The Effects of Adding Coordinate Axes to a Mental Rotations Task in Measuring Spatial Visualization Ability in Introductory Undergraduate Technical Graphics Courses

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ABSTRACT

The purpose of this research 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. The theoretical framework of the study is based on Paivio's dual-coding theory (1991). 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. Eighty-one undergraduate students enrolled in introductory graphic communications classes during the 1997 fall semester completed a computer version of the PSVT. The instrument consisted of two parts (each part containing 30 items). Coordinate axes were added to Part 2 of instrument for the experimental group. Item responses, response times, and demographic data were collected within the instrument. The addition of coordinate axes had no significant effect on scores when differences were examined between the experimental and control groups. It appears, however, that the addition of the axes eliminated gender difference on the PSVT. There was no significant mean score difference between males and females on Part 2 of the PSVT for the experimental group. Analyses of response times indicated that more time was required to process the additional information present with the coordinate axes. 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

Review of Literature

Concerns for Developing Spatial Ability

Until recently, not many studies had been conducted by engineering and technical graphics educators to examine how spatial visualization ability is developed and measured. Within the last eight years, a number of researchers have tried to determine the best way to measure a person's spatial visualization ability and the best methods for improving it (Bertoline & Miller, 1990; Deno, 1995; Miller, 1992; Sorby & Baartmans, 1996; Wiebe, 1993 & 1996).

The concern for developing spatial ability in students can be seen across the United States. Nationally funded curriculum development projects such as the NSF Curriculum Development Project for Engineering Design Graphics and the SIGGRAPH Curriculum Model for Engineering Graphics have called for sweeping changes in the engineering design graphics curriculum (Miller & Bertoline, 1991). The central theme of these curriculum changes revolves around spatial visualization. Miller & Bertoline (1991) also add that to be recognized and accepted as a discipline by other established disciplines, the focus of curriculum efforts in engineering design graphics must be around spatial visualization. Their recommendations have been echoed by other engineering and technical graphics educators. Chin (1993) conducted a study in which a panel of experts was asked to identify research activities in engineering graphics that are currently underway and the nature of research that should be undertaken in the future. The panel concluded "the data tend to suggest that additional efforts need to be directed at research in the areas of visualization and computers" (p. 15).

Spatial Abilities

Spatial abilities have been shown to be a component of success in many engineering, technical, mathematical, and scientific professions (Miller & Bertoline, 1991). What is difficult to interpret is the type of spatial ability being used to predict success in the different areas. According to McGee (1979), there is more than one spatial ability factor. Spatial visualization involves being able to "mentally manipulate, rotate, twist, or invert pictorially presented visual stimuli." It involves being able to recognize, retain, and recall a configuration in which the object has been manipulated in three-dimensional space. Spatial orientation involves the arrangement of components within a visual stimulus pattern, the aptitude for remaining unconfused when orientations of stimuli have been changed, and "the ability to determine spatial relations in which the body orientation of the observer is an essential part of the problem" (pp. 3-4). Lohman (1988) introduced a third factor referred to as speeded rotation. It is present in mental rotations of forms or objects in motion. Objects used to test this factor tend to be simple because the speed of rotation is of main importance.

Problems with Tests Measuring Spatial Ability

There are many tests that claim to measure an individual's spatial ability. Research has shown that these tests do not all measure the same spatial ability factor. The Purdue Spatial Visualization Test-Visualization of Rotations (Guay, 1977) and the Shepard-Metzler Rotations Test (Shepard & Metzler, 1971) appear to have high construct validity in the area of spatial visualization ability (Guay, 1980). The Revised Minnesota Paper Form Board Test (Likert & Quasha, 1970) appears to measure spatial orientation since it requires a high degree of analytical processing (Guay, McDaniel, & Angelo, 1978). The Purdue Spatial Visualization Test-Visualization of Views and Visualization of Developments tests appear to measure spatial orientation ability. Both tests require analytical and holistic processing strategies (Guay & McDaniel, 1979). Finally, there is evidence supporting the Spatial Ability section of the Differential Aptitude Test (Bennett, Seashore & Westman, 1981) as a measure of spatial orientation ability (Kovac, 1989; Juhel, 1991). Correlations among tests of spatial ability are variable and tend to be modest. This suggests that they are tapping different specific abilities or skills within the general spatial ability domain (Paivio, 1986).

