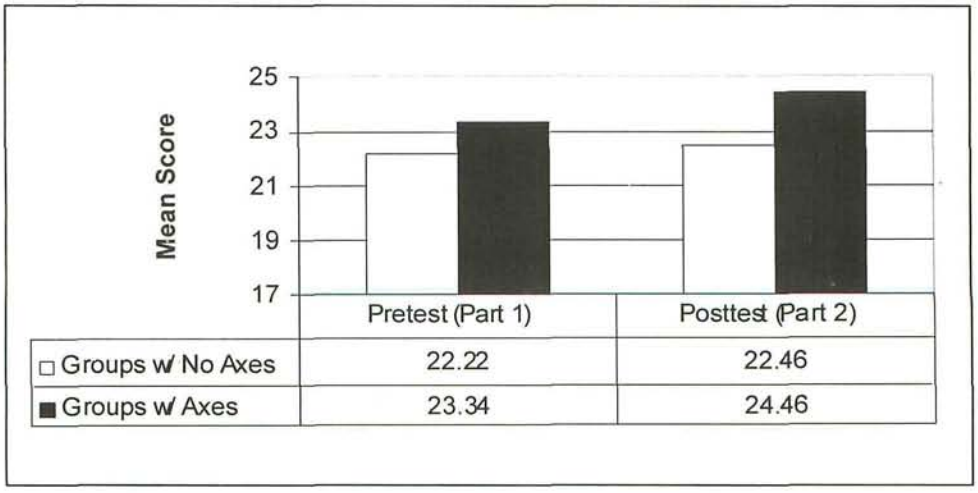
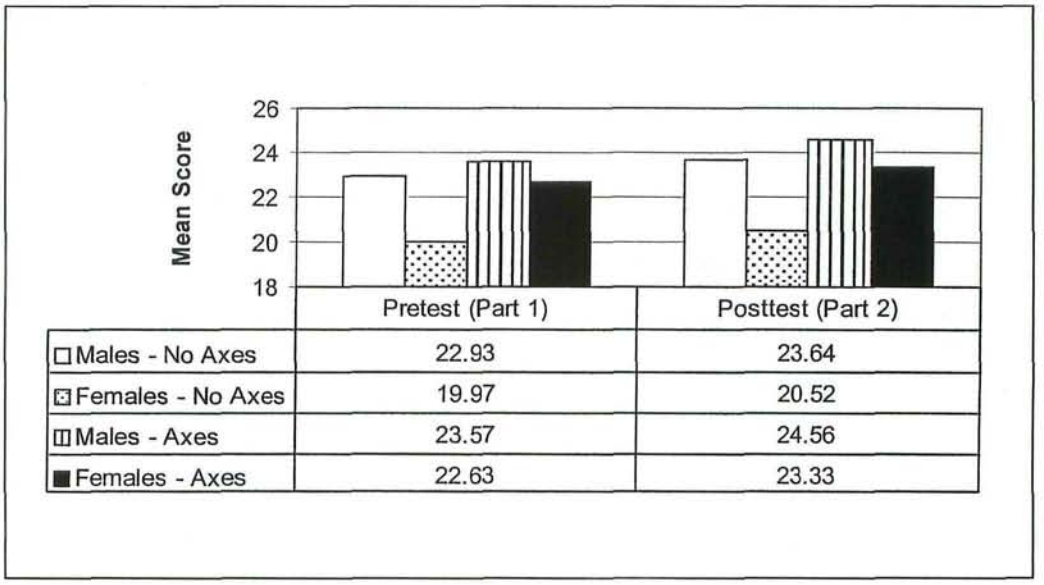


***Table 7** - Effects of axes on mean scores.*



	Pretest (Part 1)	Posttest (Part 2)
□ Males - No Axes	22.93	23.64
⊡ Females - No Axes	19.97	20.52
◫ Males - Axes	23.57	24.56
■ Females - Axes	22.63	23.33

***Table 8** - Mean scores by gender.*

p=0.0016) and significant interaction between groups (F=3.86, df=245, p=0.0101). The mean score on Part 1 for Group 4 (23.6) was significantly higher than the mean score on Part 1 for Group 1 (21.38). The mean score on Part 2 for Group 2 (24.57) was significantly higher than the mean score on Part 2 for Group 1 (22.19). The mean score on Part 2 for Group 3 (23.95) was significantly higher than the mean score on Part 2 for Group 1 (22.19).

Analysis of Response Times

Table 9 examines the response times obtained on the PSVT for all treatment groups.

Hypothesis #2 - Since both Groups 1 and 2 completed the same version of the PSVT for Part 1 (no coordinate axes present), it was hypothesized that there would be no difference in Part 1 mean response times. No significant difference was found between the mean response times at α=.05 (F=0.73, df=125, p=0.3956). The findings support Research Hypothesis #2.

Hypothesis #4 - Since both Groups 3 and 4 completed the same version of the PSVT for Part 1(coordinate axes present), it was hypothesized that there would be no difference in Part 1 mean response times. No significant difference was found between the

Group	Part 1 Mean*	Std Dev*	Part 2 Mean*	Std Dev*
Group 1	1027.230 (17.12)	473.802	753.944 (12.57)	325.264
Group 2	961.448 (16.02)	388.049	801.381 (13.36)	251.330
Group 3	966.464 (16.11)	460.260	747.615 (12.46)	276.729
Group 4	1117.360 (18.62)	476.464	731.129 (12.19)	254.319
Total	**1017.530 (16.96)**	**439.560**	**758.781 (12.65)**	**278.228**

*Means and standard deviations are in seconds. Times given in parentheses are minutes.

