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The effectiveness of real- and computer-generated models to advance the spatial abilities of visual/haptic engineering students

Miller, Craig Lester, Ph.D.
The Ohio State University, 1992
THE EFFECTIVENESS OF REAL- AND COMPUTER-GENERATED MODELS TO ADVANCE THE SPATIAL ABILITIES OF VISUAL/HAPTIC ENGINEERING STUDENTS

Dissertation

Presented in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in the Graduate School of The Ohio State State University

by

Craig Lester Miller, B.S., M.Ed.

* * * * *

The Ohio State University

1992

Dissertation Committee:    Approved by:
E. K. Blankenbaker
J. C. Belland
E. T. Boyer

Advisor
College of Education
To my wife, Sue, for her constant understanding and support throughout this endeavor and for her caring in all aspects of our life together
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VITA

March 2, 1960 .............................. Born - Troy, Ohio

1982 ................................. Bachelor of Science
Bowling Green State University
Bowling Green, Ohio

1982-1983 ......................... Graduate Teaching Assistant
School of Technology
Bowling Green State University
Bowling Green, Ohio

1984 ................................. Master's of Education
Bowling Green State University
Bowling Green, Ohio

1983-1984 ......................... Industrial Technology Teacher
Vandalia High School
Vandalia, Ohio

1984-1985 ......................... Adult Education Instructor
Upper Valley Joint Vocational School
Piqua, Ohio

1986-1989 ......................... Graduate Teaching Associate
Department of Engineering Graphics
The Ohio State University
Columbus, Ohio

1989-Present .................... Assistant Professor
Department of Technical Graphics
Purdue University
West Lafayette, Indiana

PUBLICATIONS


FIELDS OF STUDY

Major Field ..................... Education:
Industrial Technology
Dr. E. K. Blankenbaker

Minor Field ...................... Education:
Instructional Systems Design
Dr. J. C. Belland

Minor Field ...................... Engineering:
Engineering Graphics
Dr. E. T. Boyer
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CHAPTER 1
INTRODUCTION

The ability to spatially visualize solutions to problems is an important skill for individuals in many diverse professions. In a survey of professional engineers in educational and industrial settings, Jensen (1986) found that spatial abilities are the most important engineering graphics concept that an individual should possess to be successful in the engineering profession. Bertoline (1988) notes that spatial ability attributes are important for the seemingly unrelated areas of achievement in mathematics (Maccoby & Jacklin, 1974), chemistry (Talley, 1973), biology (Lord, 1985), and science (Small & Morton, 1985).

Even though spatial abilities are important for many fields, secondary schools and universities continue to emphasize a verbal approach to learning (Horton, 1982). Bertoline (1987) notes that students receive little or no formal instruction in the use and development of spatial abilities. Liben (1981) contends that background experiences, and McGee (1979) claims that sexual differences, may cause individuals initially to possess lower spatial abilities, but they note that spatial abilities can be developed and enhanced through formal education and informal experiences. If engineering education aims to prepare individuals for various engineering professions, instructional approaches should be developed to allow students to augment and advance their spatial abilities. Without an opportunity to develop and enhance their spatial abilities through educational experiences they may abandon their quests to become engineers or fail to achieve their potential as practicing engineers.

Sheahan & White (1990) contend students who fail to become engineers could present several problems to the stability of the engineering profession. First, fewer students are available to become engineers and many are not choosing the engineering field.
Compounded by current retirement rates, a shortage of qualified engineers could result. Second, the percentage of females in engineering programs has begun to drop after a ten-year period of growth. Because women are underrepresented in the engineering profession, engineering education programs should take steps to reverse this trend (Baum, 1989). Third, minorities also are underrepresented in the engineering profession. Friedman & Kay (1990) argue that engineering educators should take steps to retain minority students and that current engineering curriculum should be reviewed. Finally, students who never become engineers might have possessed unique talents and brought new insights to the solution of existing engineering problems.

The formal engineering educational setting that focuses on the development and enhancement of spatial abilities is engineering graphics. Research studies and reports (Miller & Bertoline, 1989; Bertoline & Miller, 1989; Bowers, Raudebaugh, & Beakley, 1987; Kelso, 1987; Simoneau, Fortin & Ferguson, 1987; and Anand, 1987) note the importance of spatial abilities in engineering graphics. Industry spokespersons and engineering educators have indicated for years that spatial ability is the single most important graphic skill needed by engineers (Bowers, Raudebaugh, & Beakley, 1987) and technologists (Bertoline, 1987). Simoneau, Fortin & Ferguson (1987) claim that there are two main goals for engineering graphics:

1. To teach the technical graphics language
2. To develop students' ability to visualize and solve problems in three dimensions (p. 5)

Because of the continuing importance of spatial abilities, most engineering and technical educational programs have included engineering graphics as a basic component of their curricula (Bertoline, 1987). Presenting abstract conceptual ideas graphically through the use of sketches, mechanical drawings, and CADD data bases is a fundamental tool used by engineers and technologists (Simoneau, Fortin, and Ferguson, 1987).
Although the development and advancement of spatial abilities is a very important objective in the foundation and development of many different disciplines, including engineering graphics, curriculum typically does not address student learning style differences. In an extensive review of engineering graphics education literature Miller (1990) shows that student learning style differences typically are not considered in planning spatial instruction in engineering graphics and that research in learning styles is limited. Oversight of the impact of learning styles in engineering graphics curriculum may have caused, and may continue to cause, students to have problems developing and advancing their spatial abilities.

Languis (1983) defined learning style as:

the consistent pattern of behavior and performance by which an individual approaches educational experiences. It is the composite of characteristic cognitive, affective, and physiological behaviors that serve as relatively stable indicators of how a learner perceives, interacts with, and responds to the learning environment. It is formed in the deep structure of neural organization and personality which molds and is molded by human development, and the cultural experiences of home, school, and society (p. 8).

Learning style differences can influence performance on spatial tasks allowing some individuals to excel while others fail. Piaget and Inhelder (1967) suggest that spatial cognition is a learned trait that develops in various sequential stages. Liben (1981) suggests that different factors influence the development of spatial cognition. McGee (1979) contends that there is empirical evidence for sex differences in spatial cognition. Research also indicates that various learning styles must be considered as significant factors when developing and planning curricula involving the development and advancement of spatial cognition (Ausburn and Ausburn, 1978). Thus, individual learning style differences can affect the development of an individual's spatial cognition and should be of central interest in any engineering graphics curriculum.

The information indicates that spatial ability is of central importance to many professions, including engineering, and that individuals possess learning style differences.
Because engineering graphics is the formal educational setting for the development and enhancement of spatial abilities, instructional systems should be developed that are specifically tailored to the student's learning style. Any instructional system, including media, should have a formal research base and be tested thoroughly before being implemented into widespread instructional use.

Salomon (1970, p. 40) distinguishes between research on instructional media and research with media. He contends that research with instructional media is involved with "... the unique cognitive functions that unique modes of presentation can accomplish." Research with media, Salomon contends, does not inform the researcher about the functions of the media with respect to the special characteristics of the learner. Salomon (1970, p. 41) defines research on media as "... an inquiry into the relations between unique psychological functions under specific task requirements and specific learners." Thus research in instructional methods and media consists of three major components: It must consider the method used to convey the information, the psychological requirements of the task to be undertaken, and the individual characteristics of the learners (Salomon, 1970).

Individual characteristics of the learners could be interpreted as learning styles. The engineering graphics educator must investigate how different forms of instructional methods and media affect various learning styles. The literature in learning styles is so broad that the engineering graphics educator must focus on delineated topics to complete research studies successfully.

Manfredo (1987) notes that cognitive style and learning style terms are often interchanged. Keefe (1979) contends that learning style is a more global term than cognitive and that cognitive, affective, and physiological styles fall within learning styles.

Viktor Lowenfeld (1945) identified two different perceptual types of learners: the visual and the haptic. A perceptual type, mode, or aptitude is how an individual perceives or reacts to experiences. Perceptual mode has been classified as a subset of learning style, but various researchers contend that it is related to different areas of learning style.
Ausburn (1979) contends that perceptual mode is related to cognitive style while Dunn, Dunn, & Price (1979) suggest that perceptual mode is related to physiological style. Manfredo (1987) claims that there is no clear evidence as to which style relates to perceptual mode and advocates that it be separated from either cognitive or physiological style.

Lowenfeld developed visual/haptic learning style theory after extensive research in art education in Europe and the United States. Lowenfeld (1939) distinguishes between two distinct types of individuals and how they perceive and react to the world of experiences or how they perceive and organize their external environment. He identified two learning style types, the visual and the haptic.

Lowenfeld contended that these two learning styles fall on opposite ends of a continuum of how individuals perceive the external world. The visual type, Lowenfeld (1945, p. 101) states, “...has the ability to see first the whole without the awareness of details, then to analyze it into detailed or partial impressions and to build these parts up again into a new synthesis of the whole.” The visual type relies almost entirely on visual imagery as a means of perception and would be lost without it. The visual type is a perceptual observer or spectator who normally approaches objects from their visual appearance, uses the eyes to discover the surrounding environment, and transforms kinesthetic and tactile experiences into visual ones (Lowenfeld and Brittain, 1987).