Individual Differences in Spatial Abilities

Most research related to individual differences in spatial abilities focuses on gender differences. In general, males tend to score higher on measures of spatial ability than females. One explanation for this is that there is more variability in scores for females than scores for males on spatial ability tests. In a study involving the locus of sex differences in spatial ability (Kail, Carter & Pellegrino, 1979), approximately "70% of the women mentally rotated stimuli at rates comparable to men, while 30% of the women did so at a slower rate" (p. 185). The researchers attributed the difference in speed of rotation to the processing strategy used by the subjects. They hypothesized that women who had slower rotation rates might have used an analytical processing strategy while women who had faster rotation rates might have used a holistic processing strategy. In another study involving spatial reasoning

(Hsi, Linn & Bell, 1997), the researchers speculated that males outperformed females because they found solutions quickly using holistic means. Females, on the other hand, relied on "analytical techniques to algorithmically construct a solution more slowly" (p. 157). Lohman (1984) found that on a measure of spatial ability, subjects shifted strategies predictably over test items. Males tended to use a spatial strategy while females used a verbal analytical strategy.

The study of human memory is a key component of the information-processing model.

Several studies reject neurophysiological explanations for gender differences. Guay and McDaniel (1979) reported that self-perceived spatial ability, trait anxiety, enjoyment, and familial influence have some potential for explaining gender differences, but all neurophysiological factors have little potential. Pearson and Ferguson (1989) concur that sex role socialization plays a key role in contributing to gender differences in spatial ability.

Other individual differences have also been found to be related to spatial ability. In a study involving 93 university freshmen, individuals who scored higher on certain measures of spatial ability showed greater participation in spatial activities, were influenced more by their mothers, had greater anxiety, and had mothers who had more nontechnical careers than did individuals with lower scores (Guay & McDaniel, 1982). Guay (1978) also found that "university students who were born neither first nor last in their family perform significantly better on some types of spatial tests than university students who were born either first or last in their family" (p. 14). He also found that students who participated in activities requiring spatial thought tended to outperform those who did not on some spatial tests. In another study involving undergraduates, individuals with high spatial scores tended to have faster response times on a spatial task (Mumaw & Pellegrino, 1984). Differences were more evident as the spatial tasks became more complex.

Cognitive Psychology and Information-Processing

Because human beings are so complex, it is virtually impossible to study the totality of the human system. Information-processing research usually begins by defining manageable subsystems. Traditionally, information-processing theory involves the study of how people collect, store, modify, and interpret environmental information. It also examines how new information is added to permanent knowledge of the world, how it is accessed, and how it is used in every facet of human activity. Most of this activity happens without conscious awareness on the part of the individual (Lachman, Lachman & Butterfield, 1979).

Information-processing theorists view the learner as someone who is hungry for information. The learner does not passively sit back and wait for environmental stimulus. Information-processing theorists also believe humans have certain innate abilities. These abilities coupled with experience produce cognitive performance (Lachman et al., 1979).

Encoding Theories

The study of human memory is a key component of the information-processing model. Objects must be represented or encoded in memory in order to be matched up with currently perceived objects so that action can take place on the part of the individual. During encoding, stimulus information is taken into the system and processed so that it can be converted to an appropriate form for the task at hand (Rose, 1980). There are two theories that explain how information is encoded into long-term memory. The first theory describes a verbal coding system. Supporters of this theory believe that all information is ultimately represented verbally. Although the importance of imagery is acknowledged, images are said to be reconstructed from verbal information. The second model for explaining how information is encoded in long-term memory is referred to as the dual-coding model. According to this theory, information is encoded in memory through two processing systems - the verbal and nonverbal systems. As information is perceived through the senses, it is coded in the verbal system, the nonverbal system, or both. When information is coded in both processing systems it is said to be dual coded (Gredler, 1992). The verbal system stores words and deals with information sequentially. In contrast, the nonverbal system stores images and processes information in parallel. Abstract information is more likely to be coded through the verbal system while concrete information is more likely to be coded through the nonverbal system. When something is dual coded in memory, the particular task being performed determines whether an individual works through the verbal or nonverbal system. When verbalizing after nonverbal information processing, coordination is necessary between the two systems. Having a verbal code connected with a nonverbal image becomes critical (Hample, 1982).

The Dual Coding Model

Information processing under the dual coding model includes encoding, recoding, organization and elaboration of information within the verbal and nonverbal systems, and transformation, manipulation, and retrieval of information from either system (see *Figure 1*). Encoding occurs when the verbal or nonverbal system is activated by appropriate stimuli from the environment. Recoding occurs when the verbal system is activated by cues from the nonverbal system or when the nonverbal system is activated by cues from the verbal system (Paivio, 1986).