***Table 9** - Response times for PSVT-Part 1 and Part 2 by treatment group.*

mean response times at α=.05 (F=3.58, df=122, p=0.0610). The findings support Research Hypothesis #4.

Hypothesis #6 - Since coordinate axes were present for Groups 3 and 4 on Part 1 of the instrument, it was hypothesized that the additional cues would require more processing time than Groups 1 & 2. No significant difference was found between the mean response times at α=.05 (F=0.71, df=248, p=0.4004). The findings do not support Research Hypothesis #6.

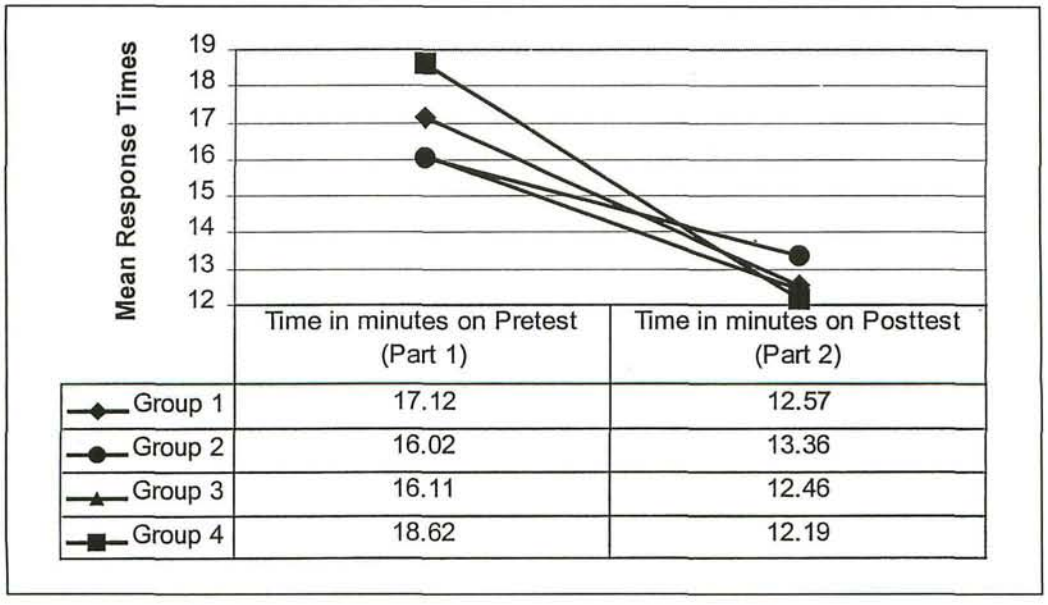
Hypothesis #12 - The Fall 1997 study revealed a learning factor where students completed Part 2 of the PSVT in less time than was required to complete Part 1 (Branoff, 1998). The mean response time on Part 2 of the PSVT was significantly lower than the mean response time on Part 1 for students in all Groups at α=.05 (t=-13.247, p=0.0001). The findings support Research Hypothesis #12.

Hypothesis #13 - There was no significant mean response time difference between combined Group 1 & 4 (no coordinate axes present) and combined Group 2 & 3 (coordinate axes present) on Part 2 at α=.05 (F=0.82, df=248, p=0.3653). The findings do not support Research Hypothesis #13.

Additional Analyses - A repeated measures analysis of variance procedure revealed significant response time differences (F=186.99, df=245, p=0.0001) and significant interaction between groups (F=6.42, df=245, p=0.0003) at α=.05. The mean response time on Part 1 for Group 4 (18.62 minutes) was significantly higher than the mean response time on Part 1 for Group 2 (16.02 minutes). No significant differences existed between the Groups on Part 2 of the PSVT *(see Table 10)*.

Conclusions and Discussion

Effects of Coordinate Axes on Scores - On Part 1 of the PSVT, the mean score for groups with the axes present was higher (23.34) than the mean score for groups where the axes were not present (22.22). As mentioned earlier, this difference was not significant. On Part 2 of the PSVT, the mean score for groups with the axes present (24.26) was significantly higher than the mean score for groups without the axes (22.46). Previous results concerning gender differences were verified during the current study. Males scored significantly higher than females when the axes were not present.



	Time in minutes on Pretest (Part 1)	Time in minutes on Posttest (Part 2)
Group 1	17.12	12.57
Group 2	16.02	13.36
Group 3	16.11	12.46
Group 4	18.62	12.19

***Table 10** - Mean response times by group.*

When the axes were present, no mean score differences existed between males and females.

Effects of Coordinate Axes on Response Times - The addition of coordinate axes to the PSVT had little influence on response times. The only significant difference was found between Group 1 (no axes present) and Group 4 (axes present) on Part 1 of the PSVT.

Implications for Teaching Methods in Graphics Education

Although the addition of coordinate axes to the PSVT did produce statistically significant differences in mean scores, educators need to examine the practical significance of adding coordinate axes to instructional materials in the classroom. Adding coordinate axes to instructional materials as well as sketches made on the board may help some students. It is clear from this study that the addition of the coordinate axes seemed to eliminate gender differences for scores on the PSVT.

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 two areas of further research:

1. 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.
2. The study needs to be replicated with a different target population to verify the effects of the coordinate axes. The coordinate axes may influence scores and response times differently for high schools students or undergraduate, non-engineering students.

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