An extreme haptic individual does not have the tendency visually to see a whole object, break it up into component parts, and reassemble it into a whole. Lowenfeld (1945) contends a haptic individual “... uses his eyes only when he is compelled to do so; otherwise he reacts as would a blind person who is entirely dependent upon touch and kinesthesia.” (p.101) Haptic individuals usually do not transform kinesthetic and tactile experiences into visual imagery but rely upon touch or the kinesthetic mode of perception (Lowenfeld & Brittain, 1987).
Lowenfeld (1945) developed a battery of five tests that were used to identify the visual/haptic learning style of an individual. After using these tests on a sample of 1,128 subjects, Lowenfeld reported that 47 percent of the subjects were clearly visual, 23 percent were haptic, and the remaining 30 percent were not identifiable. A study of Ausburn in 1979 replicated these results. Ragan (1979) notes that these tests are based on several theoretical distinctions:

1. Whereas the visual has the ability to see a whole, break it up and see its component details, and then resynthesize the details back into a whole, the haptic is unable to do this.
2. Whereas the visual tends to react to stimuli as a spectator and to "see" experiences, the haptic tends to react emotionally, to "feel" stimuli, and to place one's self into the situation.
3. Whereas the visual has the tendency and ability to visualize and integrate tactile and visually to complete partial experiences, the haptic has neither this tendency nor ability.
4. Whereas the visual has the ability to maintain visual imagery mentally, the haptic is unable to do this. (p. 21)

These four theoretical distinctions of Lowenfeld's visual/haptic learning style should be considered in the planning and development of instruction and media in engineering graphics education. Not all instructional approaches may be appropriate for the haptic or visual learning style of an individual. Except for the use of real-models, most traditional engineering graphics instruction has been suitable for only visual learning style type individuals because it is based on visual imagery. Since approximately 25 percent of the population may be haptic learning style type learners, these individuals are at a distinct disadvantage when asked to use their spatial abilities in traditional engineering graphics curricular experiences. If individuals are haptic, a significant number of engineering
students may lose engineering career opportunities because traditional curricular approaches did not match their learning style.

The engineering graphics educator must question how instructional materials or media can be developed to allow haptic learning style types to develop or advance their spatial abilities. Salomon (1970) advocates the use of instructional approaches and media that execute the mental processes for learners when they are unable to do so themselves. He terms this process supplantation and defines it as “the function accomplished by an explicit presentation of what would otherwise have to be done covertly by the learner himself, such that certain learning objectives will be obtained.” (Salomon, 1970, p. 41) The practical utilization of the supplantation theory could be the bridge that allows haptic learning style type individuals to develop and enhance their spatial abilities. These supplantation techniques might not be needed by the visual learning style type of individual. Because visual individuals already possess advanced spatial abilities, development and utilization of nontraditional instructional approaches for these individuals could waste time and resources.

Traditionally, engineering graphics educators have debated the use of real-models for instructional use. One group who advocates real-models claims that their use allows students to grasp the concepts of three-dimensional thinking through orthographic projection (Vanderwall, 1981; Young, 1952; Rowe, 1938, 1945). Other educators claim that the use of models is nothing more than a crutch (French, 1913; Orth, 1941).

More recently, research by Zavotka (1985), Anand, et al. (1987), and Bertoline and Miller (1989) has used computer-generated wireframe and surface models to allow students to improve their spatial abilities. If students are haptic in nature, then the use of real- or computer-generated models may supplant the transformation from the real object to the three-dimensional representation of the object onto a two-dimensional plane through use of orthographic projection theory. This supplantation technique may allow haptic learners to develop and advance their spatial abilities. The use of computer-generated models may not
be needed by visual learners, thus utilizing expensive computer hardware and software on visual learners may not enhance their spatial abilities.

Haptics individual who do not have the ability visually to see the whole object, then break it up into its component parts and reassemble it into a whole, should be more able to do so with the use of a real-model of the abstract line drawing. They will be able to see and touch the component parts of the object and relate these parts to individual lines and surfaces of the two-dimensional line drawing.

Because of their reliance upon tactile and kinesthetic experiences, haptic individuals should through the use of real-models be able to supplant tactile and kinesthetic experiences into visual experiences if real-models are used in the learning environment. Because haptic individuals favor and utilize kinesthetic experiences and do not have the tendency to integrate tactile or complete partial visual experiences into visual imagery, the real-model might provide the supplantation required that allows this process to occur.

Finally, because the haptic individual cannot maintain visual imagery, the real-model experience should allow the visual imagery to remain with the learner. For haptic learners, use of real-models should supplant the need to retain the visual imagery when they are working with the purely visual media of line drawings.

Many of the same qualities of supplantation provided by real-models may be provided also through the use of computer-generated models. The exception would be the kinesthetic and tactile interaction provided by the real-model. The learner cannot hold or touch the computer-generated model but can control it through physical interaction with the computer. Although the kinesthetic and tactile experiences will not be the same as real-models, the use of computer-generated models may help haptic learners in many of the same ways as do real-models. Languis (1983) notes that haptic learners benefit from computer-assisted instruction more than other individuals with different learning styles because of the step-by-step presentation and learner control of the presentation of the material.
Haptic individuals who do not have the ability visually to see the whole object, break it up into its component parts, and reassemble it into a whole, should be more able to do so with the use of computer-generated models of the abstract line drawing. By physically controlling the rotation of the computer-generated model, they can see the various component parts from different vantage points in much the same way that a real-model can be manipulated to show the component parts in various orientations.

Computer-generated models, like real-models, should provide the necessary supplantation to the haptic individual who cannot maintain visual images. This should occur because the computer-generated model will provide or supplant for the haptic learner the visual image of the object in question. If haptic learners cannot visualize the object as it would appear from a different vantage point, they will be able to rotate, in the same manner as the real-model, the computer-generated model, and have a visual image of the different orientation of the model. Thus, the computer-generated model should supplant the need to retain the mental images for the haptic learner when working with the purely visual media of line drawings.

Languis (1983) and Anand, et al. (1987) note that computer technology is advancing rapidly in its ability to give educators a wealth of potential tools for providing many different experiences. Although the needs of noneducation fields largely motivate technological developments, apparent promises for improving education are manifold (Languis, 1983). The advent of the computer and development of powerful computer graphics software have changed also the methods and presentation structure of the engineering graphics curriculum. Development of computer graphics technology has presented unique opportunities to the engineering graphics education profession to present abstract concepts in ways that were impossible only a few years ago. Because of the abstract nature of spatial concepts, engineering graphics educators should consider the use of computer technology in the development of spatial abilities. Utilization of the computer in educational settings must be controlled by existing literature in learning, learning styles,
and instruction. The use of computer technology has entered into the engineering graphics curriculum with limited identifiable research efforts in learning styles; thus, many students’ learning styles will not match instruction as it is presented.

Statement of the Problem

Will the use of nontraditional (computer-generated and real- models) instructional approaches develop and advance the spatial abilities of engineering students who possess different learning styles (visual/haptic)?

Significance of the Study

The preceding information makes clear that students must be able to develop spatial abilities to become successful in various professions. The engineering graphics profession should develop a research base in spatial abilities and learning styles. At present, limited amounts of educational research in spatial abilities and learning styles have been conducted by engineering graphics educators (Miller, 1990). The engineering graphics profession should undertake research in learning styles to determine what instructional methods are successful for specific learning styles. Thus, through a series of research studies, it could be determined if certain learning styles interact with various instructional methods to develop and enhance spatial abilities of engineering students.

Knowledge gained specifically from this study could be useful to determine how best to advance the spatial abilities of engineering students based on their visual and haptic learning style variables. The results of this study should show also how the application of real- and computer-generated models, combined with traditional technical graphics instructional methods, may be effective in the development of spatial abilities of visual and haptic learning style individuals.

This experimental engineering graphics curriculum approach, which may never have been possible with traditional methods, could start the foundation of engineering graphics research in spatial abilities and learning styles. Findings from this research could justify
nontraditional instructional approaches that may allow individuals with unique learning styles the opportunity to develop and advance their spatial abilities. Bertoline (1987, p. 3) states, “Improved visual-spatial skills can be used to enhance analytic skills, leading to greater creativity, flexibility, and intuitive thinking among engineering students. Possible long-range benefits for society include a better understanding of the engineering design process and increased innovation and productivity in engineering and technology.”

Also, because of shrinking budgets and growing instructional costs, this study could be used to determine the instructional efficiency of real- and computer-generated models for visual and haptic students. If it is determined that either of these instructional approaches is not beneficial for visual or haptic students, then this instructional approach would not be used in the future. The reverse could be true. If one instructional method is very beneficial for either the visual or haptic student, then more developmental time, money, and effort would be focused on the specific instructional method.

Finally, the results of this study could be used to increase the retention rates of engineering students. Retention will be vital because fewer are available to become engineers and many are not choosing the engineering field. Because minority students are underrepresented, engineering education programs should take steps to recruit and retain these students. Students not retained in engineering education programs will be a lost resource that could affect the future stability of the engineering profession.

**Purposes of the Study**

The purposes of this study were to determine:

1. The effectiveness of computer-generated models compared to traditional methods to develop students’ spatial abilities.

2. The effectiveness of real-models compared to traditional methods to develop students’ spatial abilities.
3. The effectiveness of computer-generated models compared to real-models to develop students' spatial abilities.
4. The extent the measurement of visual/haptic learning style related to the measure of spatial abilities.
5. If Victor Lowenfeld's claim that 47 percent of the population are visuals, 23 percent are haptics, and the remaining 30 percent are indefinites holds true for the population used in this study.
6. If the Successive Perception Test I (Gibson, 1947) is a valid and reliable instrument to determine visual/haptic learning style type for the population used in this study.
7. If there is an interaction between learning style (visual/haptic) and treatment (control, real-model, or computer-generated model).