Paivio (1986) defines two types of representational units within the dual coding model. *Imagens* "correspond to natural objects, holistic parts of objects, and natural groupings of objects" (p. 59). The information represented can be static or dynamic and "is organized in a synchronous or simultaneous manner into perceptual hierarchies of nested sets" (p. 60). For example, the dashboard of an automobile is a combination of many different objects - gauges, radio controls, air conditioning controls, and so on. All of the objects are organized within a hierarchical structure, which is itself part of an even larger structure - the whole automobile. What is meant by synchronous or simultaneous organization is that the parts are typically perceived together through the visual system. They are, however, available for processing simultaneously. In other words, one can describe a dashboard by beginning at many different points and still give an accurate description. The order in which the information is processed is not random, but what is important "is that it is not sequentially constrained by the representational structure itself" (p. 60).

Abstract information is more likely to be coded through the verbal system...

Logogens "differ from imagens in internal structure so that smaller units are organized into larger units in a sequential or successive fashion" (p. 61). The structure of logogens is most evident by examining the auditory-motor representations of the heard or spoken language. Within this system "phonemic units are organized in syllables, syllables into words, and so on, up to sequential structures as extensive as poems or entire plays" (p. 61).

The verbal and nonverbal symbolic systems can work independent of one another or

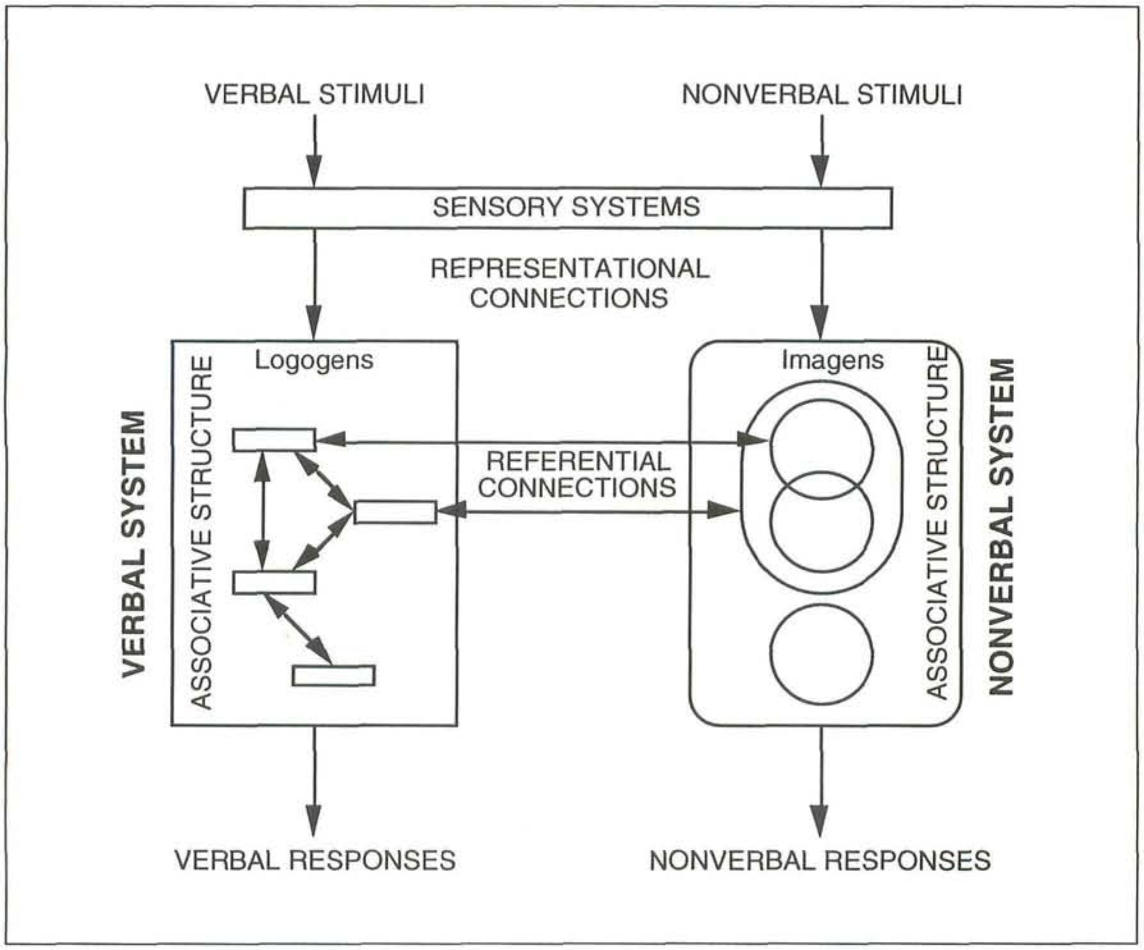

Figure 1 *- Schematic of dual coding model.*

work in parallel. The essence of the dual coding model is that one system triggers activity in the other system. This is important because it allows for flexible yet organized processing activity. The two symbolic systems can work independently for some activities or coordinate processing for other activities. The connections between the two systems go in both directions. It is not a one-to-one connection. The connections are one-to-many in both directions. There are objects that have many names and names that can represent many objects (Paivio, 1986).

Not only do processing activities occur between the two systems, but there is activity that occurs within each system. Through associative experience, auditory-motor logogens are linked to one another in a many-to-many fashion. In other words, one word can evoke associations with many other words which in turn can evoke associations with many more words. For example, the word red might be associated with a car, dress, cup, or blood. The word car might then evoke associations with other words such as tire, fast, or new. Imagens, however, cannot be characterized in terms of relations among discrete entities. One's knowledge of the world "must reflect the continuous nature of organized objects and events" (p. 65). When imagining the dashboard of an automobile, one typically imagines it as part of its immediate environment - within the structure of the car. It is possible to then imagine the car within an even larger environment.

Verbal and nonverbal representations are activated based on a combination of environmental variables and individual difference variables. The environmental variables include both the target stimuli and the contextual stimuli within a particular task. According to Paivio (1986), "the target stimuli are those that are presented for processing, such as items to be remembered, compared, comprehended, or mentally manipulated in some way" (p. 68). Empirical observations have shown that the activation of nonverbal representations is a function of the concreteness or image-arousing value of the stimuli. In other words, imagery is more likely to be evoked when pictures are used rather than words or when concrete words are used instead of abstract words (Paivio, 1986).

The dual coding model also allows for several levels of processing - representational, referential, and associative. Representational processing is the relatively direct activation of verbal representations by verbal/linguistic stimuli and the activation of nonverbal representation by nonverbal/nonlinguistic stimuli. It is considered relatively direct because neither type of stimuli is pure. Linguistic stimuli includes some nonlinguistic stimuli just as nonlinguistic stimuli includes some linguistic stimuli. *Referential* processing refers to the cross-over activity between the verbal and nonverbal systems. The verbal system can be activated by nonverbal stimuli or the nonverbal system can be activated by verbal stimuli. For example, a word may evoke images or an image may evoke different words. Finally, associative processing refers to the activity that goes on within either the verbal or nonverbal systems. Within the verbal system, words may evoke associations with other words. Within the nonverbal system, nonverbal objects or events may trigger other nonverbal objects or events (Paivio, 1986).

As discovered during the spatial ability studies conducted to examine neuropsychological differences (Guay & McDaniel, 1979, Pearson & Ferguson, 1989), the dual coding model also emphasizes the influence that environmental factors have on the development of representational systems. The influence of genetics is not ignored, but the model is guided by the empiricist assumption that experience plays a major role in knowledge and what can be done with that knowledge (Paivio, 1986).

A person develops their knowledge representation systems by building knowledge structures or schemas (Gredler, 1992). Paivio (1986) describes the development of nonverbal representations and skills as follows:

> *The inescapable general conclusion is that representational development involves the formation of an indefinitely large (and expanding) set of representational variants, or tokens, all of which are complex, integrated structures that incorporate information from different modalities in varying degrees. This conclusion is a version of the exemplar approach to nonverbal concepts, together with the idea that some narrow range of representational variants may be more typical or prototypical than others because of a high frequency of experience with the represented objects in particular orientations and, sometimes, in particular settings. The most relevant evidence has come from experimental studies of the effect of experience with exemplars on the formation of representations to perceptual concepts (p. 89).*

These dynamic knowledge structures allow new information to be interpreted within the new context. The structures are continually being organized and reorganized to provide for the most efficient processing (Gredler, 1992). Organizational and transformational abilities provide some examples of the dynamic nature of the knowledge structures. Organization occurs during encoding when new information is simply reorganized within the existing structure. For example, if a child sticks a nail into an electrical outlet and received a shock, it is likely that the child's knowledge structure would reorganize to conceptualize an interacting image of the nail and the socket. The manipulation of mental images are required for transformations to occur. One of the most familiar nonverbal transformation activities is the mental rotation of objects. Being able to imagine how an object looks from a different perspective requires the manipulation of a mental image (Paivio, 1986).

Processing Assumptions

The dual coding model makes two assumptions about processing that occurs over representational structures allowing for semantic decisions to be made between concepts over several levels of generality. First, spreading activation is assumed to occur over the referential and associative processing structures. In other words, when representations are closely related, one representation spreads to activate another. A second assumption is that matching occurs during perceptual recognition where perceptual patterns are compared with representations in long-term memory. Semantic decisions are based on feature matching where relationships are made between concepts that share similar features. The comparison process in dual coding theory is assumed to "be based either on the global shape of perceptual or semantic representations [holistic processing], or on particular perceptual components or dimensions of those patterns [analytical processing], depending on task demands or contextual cues" (Paivio, 1986, p. 125).