Objectives of the Study

The objectives of the study were:
1. To develop a means to advance spatial abilities of engineering students based on their learning styles.
2. To develop, implement, and evaluate a spatial abilities-centered experimental engineering graphics curriculum based on the learning style variables of visual and haptic.
3. To develop computer-generated models that can be integrated into the curriculum for use by students.
4. To develop real-models (wooden) that can be integrated into the curriculum for use by students.
5. To develop a strong interdisciplinary research base in the areas of spatial abilities and learning styles.
Research Hypotheses of the Study

The research hypotheses for this study were:

1. Lowenfeld’s claim that 47 percent of the population are visuals, 23 percent are haptics, and the remaining 30 percent are indefinites will hold true for the population drawn for use in this study.

2. The experimental instructional methods and media (traditional supplemented by real-models, and traditional supplemented by computer-generated models) will allow students with different learning styles (visual/haptic) a greater chance of advancing their spatial abilities than would have occurred with the traditional engineering graphics instructional methods or media.

3. The measurement of visual/haptic learning style will not correlate with the measure of spatial ability.

4. The instructional methods and media will not change an individual’s visual/haptic learning style type as measured by the Successive Perception Test I.

Hypotheses

The statistical hypotheses utilized for this study are listed below in the null form:

HO1: The proportion of visual/haptic learning style types in the population for this study will not differ significantly from the 47 percent visuals, 23 percent haptics, and 30 percent indefinites found in the research of Lowenfeld.

HO2: There will be no significant interaction between visual/haptic learning style and instructional treatment of the group mean scores on the Mental Rotations Test.

HO3: There is no significant difference between group mean scores on the Mental Rotations Test between subjects classified as being visual or haptic learning style types.

HO4: There is no significant difference between group mean scores on the Mental Rotations Test between subjects who used traditional exercises and students who used real-model exercises.
H05: There is no significant difference between group mean scores on the Mental Rotations Test between subjects who used traditional exercises and students who used computer-generated model exercises.

H06: There is no significant difference between group mean scores on the Mental Rotations Test between subjects who used computer-generated model exercises and students who used real-model exercises.

H07: There is no significant difference between group mean scores on the Mental Rotations Test for visual subjects using traditional exercises and visual subjects using real-model exercises.

H08: There is no significant difference between group mean scores on the Mental Rotations Test for visual subjects using traditional exercises and visual subjects using computer-generated model exercises.

H09: There is no significant difference between group mean scores on the Mental Rotations Test for visual subjects using computer-generated model exercises and visual subjects using real-model exercises.

H010: There is no significant difference between group mean scores on the Mental Rotations Test for visual subjects by treatment.

H011: There is no significant difference between group mean scores on the Mental Rotations Test for haptic subjects using traditional exercises and haptic subjects using real-model exercises.

H012: There is no significant difference between group mean scores on the Mental Rotations Test for haptic subjects using traditional exercises and haptic subjects using computer-generated model exercises.

H013: There is no significant difference between group mean scores on the Mental Rotations Test for haptic subjects using computer-generated model exercises and haptic subjects using real-model exercises.
HO14: There is no significant difference between group mean scores on the *Mental Rotations Test* for haptic subjects by treatment.

HO15: There is no significant difference between group mean scores on the *Mental Rotations Test* for haptic subjects using traditional exercises and visual subjects using traditional exercises.

HO16: There is no significant difference between group mean scores on the *Mental Rotations Test* for haptic subjects using real-model exercises and visual subjects using real-model exercises.

HO17: There is no significant difference between group mean scores on the *Mental Rotations Test* for haptic subjects using computer-generated model exercises and visual subjects using computer-generated model exercises.

HO18: There is no significant correlation between the *Successive Perception Test I* posttest results and the posttest results of the *Mental Rotations Test*.

**Assumptions**

The following assumptions were inherent in pursuit of this study:

1. Students in the sample will accurately and honestly cooperate with implementation of this investigation.

2. Students in the sample will, to the best of their abilities, complete the *Successive Perception Test I* and the *Mental Rotations Test*.

3. Students enrolled in Technical Graphics 108 at the West Lafayette, Indiana, campus of Purdue University are a representative sample of beginning engineering students in the United States.

4. Students enrolled in Technical Graphics 108 at the West Lafayette, Indiana, campus of Purdue University will have a similar distribution as Lowenfeld’s prediction of 47 percent of the population as visuals, 30 percent as indefinites, and 23 percent as haptics.
Limitations

The following limitations were inherent in pursuit of this study:

1. The numbers of sections offered by the Department of Technical Graphics during Fall Semester 1990.
2. The amount of cooperation that the students provide during the course of the study.
3. The *Mental Rotations Test* accurately measured students spatial ability (Vandenberg & Kruse, 1978).
4. Lowenfeld's *Successive Perception Test I* accurately measured students' visual/haptic learning style (Lowenfeld, 1945).
5. The summative evaluation instrument accurately accessed the students' feelings toward involvement and usefulness of the instructional material in the study.
6. The validity, power, and cost of the computer-graphics software that was available during the execution of the study.

Delimitations

This study was delimited to:

1. The IBM computer hardware in the Department of Technical Graphics at the West Lafayette, Indiana, campus of Purdue University.
2. The *SilverScreen* software package.
3. The first five weeks of instructional material in Technical Graphics 108 at the West Lafayette, Indiana, campus of Purdue University.
4. The instructional treatment of traditional, traditional instructional treatment supplemented with real-models, and traditional instructional treatment supplemented with computer-generated models.
5. Two levels of visual/haptic learning style within each instructional treatment group.
Definitions of Terms

The following terms are defined to assist the reader:

**Computer-aided design drafting (CADD)** - the computer-aided process of solving design problems in all areas of engineering (Earle, 1983).

**Computer-assisted instruction** - computer applications applied to traditional teaching methods such as drill, tutorial, demonstration, simulation, and instructional games (Corbin et al., 1982).

**Computer graphics** - the application of computer technology to graphical applications (Earle, 1983)

**Cognitive learning styles** - information-processing habits that represent the learner's typical nature of perceiving, thinking, remembering, and problem solving (Hinton, 1980).

**Engineering graphics** - the total field of problem solving, including two major areas of specialization, descriptive geometry and working drawings (Earle, 1983).

**Haptic learning style** - a normal-sighted person who prefers to orient him/herself to the world of experience through touch, bodily feelings, muscular sensations, and kinesthetic fusions (Lowenfield, 1945).

**Learning styles** - the consistent pattern of behavior and performance by which an individual approaches educational experiences. It is the composite of characteristic cognitive, affective, and physiological behaviors that serve as relatively stable indicators of how a learner perceives, interacts with, and responds to the learning environment. It is formed in the deep structure of neural organization and personality, which molds and is molded by human development, and the cultural experiences of home, school, and society (Languis, 1983).

**Orthographic projection** - the projection system that engineers use for manufacturing and construction drawings (Luzadder & Duff, 1989).

**Perceptual type** - sometimes referred to as perceptual mode or aptitude, it is how an individual perceives or reacts to everyday experiences (Lowenfeld, 1945).
Real-model - a physical object that replicates a line drawing or scaled version of an actual object. In this study, real-models were constructed from wood and replicated line drawings.

Spatial ability - individual differences used in the processing of non-linguistic information or individual differences in performance on spatial tests (Elliot & Smith, 1983).

Spatial cognition - the spatial features, properties, categories, and relations in terms of which we perceive, store and remember objects, persons, events, and on the basis of which we construct explicit, lexical, geometric, cartographic, and artistic representations (Olson & Bialystok, 1983).

Spatial visualization - the mental ability to manipulate, rotate, twist, or invert pictorially presented visual stimuli (McGee, 1979).

Supplantation - the function accomplished by an explicit presentation of what would otherwise have to be done covertly by learners themselves, such that a certain learning objective will be obtained (Salomon, 1970).

Surface model - an interactive computer-generated model that produces realistic two-dimensional color surface shaded renderings of three-dimensional models (Mortenson, 1985).

Visual learning style - a normal-sighted person who depends upon his/her eyes as a primary intermediary in perception (Lowenfield, 1945).

Wireframe model - a computer-generated interactive model composed of lines and curves defining the edges of an object (Mortenson, 1985).

Summary

Chapter 1 presents an overview of the research problem, which was to determine the effectiveness of real- and computer-generated models to develop and enhance the spatial abilities of visual/haptic learning style engineering students. The purposes of the study were to determine: (1) the effectiveness of computer-generated models to develop students’
spatial abilities when compared to using traditional methods, (2) the effectiveness of using real-models to develop students' spatial abilities when compared to using traditional methods, (3) the effectiveness of using computer-generated models to develop students' spatial abilities when compared to using real-models, (4) to what extent the measurement of visual/haptic learning style was related to the measurement of spatial abilities, (5) if Viktor Lowenfeld's claim that 47 percent of the population are visuals, 23 percent are haptics, and the remaining 30 percent are indefinites was true for the population in this study, (6) if the *Successive Perception Test I* (Gibson, 1947) was a valid and reliable instrument in determining visual/haptic learning style for the population in this study, and (7) if there was an interaction between learning style (visual/haptic) and treatment (control, real-model, or computer-generated model). Also included were the objectives, research hypotheses, hypotheses, assumptions, limitations, delimitations, and definitions of terms.

Chapter 2 provides a review of literature, which includes a historical review of engineering graphics, a historical review of spatial research, various spatial theories, spatial abilities, spatial tests, developmental theories of spatial cognition, sources of variance in spatial cognition, learning styles, visual/haptic learning style theory, and supplantation theory.