Coordinate Axes

For certain spatial tasks, perceptual axes provide a frame of reference for coding a display in memory (Bialystok, 1989). In a study of children's mental processing, subjects were asked to keep track of both the appearance and orientation of a display and make predictions about the appearance of an abstract object in a specified final orientation. The subjects were asked to match their predictions with images on a series of cards. Difficulty of rotating the display "was influenced by the congruity between the final position of the shape and an implicit perceptual axis of the display" (p. 66).

As stated earlier, one of the processing assumptions of the dual coding theory in that the comparison process can be either holistic or analytic depending on the demands of the task or the contextual cues (Paivio, 1986). It appears that the perceptual axes in the Bialystok (1989) study acted as a contextual cue for activating referential and associative processing between the verbal and nonverbal representational systems. This helped subjects match their prediction of the object in its rotated position with one of the images on the cards.

Methodology

Introduction

The review of literature led the researcher to conclude that there could be other factors (not yet examined) which influence spatial visualization ability. One included the presence or absence of coordinate axes to visual representations of objects. Current psychometric tests of spatial visualization ability fail to measure this potential influence on the processing of spatial information.

Information-processing theory provides an explanation for how spatial information is processed. The encoding of information is a key component in performing spatial tasks. The dual-coding model offers some help in explaining differences in processing strategies. The review of literature has suggested that individuals who feel comfortable processing nonverbal information and are able to mentally transform images score higher on tests of spatial visualization ability. Also, when verbal cues are present with the nonverbal stimuli, the information can be dual coded. Dual coding allows the information to be processed and recalled more efficiently than if only the verbal stimuli or the nonverbal stimuli were presented alone.

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 undergraduate introductory graphic communications classes. Coordinate axes were added to the Purdue Spatial Visualization Test - Visualization of Rotations to determine whether the presence of the axes was a sufficient contextual cue for improving scores and response times.

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?*

The following 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 Purdue Spatial Visualization Test-PSVT (coordinate axes present) than on Part 1 (no coordinate 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).

Research Design

This study used a pretest-posttest control-group design (see *Table 1*). The purpose of selecting this design was to maximize the likelihood that measured differences between the experimental and control groups would reflect actual differences. When conducted properly, this type of research design can control the following threats to internal validity: maturation, history, instrumentation, testing, differential selection, statistical regression, experimental mortality, and selection-maturation interaction (Gall, Borg & Gall, 1996).

		Pretest	Treatment	Posttest
Experimental Group	R	O_1	X	O_2
Control Group	R	O_1		O_2

R: Random assignment of the subject to either the experimental group or the control group.
O_1: A computer version of the Purdue Spatial Visualization Test - Visualization of Rotations.
O_2: An equivalent form of the computer version of the Purdue Spatial Visualization Test - Visualization of Rotations.
X: Coordinate axes will be added to the 30 items in O_2.

Table 1 *- Research design.*

Instrumentation
Since the main construct of interest for this study was spatial visualization ability, the Purdue Spatial Visualization Test - Visualization of Rotations (PSVT) was used to assess this construct (see *Figure 2*). 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

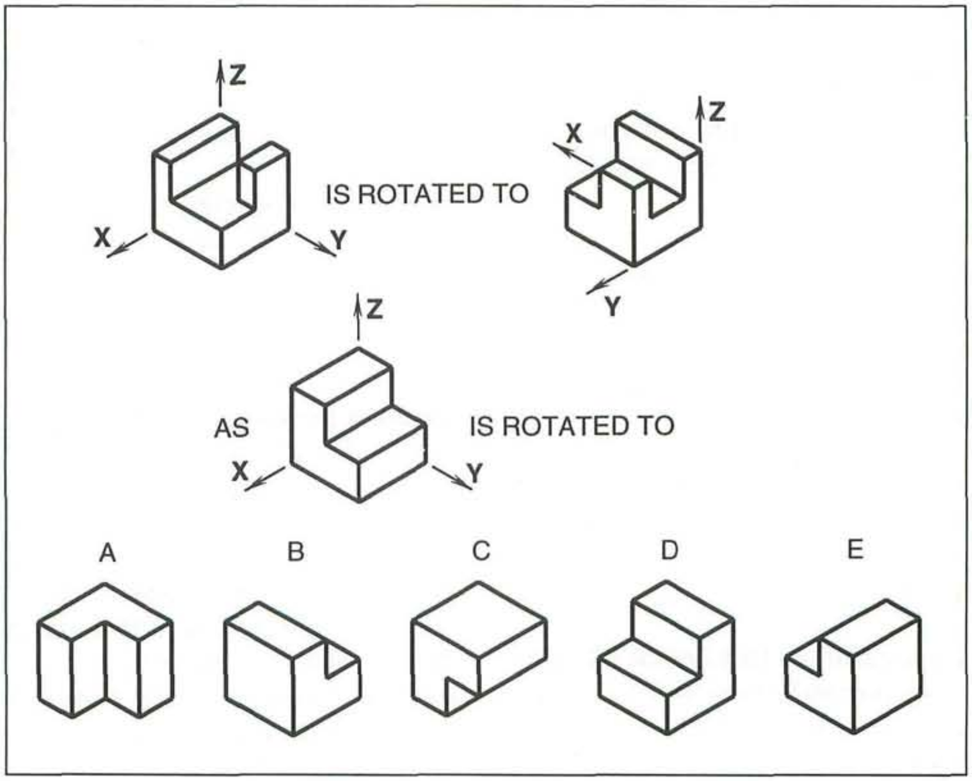

Figure 2 *- Visualization of rotations test with coordinate axes added.*

two axes, and concluding with items requiring rotation of 90° about one axis and 180° about another axis (Guay, 1977).

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). 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 current study, coordinate axes were added to the first and second stimulus objects as part of the treatment condition (see *Figure 2*). The coordinate axes consisted of X, Y & Z axes. When the first stimulus object was shown in its new, rotated position, the coordinate axes followed the same rotation as the object. In other words, the axes were attached to the object. Coordinate axes were also added to the second stimulus object for each problem, however, they were not added to the five solution choices.

To check the internal consistency of the computer version of the Purdue Spatial Visualization Test - Visualization of Rotations, KR-20 values were computed for the two parts of the instrument. Internal consistency coefficients of .82, .74, and .83 were computed for the first 30 items for all participants, the second 30 items given to the experimental group (coordinate axes), and the second 30 items given to the control group (no coordinate axes), respectively.

Target Population

The intent of the study was to examine the construct of spatial visualization and examine the influence coordinate axes have on an individual's ability to mentally rotate objects. Since humans do not develop this ability until early adolescence (Guay, 1980 and Piaget, Inhelder, & Szeminska, 1960), the target population for this study was individuals in late adolescence and early adulthood. This population is of interest to teachers in the graphic sciences at the high school and post-secondary level. Three-dimensional computer-aided design programs are frequently used in graphics classes which require students to exhibit good spatial visualization ability in order to be successful. For the purpose of generalizing the results to other settings, individuals targeted for the study were students enrolled at a large (approximately 21,500 undergraduates), land-grant, research university in the southeastern United States.

Sample

A random sample of 150 undergraduate students enrolled in introductory Graphic Communications courses at North Carolina State University during the 1997 fall semester was selected. Class rolls for GC101-Engineering Graphics I, GC120-Foundations of Graphics, GC210-Introduction to Engineering Graphics for Industrial Engineers, and GC211-Introduction to Engineering Graphics for Mechanical and Aerospace Engineers were used as the sampling frame. Of the initial 150 students sampled, one-hundred thirty-three students signed-up to participate. Eighty-one of the 133 students completed the study.

Procedures

During the summer of 1997, two computer versions of the Purdue Spatial Visualization Test - Visualization of Rotations were devel-

	Frequency	Percent
Gender		
Female	17	21.0
Male	64	79.0
Class		
Freshman	17	21.0
Sophomore	49	60.5
Junior	10	12.3
Senior	.5	6.2
Major		
Design	7	8.6
Education	4	4.9
Engineering	54	66.7
First Year College	10	12.3
Other	6	7.4
Course		
GC101 - Engineering Graphics I	17	21.0
GC120 - Foundations of Graphics	43	53.1
GC210 - Intro to Engineering Graphics for IE	10	12.3
GC211 - Intro to Engineering Graphics for MAE	11	13.6

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

oped by the researcher using Macromedia's Authorware 3.5TM on Microsoft Windows95 TM 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.

Testing took place during the second through sixth weeks of the fall 1997 semester. As students arrived to participate in the study, each was alternately assigned to the control or experimental group. Both groups were administered Part 1 of the PSVT which consisted of the 30 items on the original paper-pencil test. After a short rest period, Part 2 of the PSVT was administered. The rest period between Parts 1 and 2 ranged from approximately 1-5 minutes. At the end of the test, students were asked to give demographic information relative to gender, age, academic major, number of previous graphics courses taken in high school, number of graphics courses completed since high school, current graphic communications course, and the method used to solve the items on the test.

All data collected during the testing was written to a spreadsheet on a 3.5" floppy diskette.