Chapter 3 describes the procedures used to execute the study including the sample selected for the study, the instruments, and instructional setting. Also described is the methodology used to perform the study including selection of software and exercises, development of instructional materials, training of laboratory instructors, development and administration of the consent for participation form, human subjects' approval, administration of the pretest, selection of the sample, and administration of the treatment. The research design and data analysis also are described in the third chapter.

Chapter 4 presents the analysis of data for the study. The null hypotheses that were tested and the results of the hypotheses are presented. These analyses are presented in three major parts: (1) the Cronbach Alpha Reliability statistic to establish the reliability of
the *Successive Perception Test I* for this study, (2) the Pearson Correlation Coefficient to determine the correlation between the posttest administration of the *Successive Perception Test I* and the *Mental Rotation Test*, and (3) the comparison of posttest scores to determine statistical significance.

Chapter 5 presents a discussion of the findings along with conclusions derived from the results. Recommendations for future studies also are presented.
CHAPTER II
REVIEW OF RELATED LITERATURE

The literature reviewed here was deemed important to provide the background for the present investigation. This review is grouped into four major sections. The first a brief history of engineering graphics and the examination of a model for the body of knowledge of engineering graphics. The second deals with spatial research and includes a history of spatial research, several spatial theories, spatial abilities, spatial tests, developmental theories of spatial cognition, and various sources of variance in spatial cognition. The third contains research on learning styles including the theory of visual/haptic perception. The fourth presents the theory of supplantation and how it relates to instruction.

Engineering Graphics

Before research can be undertaken in a particular subject, the body of knowledge of the curricular area must be stated and understood, but until very recently a defined body of knowledge in engineering graphics did not exist.

Graphic representation has evolved since ancient times to form what is known today as engineering graphics. Higbee (1946) outlines the development of four periods of graphic representation. The first period, which spans ancient times through 1750, reveals the use of various means of presenting graphic information was appreciated and important.

The second period from 1750 to 1850, was a more important time when Gaspard Monge discovered and advocated the science of orthographic projection and descriptive geometry principles. This period also saw the establishment of engineering education, which included the teaching of the graphic language and its principles (Higbee, 1946).
The third period of graphic representation, 1850 to 1900, was significant because it established drafting as an integral part of the Industrial Revolution. Drafting was central to the art of representation of the tools and machines that powered the beginning of the Industrial Revolution (Higbee, 1946).

The fourth period of graphic representation Higbee, (1946) contends, began in 1900. It witnessed standardization of graphic practices, inclusion of computer technology, a well-defined literature base, and various teaching methods. The only item missing has been a body of knowledge of engineering graphics.

Bertoline, Bowers, McGrath, & Pleck (1990) have developed a knowledge-based engineering graphics curriculum model. They place engineering graphics as a subset of the graphic science curriculum model under the technical application of graphic science (see Figure 1). Graphic science is defined as “the knowledge and study of the theory and technique, psychomotor and cognitive foundations, and applications for all types of drawings” (p. 1). They contend that as the foundation for all kinds of drawings, graphic science the subject matter basis for all related curricula (Bertoline, et al., 1990).

Viewing the model (see Figure 1), the circle surrounding the curriculum model represents graphic science because all the enclosed elements are important topics in this knowledge-based curricula. The three axes within the model correspond to the subject matter, foundations, and applications of graphic science. The first axis is the subject matter areas of graphic science including tools, techniques and theory, and standards.

The second axis is the foundation, which is concerned with the psychomotor, visualization, and evaluation requirements needed for successful application of graphic science knowledge. The third axis contains two major categories: artistic and technical. Artistic drawings or applications would be concerned with the arrangement and production of various elements, colors, and forms that affect the sense of beauty. Technical applications or drawings would be concerned with the creation of drawings that allow for the documentation of ideas and their clarification (Bertoline, et al., 1990).
Figure 1. Graphic science curriculum model.

Figure 2 refers to the Technical Drawing Curricular Model. The application axis is singular in this model with the art application dropped. In this model the application of technical drawings is for ideation, clarification, and documentation. Ideation drawings are used to explore and generate new ideas and to communicate these ideas with oneself. These drawings frequently are very informal sketches and assist the designer to remember and refine initial ideas (Bertoline, et al., 1990).

Clarification drawings are further developed ideation drawings that are used to communicate refined ideas to other persons. The clarification drawings may allow the designer to develop a single refined idea from a combination of ideation sketches. Clarification drawings can range from simple sketches to sophisticated finite element models (Bertoline, et al., 1990).
Figure 2. Technical drawing curriculum model.

Documentation drawings are the most formal of all drawings. They are used for recording and communicating engineering designs through accepted standards. These drawings allow for communication between human beings or between machines through data bases (Bertoline, et al., 1990).

The Graphic Science Curriculum Model has been identified because it is the only known engineering graphics curriculum model that is knowledge based. It identifies subject matter, foundations, and applications of the body of knowledge of engineering graphics; thus, it provides course developers and researchers with a rationale of what should be taught in engineering graphics and how it should be taught. Because this model identifies visualization as one of the foundations of the engineering graphics curriculum, research in visualization should be one of the central activities of engineering graphics educators. Research in visualization is large and broad in scope; thus, the engineering graphics educator must have a thorough understanding of this topic. The next section of the literature will focus on the area of visualization which is a subset of spatial abilities and spatial cognition.
**Spatial Research**

Wiley (1989) claims that many goals of visual disciplines, including engineering and technical graphics, are weak and do not produce meaningful amounts of effective research. He advocates the development of visual perception as the major focus of the curriculum of engineering and technical graphics. With this thought in mind, if engineering graphics educators expect the engineering and technical design graphics curriculum to become accepted as a recognized discipline by other established disciplines, one important area of research and curriculum efforts should be in the study of spatial abilities. Research in spatial cognition and development of spatial abilities have been shown repeatedly to be a vital component of success in a wide range of engineering, technical, mathematical, and scientific professions.

Engineering graphics educators are in a unique position to become leaders in spatial research and thus become accepted as a curriculum equal to others in psychology, chemistry, and various specializations within engineering because of the expertise they possess in visual communication and the development of spatial abilities. Although engineering graphics educators have been experts in spatial abilities for years, meaningful amounts of effective research have not been developed, investigated, or published by the engineering graphics profession. Now, however, increased interest in visual research in many disciplines, coupled with recent advancements in computer technology, has provided engineering graphics educators the opportunity to conduct more research in spatial abilities and become the leaders in this area. This opportunity should give engineering graphics educators the chance to justify their claim that engineering and technical graphics are worthy of being called a discipline. Which other disciplines have conducted research in spatial abilities? What results have they found? What have they concluded from these results? What do they recommend for further study? Without knowledge of prior research, theories, and other related information on spatial abilities, the engineering graphics profession would essentially be “reinventing the wheel” to research this area.
further. Engineering graphics educators must investigate all prior research that has been conducted in spatial abilities as well as closely related study areas. The intent of the next section of literature is to give an overview of prior research that has been conducted in spatial abilities and closely related topics. This overview will introduce theories, terms, concepts, and prior research conducted in spatial abilities.

The History of Spatial Research

Research in spatial abilities has been conducted by many different disciplines, including psychology, art education, mathematics, science, and engineering graphics. The majority of this prior research has been undertaken by psychologists investigating spatial testing. Eliot and Smith (1983) identified three major phases in the development of spatial testing, which in turn led to various theories and research investigations in spatial abilities.

The first phase (1901-1938) was an effort by psychologists to establish and identify the presence of a spatial factor. Historically, because of Greek influences, intelligence was viewed erroneously as the sole ability to perform verbal tasks. Visual tasks were not considered a measure of intelligence. Evidence of this bias could be found in such tests as the Binet-Simon Scales of Intelligence and United States Army military personnel evaluations.

The intent of the United States Army test was to measure a person's verbal and nonverbal abilities. The test was divided into two sections: the Alpha test, which measured verbal ability, and the Beta test, which measured a variety of performance tasks. The Beta test was significant as the first non-verbal test battery administered to a very large sample of subjects. If a person scored well on the Alpha test, he was considered educated or verbally literate, while a person who scored well on the Beta test, was considered uneducated or verbally illiterate. Thus, the Alpha and similar tests were a biased means of measuring intelligence based on verbal abilities.
Many psychologists did not agree with the theory that intelligence was limited to the verbal realm. Research studies and testing conducted by El Koussy (1935), Kelly (1928), and Thurstone (1938), among others, established the identification of the spatial factor as a very important aspect of human intelligence (Eliot and Smith, 1983).

The second phase (1938-1961) of research in spatial testing and intelligence noted by Eliot and Smith (1983) tried to identify different spatial factors and how they varied from each other. During this stage, large-scale research studies were conducted on spatial testing and spatial intelligence, resulting in a large number of paper-and-pencil spatial tests. Various researchers advocated several terms, such as spatial relations, visualization, spatial orientation, and imagery, which could be grouped into two major categories: 1. the ability to recognize spatial configurations, and 2. the mental ability to manipulate spatial configurations (Eliot and Smith, 1983). Although researchers did not agree on how many spatial factors existed or what they should be labeled, they concurred, that at least two spatial factors did exist and that paper-and-pencil spatial tests could be used to measure a person’s spatial ability.

The third historical stage (1961-1982) of research and testing of spatial factors and spatial intelligence identified by Eliot and Smith (1983) centered on studies determining the interrelation of spatial abilities with other abilities and the discovery of different sources of variance in testing of spatial abilities. Studies were conducted to determine if spatial abilities were related to a person’s sex, age, environmental upbringing, and hereditary influences. The studies conducted during this stage showed different areas of variance did indeed affect a person’s spatial ability.