Presentation of Data

Description of the Participants

Table 2 provides data on the participants in the study by gender, classification, major, and graphic communications course in which currently enrolled.

Table 3 describes the historical experience of the participants in graphics courses.

Students were randomly assigned to two treatment groups. Forty-one students were randomly assigned to the experimental group and forty students were randomly assigned to the control group (see *Table 4*).

Table 5 shows the mean ages of the participants in both the experimental and control groups.

Analysis of Scores

Table 6 examines the scores obtained on the PSVT for both the control and experimental groups.

Hypothesis #1 - 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

	Frequency	Percent
Number of High School Courses		
No High School Courses	48	59.3
1 High School Graphics Course	19	23.5
2 High School Graphics Courses	9	11.1
3 High School Graphics Courses	1	1.2
4 or more High School Graphics Courses	4	4.9
Number of Post-Secondary Graphics Courses		
No Courses Since High School	73	90.1
1 Course Since High School	5	6.2
2 Courses Since High School	2	2.5
3 Courses Since High School	0	0.0
4 or more Courses Since High School	1	1.2

Table 3 *- Previous graphics courses taken.*

Group	Frequency	Percent
Experimental	41	50.6
Control	40	49.4

Table 4 *- Treatment groups.*

	N	Mean	Std Dev	Minimum	Maximum
Experimental Group	41	19.93	3.76	17	41
Control Group	40	20.23	3.43	18	33
Total	81	20.07	3.58	17	41

Table 5 *- Mean age of the participants.*

	Control Group		*Experimental Group*	
Variable	**Mean**	**Std Dev**	**Mean**	**Std Dev**
score1 (PSVT-Part 1)	23.325	5.512	23.634	4.460
score2 (PSVT-Part 2)	24.725	4.679	25.732	3.755

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

mean score on Part 2 of the Purdue Spatial Visualization Test was significantly higher than the mean score on Part 1 for students in the experimental group (t=5.098, p=0.0001) at a=.05. The findings support Research Hypothesis #1.

Hypothesis #2 - In order to determine whether improvements in scores on the Purdue Spatial Visualization Test were due only to the addition of the coordinate axes, persons in the control group were given a version of the test which did not include the axes. It was hypothesized that there would be no difference in the mean scores for parts 1 and 2 for the control group. The mean score on Part 2 of the Purdue Spatial Visualization Test was significantly higher than the mean score on Part 1 for students in the control group (t=2.916, p=0.0059) at a=.05. The findings do not support Research Hypothesis #2.

Hypothesis #3 - Random sampling and random assignment to experimental and control groups was done in order to use statistical procedures that assume equal variation between the two treatment groups. In addition to these procedures, several analyses were completed to check equality between the control and experimental groups. It was hypothesized that there would be a significant difference between the mean score on Part 2 of the PSVT for the experimental group and the mean score on Part 2 of the PSVT for the control group. No significant difference was found between the mean scores (F=1.14, df=80, p=0.2882) at a=.05. The findings do not support Research Hypothesis #3.

Hypothesis #7 - Also of interest to the researcher and others in the technical graphics field are gender differences is spatial visualization ability. It was hypothesized that the mean score for males would be higher than the mean score for females on Part 1 of the PSVT. Research indicates that males tend to mentally transform objects holistically more than females. The PSVT favors persons who take a holistic approach to solving the test items. The mean score for males was significantly higher than the mean score for females (F=5.66, df=80, p=0.0198) at a=.05.

The findings support Research Hypothesis #7.

Hypothesis #8 - The researcher hypothesized that the addition of coordinate axes to items on the PSVT would help individuals who take an analytical approach to solving mental rotation tasks. Previous research indicates that females tend to use an analytical approach when solving problems of this nature. Therefore, the researcher hypothesized that there would be no difference in mean scores between males and females when the coordinate axes were present (Part 2 of the PSVT for the experimental group). No significant difference was found between males and females for Part 2 of the PSVT (F=2.21, df=40, p=0.1449) at a=.05. The findings support Research Hypothesis #8.

Analysis of Response Times

Table 7 examines the response times obtained on the PSVT for both the control and experimental groups.

Hypothesis #4 - Another method of measuring the influence of the addition of coordinate axes to the PSVT was to examine differences in response times. It was hypothesized that the addition of coordinate axes would improve students' response times for the test items. There was a significant difference between the mean response time on Part 1 and the mean response time on Part 2 for students in the experimental group (t=2.450, p=0.0187) at a=.05. The findings support Research Hypothesis #4.

Hypothesis #5 - To determine if response time differences were only due to the addition of the coordinate axes, differences in mean response times were examined between Part 1 and Part 2 for the control group. It was hypothesized that there would be no difference in the mean response times for parts 1 and 2 for the control group. The mean response time on Part 2 of the Purdue Spatial Visualization Test was significantly higher than the mean response time on Part 1 for students in the control group (t=6.129, p=0.0001) at a=.05. The findings do not support Research Hypothesis #5.

Hypothesis #6 - In addition to examining differences in mean scores between the experimental and control groups, differences in mean response times were analyzed. It was hypothesized that the mean response time on Part 2 of the PSVT for the experimental group would be significantly lower than the mean response time on Part 2 of the PSVT for the control group. The analysis yielded no significant difference between the mean response times, but the difference approached significance in the direction contrary to the research hypothesis. The mean response time for the control group was lower than the mean response time for the experimental group (F=3.07, df=80, p=0.0837) at a=.05. The findings do not support Research Hypothesis #6.

Hypothesis #9 - Research has indicated that holistic rotations require less time than analytical rotations (Kail, et al., 1979). It was

	Control Group		*Experimental Group*	
Variable	**Mean ***	**Std Dev ***	**Mean ***	**Std Dev ***
time1 (PSVT-Part 1)	1133.670	436.322	1098.860	426.793
time2 (PSVT-Part 2)	863.609	296.948	1003.120	409.431

** Means and standard deviations are in seconds.*

***Table 7** - Response times for PSVT-Part 1 and Part 2 by treatment group.*

hypothesized that response times for males would be significantly less than response times for females on both parts 1 and 2 of the PSVT. No significant differences were found between males and females for response times on either Part 1 or Part 2 of the PSVT (Part 1: F=1.08, df=80, p=0.3021; Part 2: F=0.60, df=80, p=0.4418) at a=.05. The findings do not support Research Hypothesis #9.

Additional Analyses - Several other questions were of interest to the researcher. First, since some of the results contradicted a number of the research hypotheses, repeated measures analysis of variance procedures were conducted to determine if treatment group interaction was present when examining both scores and response times. No treatment group interaction was present when mean scores were examined (F=1.22, df=79, p=0.2724) at a=.05. Significant treatment group interaction was present when mean response times were examined (F=8.78, df=79, p=0.0040) at a=.05. Although the mean response times for Part 2 of the PSVT decreased for both the experimental and control groups compared to the mean response times on Part 1, the mean response time for the control group decreased significantly more than the mean response time for the experimental group.

The presence of coordinate axes also appears to have influenced response times.

An additional analysis was conducted to look at gender differences on Part 2 of the PSVT. Although there was no significant mean score difference on Part 2 of the PSVT between males and females for the experimental group, there was significant difference between males and females on Part 2 when all participants were examined (F=5.34, df=80, p=0.0234) at a=.05.

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 Purdue Spatial Visualization Test - Visualization of Rotations 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). This significant increase supports Research Hypothesis #1. 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). This significant increase does not support Research Hypothesis #2. 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 may have provided the extra cues necessary to verify particular rotations 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). This significant decrease supports Research Hypothesis #4. 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). This significant decrease does not support Research Hypothesis #5. Analyses of response times indicated that 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 (Guay, 1980), males tend to score higher than females on the Purdue Spatial Visualization Test - Visualization of Rotations and on other tests of spatial visualization ability. This was verified when examining gender differences for scores on Part 1 of the PSVT. The mean score for males was significantly higher than the mean score for females. 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.

The purpose of examining response times was to examine the influence of the coordinate axes and to build an understanding for the approach students take to solving mental rotation tasks. Previous research suggests that individuals who use an analytical approach to solve mental rotation tasks take longer than students who use a holistic approach (Kail, et al., 1979; Hsi, et al., 1997; Lohman, 1984). The research also suggests that more females tend to use an analytical approach than a holistic approach. More males, however, tend to use a holistic approach than an analytical approach. Therefore, it was hypothesized that response times for females would be greater than response times for males. The analysis revealed no significant difference between the mean response times for females and the mean response times for males. One 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.

The addition of the coordinate axes appears to have eliminated biases based on method of rotation.

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.

The wait period between the two parts of the test was relatively short for two reasons. First, the researcher wanted to take a "snapshot" of students spatial visualization ability. Having an extended period of time between the two parts of the PSVT might have allowed other factors to influence scores and response times on Part 2 (specifically instruction occurring in the graphic communications courses). The second reason for having the shorter wait period was to limit the time burden on students. The researcher felt participation in the study would be higher if students were only required to commit to one 1.5 hour session rather than two 1 hour sessions.

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 or a different research design (Solomon 4-group design) might begin to reduce this factor.

2. A larger sample that includes more females should be examined to confirm 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 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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