Various Spatial Theories

Liben (1981) notes that to understand, theorize, and conduct spatial research, one must first have a definition of space. Space can be identified as being either absolute or relative. Absolute space is a framework that exists independent of anything within it. Conversely,
relative space is a set of relationships among objects and is changed by altering the position of the objects or the point of an observer within it. She also notes that space is defined typically by the Euclidian three-dimensional model. Liben contends that the study of space should be approached as relative and three-dimensional in nature. This position, which is maintained usually by the engineering graphics discipline, will be used throughout this paper.

Liben (1981) also states three radically different epistemological positions regarding the biological developmental theories of space. The first is the empiricists' position in which psychological space is derived directly from experiences with physical space. Sharply contrasting with this view is the nativists' position in which psychological space is determined by inheritance. The third is the constructivists' position in which psychological space is developed in an individual by a combination of inheritance and environmental factors.

Although researchers disagree on the epistemological positions regarding biological developmental theories of space, most of this conflicting research has been conducted solely in spatial cognition. Most of this research has been conducted by developmental psychologists who define spatial cognition as:

[I]Inner space or spatial cognition, the spatial features, properties, categories and relations in terms of which we perceive, store and remember objects, persons, events, and on the basis of which we construct explicit, lexical, geometric, cartographic, and artistic representations (Olson & Bialystok, 1983, p. 2)

and

... the knowledge and internal or cognitive representation of the structure, entities, and relations of space; in other words, the internalized reflection and reconstruction of space in thought (Hart & Moore, 1973, p. 248).

It is appropriate to differentiate between terms that are sometimes associated with, or used in place of, spatial cognition. Hart and Moore (1973) contend that an important distinction should be made between spatial cognition and spatial perception. They maintain that spatial cognition is the overall function of spatial representation and includes the
following subsystems: spatial perception, spatial thinking, spatial imagination, spatial reasoning, spatial judging, and spatial memory. They consider spatial perception as both a function and subsystem of spatial cognition. Therefore, spatial perception is used to observe spatial phenomena, but once spatial phenomena has been perceived, spatial thinking, spatial imagination, spatial reasoning, spatial judging, and spatial memory work together to allow spatial cognition to occur. Thus, spatial perception is a distinct subsystem and an interchanging process of spatial cognition.

Theories of Jean Piaget (1970) consider knowledge of the world to be divided into two aspects: the figurative and the operative. Figurative knowledge is related to the perception or imagery of the configurations of the world in successive or momentary states through immediate direct contact. Operative knowledge is the inner intervention of successive or momentary states of figurative knowledge that transforms this knowledge into recognizable patterns and schemes. In this theory spatial cognition is based on the operative mode while spatial perception is one of many aspects of figurative knowledge.

Other researchers, such as Rudolph Arnheim, do not agree with theories separating spatial cognition and spatial perception with spatial cognition. Arnheim (1986) makes a direct connection between spatial perception and spatial cognition:

Perceiving and thinking require each other. They complement each other's functions. The task of perception is supposed to be limited to collecting the raw materials for cognition. Once the material has been gathered, thinking enters the scene, at a supposedly higher cognitive level, and does the processing. Perception would be useless without thinking; thinking without perception would have nothing to think about (p. 147).

Olson and Bialystok (1983), and Hart and Moore (1973) contend that a distinction also must be made between spatial cognition and spatial abilities. They theorize that spatial cognition is a set of mental representations and procedures that allows an individual to demonstrate a certain spatial ability or a range of spatial abilities. Defining and measuring specific spatial abilities is adequate as long as the use of these definitions and measurements is concerned solely with the problems of individual differences and learning styles or for
the prediction of performance differences between individuals, but these different spatial abilities cannot by themselves define or represent spatial cognition. Spatial cognition, they contend, is the set of mental representations and operations that underlie and allow spatial ability.

Spatial cognition, then, is the underlying mental process that allows an individual to develop spatial abilities. Thus, if a person has a highly developed set of mental representations and operations or spatial cognition, various spatial ability measurements might predict that individual may perform better on spatial tasks than someone who does not have as highly developed spatial cognition. But what are some of the accepted spatial factors that will allow researchers to measure spatial abilities and thus predict an individual’s performance on various spatial tasks?

**Spatial Abilities**

Lohman and Kyllonen (1983) identified three major spatial factors that usually are tested to determine an individual’s spatial abilities:

1. **spatial relations** - ... are tests that are parallel forms of one another, and the factor emerges only if these or highly similar tests are included in the battery. Although mental rotations is the common element, the factor probably does not represent the speed of mental rotation; rather it represents the ability to solve such problems quickly by whatever means.

2. **spatial orientation** - ... the ability to imagine how a stimulus array will appear from another perspective. In the true spatial orientation test, the subjects must imagine that they are reoriented in space, and then make some judgment about the situation.

3. **visualization** - The tests load on this factor (visualization), in addition to their spatial-figural content, share two important features: they are all administered under relative unspeeded conditions, and most are much more complex than corresponding tests that load on the more peripheral factors (p. 111).

Eliot and Smith (1983) note that different researchers have described many different spatial factors. Kelly in 1928 described two spatial factors: 1. sensing and retention of visual forms; and 2. manipulation of spatial relations. Anderson, et al., in 1954 also
identified two spatial factors that were very close to Kelly's earlier descriptions: 1. spatial relations, which was described as the ability to determine the relationships between different spatially-arranged stimuli and responses, and the comprehension of the arrangement of elements within a visual stimulus pattern; and 2. visualization, which was described as the ability to imagine the rotation of depicted objects, the folding and unfolding of flat patterns, and the relative changes of positions of objects in space. French, in 1951 supported the existence of three spatial factors: 1. The spatial factor as the ability to perceive spatial patterns accurately and to compare them to each other; 2. orientation as the ability to remain confused by the varying orientation in which a spatial pattern may be represented; and 3. visualization as the ability to comprehend imaginary movement in three-dimensional space or to manipulate objects in imagination (p. 3-4).

McGee (1979) identified two distinct spatial abilities: spatial visualization and spatial orientation. He defines spatial visualization as:

[T]he ability to mentally manipulate, rotate, twist, or invert pictorially presented visual stimuli. The underlying ability seems to involve a process of recognition, retention, and recall of a configuration in which there is movement among the internal parts of the configuration, or of an object manipulated in three-dimensional space, of the folding or unfolding of flat patterns.... (p. 3-4).

and spatial orientation as:

[T]he comprehension of the arrangement of elements within a visual stimulus pattern, the aptitude for remaining unconfused by the changing orientations in which a configuration may be presented, and the ability to determine spatial relations in which the body orientation of the observer is an essential part of the problem (p. 4).

Although researchers have different beliefs on basic spatial abilities, they agree that various spatial factors can measure specific spatial cognitive abilities. But what measurement instruments have been used to measure spatial abilities and are all of these valid measures of spatial abilities? The following section will give an overview of various spatial tests and a theory of determining their validity in measuring spatial ability.
Spatial Tests

Eliot and Smith (1983) gave an extensive overview of pencil-and-paper tests used to measure spatial ability. The first characterization (see Figure 3) involved spatial tests that required the perception and retention of mental forms or the mental manipulation of visual shapes. Thus, the spatial tests were placed into a recognition or manipulation division. Visual memory tests, copying tests, and embedded figures tests are examples of recognition tests. Surface development, paper folding, and rotation tests would be examples of manipulation tests (p. 12).

The second characterization (see Figure 3) involved spatial tests that could be solved within or across a two-dimensional plane. Form completion tasks would be within-plane tasks and rotation tests would be examples of across-plane tests (Eliot & Smith, 1983).

The third characterization (see Figure 3) looked at the mental transformations involved in the test. The more mental transformations involved with the tasks of the test, the more complex it will be (Eliot & Smith, 1983).

<table>
<thead>
<tr>
<th>Recognition division</th>
<th>Manipulation division</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 copying</td>
<td>6 block counting</td>
</tr>
<tr>
<td>2 embedded figure</td>
<td>7 block rotation</td>
</tr>
<tr>
<td>3 visual memory</td>
<td>8 paper folding</td>
</tr>
<tr>
<td>4 form completion</td>
<td>9 surface development</td>
</tr>
<tr>
<td>5 form rotation</td>
<td>10 perspectives</td>
</tr>
</tbody>
</table>

Figure 3. Eliot and Smith's paper-and-pencil spatial test classification.
Although many spatial tests exist and have been included in Eliot and Smith's classification, how many of these tests are valid measures of spatial ability? Zimowski (1986) theorized that there are two ways in which individuals process spatial information depending upon the characteristics of the spatial test. The first, termed an analog processing of spatial information, is a holistic process. The second, termed a nonanalog processing of spatial information and, similar to the processing of verbal information. Thus, she classifies spatial tests as analog spatial tests or tests that are true or valid measures of spatial abilities and nonanalog spatial tests or tests that are impure measures of spatial abilities.

Zimowski (1986) listed the following task attributes that characterize nonanalog processing of spatial tests:

1. The tasks involve judgments among rotated stimuli.
2. The stimuli differ by orientations other than 180 degrees.
3. The distracters of the rotation tasks are mirror images of the reference stimuli or structurally equivalent forms.
4. The items require whole-whole rather than part-whole or part-part comparisons.
5. The items require the rotation of an entire object as a rigid whole rather than the rotation of only one or several pieces of the object relative to the whole.
6. The timed characteristic of the test (p. 18-22).

Using Eliot and Smith's (1983) classification of tests, Zimowski's (1986) classification of tasks that characterize nonanalog processing of spatial tasks, and other research studies involving spatial abilities and the concepts of engineering graphics, three tests of spatial abilities were deemed appropriate for this study: the *Mental Rotations Test* (Vandenberg & Kruse, 1978), the *Analog Subset of the Incomplete Open Cubes Test* (Zimowski, 1985), and the test of *Visualization of Rotations* (Guay, 1977). Although all three seem to be
valid measures of spatial ability, as defined by Zimowski, the Mental Rotations Test had the following desirable characteristics that the other tests did not possess. First, this test has been used extensively in psychological and educational studies and in studies that are directly or closely related to the concepts of engineering graphics (Zavotka, 1985; Wells, 1987; McCuistion, 1990). Second, this test has been empirically measured to be a valid test of spatial ability. The Directory of Unpublished Experimental Mental Measures shows validity correlations with other spatial tests to range from .31 to .68 (Goldman & Osborne, 1985, p. 238). Vandenberg and Kruse (1978) report that this test has shown only low correlations with tests of verbal ability. The Directory of Unpublished Experimental Mental Measures reports that this test has reliability ratings of .88 with the Kuder-Richardson 20 technique and the one year test-retest correlations were .83 (Goldman & Osborne, 1985, p. 238). Finally, this test is readily available as compared to the other tests identified and could be considered an accepted benchmark against which other spatial tests are compared.

Although spatial abilities can be measured in human beings to determine the spatial ability level of individuals, how do these abilities develop? What are some of the theories on cognitive spatial development? The next section will give an insight into how researchers theorize cognitive spatial development occurs.

Developmental Theories of Spatial Cognition

The study of spatial cognition would not be complete without reviewing the theories and research related to this area. Spatial development is vital in the process of cognitive development in human beings from infancy to death. Most researchers agree that the concept of cognitive development is not limited to a relation of age ranges but is controlled by the theory of natural development. Thus, spatial cognitive abilities may vary among individuals of the same age because these individuals may be at a different natural age of cognitive development.
Hart and Moore (1973) note that Ernest Cassier was one of the first theorists to use developmental theories in the area of spatial cognition. Cassier divided spatial experience into three types: 1. organic or active space, which is used by the lowest order of animals; 2. perceptual space, which is used by higher-order animals; and 3. symbolic or abstract space, which human beings alone possess.

Hart and Moore (1973) also note that the first comprehensive developmental theory of space to be theorized from empirical findings was the organismic-developmental theory of Werner. Werner theorized that there are three levels of spatial development: sensorimotor, perceptual, and contemplative. These levels progress from concrete acquaintance with the world to abstract knowledge of the world.

Probably the most extensive and influential theories on the development of spatial cognition are those of Jean Piaget and his associates. Piaget and Inhelder (1967) identified four major levels in the development of spatial cognition: sensorimotor space, preoperational space, concrete operational space, and formal operational space. They also identified three major types of spatial relations: topological, projective, and euclidian, as well as three systems of reference: egocentric, fixed, and coordinated.

The sensorimotor space (birth to about age 2) is the first stage of spatial development. The child operates from a purely egocentric perceptual view of the world. Perception of the world is that of topological properties and knowledge gained through perceptual sensations (Piaget and Inhelder, 1967).

Intuitive or preoperational space (ages 2 to 7) is the second stage of spatial development. The child's frame of reference continues to be egocentric in nature; and learning is haptic (by touch) and continues to be limited to topological shape, size, and proximity features of objects (Piaget and Inhelder, 1967).

Concrete operational space (ages 7 to 12) is the third stage of spatial development. During this stage, children begin to develop concrete operations and can develop concrete spatial thoughts that are independent from images but still require the presence of actual or
represented objects. By this stage the child loses his or her egocentric frame of reference and is able to view objects from various viewpoints other than his or her own and perceive projective spatial relationships (Piaget and Inhelder, 1967).

Formal operational space (ages 13 through adulthood) is the final stage of spatial development. Abstract mathematical concepts, such as euclidian geometry, can be acquired and the individual can make use of infinite spatial possibilities (Piaget and Inhelder, 1967).

Although some theorists do not accept the notion that children's spatial cognitive development occurs in stages, most research in cognitive psychology supports the developmental theories of spatial cognition. Other theorists contend that other factors influence the spatial cognitive development of individuals. Factors such as the characteristics of the individual, physical environment, and heredity will be discussed in the next section.

Sources of Variance in Spatial Cognition

Liben (1981) contends that differences exist between persons in individual characteristics (e.g., cognitive level), cultural heritage (e.g., societal practices that affect males' versus females' freedom to explore the environment), and in physical space (e.g., the urbanization of rural environments) (p. 17).

Liben (1981) further advocates that qualities of spatial behavior can be grouped into three major categories: physical, cognitive, and socioemotional. Age is the most influential factor in the physical category. As individuals mature, their locomotion changes from dependency on other human beings to crawling, then to walking, then to bicycling, then to driving a car. Depending upon the environmental exposure throughout the various spatial developmental stages, an individual may be exposed to various environments or environmental experiences that either advance or hinder his or her spatial cognitive development and abilities (p. 17-19).
A second physical factor that can influence spatial cognition is whether an individual has physical or sensory handicaps. Handicaps such as cerebral palsy, orthopedic handicaps that restrict environmental mobility, blindness, or deafness may affect how the environment is represented spatially and cause these individuals to develop an abnormal spatial cognition.

The cognitive characteristics that Liben (1981) speaks of are closely related to the concepts of spatial cognitive development advocated by Piaget, and she agrees that cognitive spatial characteristics develop in individuals in various natural stages.

Finally, Liben (1981) claims that socioemotional factors play a vital role in the development of spatial cognition. Thus, every individual will possess various spatial abilities because of the interaction of social, environmental, and emotional experiences.

McGee (1979) claims that there is empirical evidence for sex differences in spatial cognition. He cites three different illustrative spatial tests: Thurston's Primary Mental Abilities Space Test, the Differential Attitude Space Relations Test, and the Mental Rotations Test. In the Mental Rotations Test, males scored higher in space factors despite a higher IQ for females. The Mental Rotations Test has shown internal consistency and test-retest reliability showing that sex differences have favored males over females in the entire age ranges of the general population. McGee (1979) also notes: 1. a consistent sex difference that favors males in each of the twenty items on the test; and 2. a strong positive correlation between rank-order item difficulties for the males and females. He further notes that these results would seem to rule out any explanation of the observed sex differences that relies solely on the motivational differences between the sexes (pp. 20-303).

McGee (1979) also notes that research has shown that spatial abilities could be influenced by heredity and hormonal influences within the individual. Spatial abilities are as inherited as verbal abilities. This evidence is based on research indicating that the presence of an X-linked recessive gene could have effects on spatial abilities. Because a majority of inherited traits occurs in greater frequency within males than females, this could
be a plausible explanation for sex differences in spatial cognition (pp. 203-205). McGee (1979) also suggests that hormonal levels may influence spatial abilities, although there is not sound evidence of what the relationship of these effects may be. Thus, this area of research remains an open question (p. 213).

McGee (1979) further notes that an abundance of psychological literature theorizes a difference between male and female cognitive functioning in the two separate hemispheres of the brain. Males are stronger in spatial tasks that utilize the right hemisphere while females show advantages in tasks that involve verbal abilities and utilize the left hemisphere of the brain. Although inconclusive, this evidence suggests that spatial and verbal sex-related differences may be related to basic sex differences in the makeup and function of the brain.

Clinical study results have tended to show that among right-handed adults, nonverbal and spatial information processing is completed by the right cerebral hemisphere, while verbal processing is completed by the left. This theory contends that males have greater hemispheric specialization than females, and this specialization usually is associated with the right cerebral hemisphere. Females are less hemispherically specialized in respect to both spatial and verbal functions (McGlone, 1980). Although conclusive evidence in this area has not been established, a majority of experts conducting brain research agree with this theory. Many scientists also believe that there are actual perceptual ability differences between the different halves of the brain.

Research by Bryden (1966) has identified three possible reasons for differences of cognitive abilities related to patterns of brain function:

1. There may be a fundamental biological neurologic difference in cerebral organization between males and females, so that cognitive information processing is more likely to be bilaterally represented in females than males.

2. The observed differences may arise from the test procedures; that is, females may use different strategies to perform the behavioral tests that are used to measure hemispheric spatialization.
3. It is possible that whatever sex related differences that are observed result from the interaction of strategy effects with cerebral organization (p. 215).

Background experiences or socioemotional factors as described by Liben (1981) could also have an effect on spatial ability. If an individual, because of background experiences, has been exposed to or has developed spatial learning strategies, this person might then have more dominant brain development in the right hemisphere. The opposite also could have occurred because of different experiences, making the person possess more verbal learning strategies. Because spatial ability is such an important aspect of learning in many different areas, individuals with verbal learning strategies may have extreme difficulties with spatial problems. Bertoline (1988) suggests that human beings are not born with developed spatial ability and that this ability is a cognitive function developed through ordered life experiences. If the development of spatial ability occurs in various stages of life and exposure to different learning environments influences the development of spatial ability, then students probably will possess different levels of spatial ability. Thus, the importance of individual learning style differences must be considered by the engineering graphics educators when they are planning instructional methods and media.

Learning Styles

During the past forty years individual difference variables have been discussed and debated in research literature. The literature of individual differences has been referred to as both cognitive styles and learning styles depending on who advocates which label. Manfredo (1987) notes that the terms of cognitive style and learning style often are used interchangeably. Leino (1981, 1980) states these terms are not interchangeable and contends that cognitive styles affect the learning process as well as affecting other processes such as perceptual processes. Keefe (1979) contends that learning style is a more global term than cognitive styles and that cognitive, affective, and physiological styles
fall within learning styles. The following is a definition of learning style proposed by Languis (1983), which includes cognitive styles.

> the consistent pattern of behavior and performance by which an individual approaches educational experiences. It is the composite of characteristic cognitive, affective, and physiological behaviors that serve as relatively stable indicators of how a learner perceives, interacts with, and responds to the learning environment. It is formed in the deep structure of neural organization and personality which molds and is molded by human development, and the cultural experiences of home, school, and society (p. 8).

Green (1985), writing about cognitive styles, notes three sources of individual differences in information-processing of cognitive aptitude. The first individual difference is based on the amount of information the individual possesses concerning the problem to be solved. The more information the person possesses, the more likely he/she will be able to solve the problem successfully. The second source of individual differences is concerned with the mechanics of information processing that the individual possesses. Thus, how does the individual perceive, encode, remember, retrieve, and output various forms of information? The third source of individual differences is the general process that a person uses to solve larger more complex problems. Thus, how do individuals characteristically review and solve problems (Green, 1985)?

Many researchers (Green, 1985; Messick, 1976; Keefe, 1979; Ausburn, L.J., 1979; Manfredo, 1987) contend that there is a difference between cognitive styles, abilities, and aptitudes, while other researchers (e.g., Kogan, 1971) disagree. Green (1985) claims that cognitive styles are the dominant mode of information processing. Leino (1981) claims that cognitive styles are habitual processes that individuals possess that allows them to process information in patterns that are consistent, deep-rooted, and pervasive. Green (1985) contends that abilities describe the performance of specific tasks. Leino (1981) notes that styles can be easily involved with abilities, but abilities are value directional and are more limited in scope than styles. Because cognitive abilities are limited in scope and can be used to describe performance on specific tasks and because Kogan’s theories
advocate that there are no differences between styles and abilities, this research will focus on the measurement of specific cognitive abilities.

Various researchers claim different dimensions of cognitive styles. Messick's 1970 research listed nine dimensions of cognitive styles. His 1976 research listed twenty dimensions of cognitive style. Keefe (1979) contends that perceptual mode, field independence/dependence, conceptual tempo, and leveling/sharpening, because of their practical utility and conceptual importance, are of greatest importance to research in learning processes. The perceptual mode is how an individual perceives or reacts to experiences of the world. The perceptual mode theory of visual/haptic developed by Viktor Lowenfeld, because of its practical utility and application to engineering graphics, will be the focus of this research.

Similar to the theoretical debate between learning and cognitive styles, perceptual mode has been classified as a subset of learning style but various researchers contend that it is related to different areas of learning style. Ausburn (1979) contends that perceptual mode is related to cognitive style while Dunn, Dunn, & Price (1979) suggest that perceptual mode is related to physiological style. Manfredo (1987) claims that there is no clear evidence as to which style perceptual mode is related and advocates that it be kept separate from either cognitive or physiological style.

**Visual/Haptic Learning Style**

Viktor Lowenfeld developed visual/haptic learning style theory after extensive research in art education in Europe and the United States. Lowenfeld (1939) distinguishes between two distinct types of individuals and how individuals perceive and react to the world of experiences, or in other words, how they perceive and organize their external environment. The two learning style types that he identified are the visual and the haptic.

Lowenfeld contended that these two learning styles fall on the opposite ends of a continuum as to how they perceive the external world. The visual type, Lowenfeld (1945)
states, "...has the ability to see first the whole without the awareness of details, then to analyze it into detailed or partial impressions and to build these parts up again into a new synthesis of the whole" (p. 101). The visual type relies almost entirely on visual imagery as a means of perception and would be lost without it. The visual type is a perceptual observer or spectator who normally approaches objects from their visual appearance, uses the eyes to discover their surrounding environment, and transforms kinesthetic and tactile experiences into visual ones (Lowenfeld and Brittain, 1987).

An extreme haptic type of individual, Lowenfeld (1945) contends, is not a rare individual who "... uses his eyes only when he is compelled to do so; otherwise, he reacts as would a blind person who is entirely dependent upon touch and kinesthesia" (p.101). Haptic individuals do not transform kinesthetic and tactile experiences into visual imagery but rely upon touch or the kinesthetic mode of perception (Lowenfeld & Brittain, 1987).

Lowenfeld (1945) developed a battery of five tests used to identify the visual/haptic learning style of an individual. Ragan (1979) notes that these tests are based on several theoretical distinctions:

1. Whereas the visual has the ability to see a whole, break it up and see its component details, and then resynthesize the details back into a whole, the haptic is unable to do this.

2. Whereas the visual tends to react to stimuli as a spectator and to "see" experiences, the haptic tends to react emotionally, to "feel" stimuli, and to place one's self into the situation.

3. Whereas the visual has the tendency and ability to visualize and integrate tactile and partial experiences, the haptic has neither this tendency nor ability.

4. Whereas the visual has the ability to maintain visual imagery mentally, the haptic is unable to do this (p. 21).

Lowenfeld (1945) presented and reported his battery of five tests in the *American Journal of Psychology*:

In the following tests an attempt has been made to discriminate between persons whose tendency is to use their eyes as the main intermediaries for their sense impressions and those who, though with normal sight do not use
their eyes but are more concerned with those perceptions that derive from haptic experience (p. 100).

The Integration of Successive Impressions is the first test in Lowenfeld’s visual/haptic test battery. It was designed to measure whether or not a person can integrate partial impressions, which are perceived successfully, into a whole (Lowenfeld, 1945, p.102).

A series of symbols is shown moving one at a time behind a narrow opening (see Figure 4). Through the narrow opening only a small portion of the symbol is shown. The symbol then must be matched to its corresponding symbol out of several similar figures (see Figure 5).
The Test of Subjective Impressions is the second of Lowenfeld's test battery. Concerning this test, Lowenfeld (1945, p. 103) states, "An experience which is perceivable to the same degree haptically or visually will be apprehended in one way or the other, depending on the aptitude of the individual, provided always that no other association interferes with the process." This test is divided into two parts: the Table Test and the Think-of-a-Building Test. The Table Test involves instructing the subjects to draw a table with a glass on top and to draw a table with a chessboard on top. If the subject is visual he/she will always draw an objective view of an object. Thus he/she will always draw a view of the table. If the subject is haptic in nature, he/she will draw the object from its tactile impression. Thus he/she will draw the glass from a side or elevation view and the chessboard from the top view.

The Think-of-a-Building Test asks subjects to think of a familiar building that is not their home, school, or office. Subjects are then asked: 1. how many floors the building has, 2. if they were sure, not quite sure, or unsure of the number of floors they gave, and 3. when they thought of the number of floors, did they think of: 1. how many floors they had to climb? 2. did they count the floors singly? and 3. did they think of the whole building as it appears from the outside? Subjects who pictured the entire building as they counted the floors were considered visuals. Subjects who imagined climbing the stairs as they counted them were classified as haptics. Subjects who only counted the floors were classified as neither visuals or haptics (Lowenfeld, 1945).

The Test of Visual vs. Haptic Word Association is used to find words that determine visual and haptic experiences from subjects. Subjects are given twenty words such as greeting, and walking, and are asked to write down their immediate response. For example, if given the word "climbing," the person answers "mountain," this would be considered a visual response, whereas if a subject answers "hard" to "climbing," this would be considered a haptic response. Subjects who give twelve responses in one or the
other direction are considered either visuals or haptics. Subjects who do not are considered “indefinites” (Lowenfeld, 1945).

The fourth test of Lowenfeld’s battery is the *Visualization of Kinesthetic Experience*. Lowenfeld (1945, p. 107) states, “Visually minded persons have a tendency to transform kinesthetic and tactile into visual experiences. Haptic minded individuals are, however, completely content with tactile or kinesthetic modality itself...” In this test different cardboard or plywood stencils of geometric figures of increasing complexity are given to blindfolded subjects. They are then instructed to place one finger at a starting point on the outside of the object and run another finger around the outside of the object. Then the blindfold is removed and subjects are asked to identify the figure from five line drawings of various figures drawn to scale. Because the visual subjects can transform the tactile data to visual data, they will be able to identify the figure. The haptic subjects will not be able to do so. Twenty figures are given to the subjects. If subjects identify twelve or more of the figures, they will be considered visual (Lowenfeld, 1945).

The fifth test of Lowenfeld’s battery is the *Test of Tactile Impressions*. Lowenfeld (1945, p. 109) states, “This test determines whether or not a person can recognize figures, which were perceived through tactile experience.” The figures used in the *Test of Visualization of Kinesthetic Experiences* were placed into a bag. The subjects were then asked to view line drawings of the figures. Through feeling and touch, subjects had to match the correct object in the bag to its line drawing. Twenty objects were used and subjects who scored twelve or more correct were considered haptics (Lowenfeld, 1945).

Lowenfeld (1945) suggests that these tests can be used singly or as a series. If individually administered, they can be used to identify a particular perceptual experience. Administered as a series yields a total visual score and a total haptic score. After administering these tests to a sample of 1128 subjects, Lowenfeld reported that 47 percent of the subjects were clearly visual, 23 percent were haptic, and the remaining 30 percent were not identifiable.
The research of Wiggin (1951) used three tests of visual/haptic learning style. Wiggin (1951) used a modified version of Lowenfeld’s *Test of Integration of Successive Impressions*, *Test of Visual vs. Haptic Word Association*, and *The Test of Integration of Successive Figures*.

Wiggin’s (1951) research was focused on the following four research questions:

1. To what extent may a modification of Lowenfeld’s *Test of Integration of Successive Impressions* be made into a reliable testing instrument?

2. To what extent is a modification of Lowenfeld’s *Test of Integration of Successive Impressions* a valid measure of “visual,” “haptic,” and “indefinite” type as determined by the opinion of art experts and performance in the Rorschach Ink Block Test?

3. To what extent is Lowenfeld’s *Test of Visual vs. Haptic Word Association* a valid measure of the “visual,” “haptic,” or “indefinite” type?

4. To what extent are Lowenfeld’s *Test of Visual vs. Haptic Word Association* and the modification of his *Test of Integration of Successive Impressions* correlated with each other?

Wiggin (1951) concluded that Lowenfeld’s *Test of Integration of Successive Impressions* had a Pearson Product-Moment coefficient of .57 between two different administrations of the same test. Wiggin (1951) also found that the *Test of Integration of Successive Impressions* was found to possess face validity by an expert panel of art professors who compared it with the Rorschach Ink Block Test of perception. The Rorschach test results showed that haptic individuals scored lowest, “indefinites” ranged in the middle, and visuals scored highest. This same expert panel of art educators also concluded that the *Visual vs. Haptic Word Association Test* did not show a consistent pattern of distinguishing between visual and haptic students and that it did not correlate the *Test of Integration of Successive Impressions*. Wiggin (1951) concluded that the *Test of Integration of Successive Impressions* appeared to be the most valid and reliable of the test studies and that the *Visual vs. Haptic Word Association Test* appeared to be of little value in distinguishing between visual and haptic individuals.
Erickson (1963) conducted a research study with the purpose of determining if Lowenfeld's visual/haptic learning style was a factor in the achievement success of beginning eighth grade mechanical drawing students. Three groups of students (visual, indeterminate, and haptic) were compared for their achievement in mechanical drawing and their achievement on the Iowa Tests of Basic Skills. Erickson reported that visually oriented subjects were not superior in academic achievement but showed superior achievement in mechanical drawing. Erickson developed The Integration of Partial Impressions Test, a visual/haptic test that was based on Lowenfeld's Test of Integration of Successive Impressions.

Working on his doctoral dissertation, Erickson (1966) conducted a study of Lowenfeld's visual/haptic theory to determine:

First, to what degree, if any, the visual/haptic orientation of the mechanical drawing teacher interacts with his students' visual/haptic orientation in such a way as to affect their classroom achievement.

Second, to gather additional empirical evidence to determine whether student visual/haptic aptitude is as significant a factor in achieving success in mechanical drawing as was indicated by the findings in the researcher's earlier study (p. 11).

Erickson used the Successive Perception Test I (United States Army Air Force, 1944) to determine the visual/haptic learning styles of the subjects. He chose this test because it was a film version of Lowenfeld's Test of Integration of Successive Impressions, which allows for group administration.

Erickson (1966) made the following conclusions:

First, there was no significant interaction between the personality effect of the instructor on the students' achievement in mechanical drawing.

Second, the mean level of student achievement in beginning mechanical drawing was significantly affected by and is directly related to the visual/haptic orientation of the student (p. 105).

Erickson (1969) conducted a research study that investigated the possibility that visual/haptic learning style held significant implications for the development of reading skills. Erickson used the Successive Perception Test I (Gibson, 1947) as a measure of
visual/haptic learning style and the *Iowa Tests of Basic Skills* as the measure of reading ability. His findings indicated that visual/haptic learning style, as measured by the *Successive Perception Test I*, was a significant factor in the development of reading skills. Erickson (1969) further reported that haptic subjects were in excess of one grade level below visual subjects.

Clark (1971) reported about a research study that attempted to compare the visual/haptic learning styles of students who were exposed to two learning treatments (visualization and written prerequisite principles) of orthographic projection principles. The effects of the two learning treatments and visual/haptic learning styles of the students on the number of trials the students needed to reach a set criterion were examined also. Clark (1971) concluded that this study failed to support the hypothesis that a relationship would exist between cognition of the final task and the visual/haptic learning styles of the subjects. The second conclusion was that there was not a relationship between the number of trials and the visual/haptic learning styles of the subjects.

F. B. Ausburn (1975) reported the result of a research study that investigated how different methods of visual presentations would affect the rates of retention of visual/haptic individuals. This experiment was designed to test the abilities of subjects to view three pictures of a piece of equipment through two different media presentations. It was based on Salomon's theory of supplantation. One group received a sequential linear presentation of three pictures, and the second group received a multiple image presentation of the task. The following results of the study suggested: 1. visuals performed better overall than haptics on the apprehension, retention, and utilization of visual clues; 2. the multi-image presentation of the visual stimuli resulted in better overall performance than did the linear presentation of the visuals; and 3. haptic individuals benefited more than visual individuals from the use of simultaneous multiple image presentations. Ausburn recommended further research be conducted on other populations and with different tasks to establish a pattern of
relationships between the visual/haptic learning style, the psychological requirements of the task, and various forms and applications supplantation (F. B. Ausburn, 1975).

L. A. Ausburn (1975) conducted a research study to determine the relationship between visual/haptic individuals as measured by the Successive Perception Test I, and the cognitive styles of reflective/impulsive, as measured by the Matching Familiar Figures Test, and field-independent/dependent, as measured by the Hidden Figures Test. Ausburn notes that all three of these measures require the discrimination and separation of visual detail. The results of this study implied that visual individuals tended to be more field-independent and reflective while haptic individuals tended to be more field-dependent and impulsive.

Ausburn concludes by noting that relationships did exist between visual/haptic learning style and certain kinds of visual tests and that these findings have implications for fields involved with visual testing and visual media. She further added that classroom learning tasks and presentation modes must match the learning styles of the learners or that specially designed media should be developed to supplant for the learners’ perceptual aptitude weaknesses (L. A. Ausburn, 1975).

The Successive Perception Test I (United States Army Air Corps, 1944) is a motion picture test that was developed during World War II by the United States Army Air Corps Aviation Psychology Program. It was used in the selection and training of pilot cadets. This test is very similar to and was developed from the Integration of Successive Impressions Test of Viktor Lowenfeld.

The objective of this test is to identify individuals as either visual, haptic, or indefinite learning styles. Lowenfeld (1945, p. 101) theorized, "... that visual perceptual types have the ability to see first the whole without the awareness of details, then to analyze it back into detailed or partial impressions and to build these parts up again into a new synthesis of the whole." Haptic individuals do not possess this ability.

The Successive Perception Test I contains 38 items. Three items are practice items and 35 are the actual test items. A small section of a pattern is shown through a moving slot
until the whole pattern has been viewed section by section through the moving slot. The subject then must pick the corresponding pattern from five alternatives.

F. B. Ausburn (1979) notes that the *Successive Perception Test I* has been used extensively by the United States Air Force and also has been used in various educational situations with students ranging from seventh-grade to university-level (Erickson, 1966, 1969; Clark, 1971; Bruning, 1974). The reliability of the *Successive Perception Test I* has been reported to be .56 by Gibson (1947) and .68 by F. B. Ausburn (1979).

L. A. Ausburn (1979) notes that although the reported reliability coefficients are somewhat low, prior research results were consistent with the theory-based hypotheses. L. A. Ausburn (1979, p. 9) adds further the *Successive Perception Test I* is currently the only available instrument for assessing visual/haptic learning style for which reliability has been established empirically. Face validity has also been shown by Wiggin (1951) for the *Integration of Successive Impressions Test* of Lowenfeld (1945) from which this test was developed. The *Successive Perception Test I* is the only currently available group-administered test for the measurement of visual/haptic learning style that provides both face validity and empirical reliability.

L. A. Ausburn (1975) noted that relationships did exist between visual/haptic learning style and certain kinds of visual tests and that these findings have implications for fields involved with visual testing and visual media. She contended that various classroom learning tasks and presentation modes must be matched to the learning styles of the learners or that specially designed media should be designed to supplant for the learners' learning style weaknesses if successful learning is to occur. The next section of the literature review will provide information concerning supplantation theory.

**Supplantation Theory**

Salomon (1970, p. 47) defines supplantation as, "the mental function accomplished by an explicit presentation of what would otherwise have to be done covertly by the learner
himself, such that a certain learning objective will be attained.” Salomon (1970, p. 48) adds further that supplantation theory is based upon two assumptions:

1. Signs and symbols have a dual function: they are used in overt acts of communication to affect a receiver's behavior, and they are used in covert representational capacity to guide one's own behavior. We can communicate overtly as well as stimulate and regulate our own behavior by using the same or similar signs.

2. Information to be learned is composed of events, signs, and their transformations. These, we believe, can be stored, integrated, generalized and used as internal symbolic stimuli and responses of two kinds: situational and transformational, or, as Inhelder calls them, figurative and operative aspects of cognitive functions. Situational symbolic responses are internalized representations of objects and events or of responses related to them. Transformational responses are internalized representations of activities which modify, manipulate, and transform the objects and events.

Salomon (1970) further theorizes that the covert situational and transformational behaviors are of a manipulatory origin. He contends that they are developed from prolonged daily contact with objects that are manipulated. After this manipulation period, the objects become iconic and finally progress to symbolic shapes. Once this internalization has occurred, the various internalized objects can be developed into increasingly complex internalized objects without physical manipulation of the objects.

Salomon (1970) contends that these two supplantation assumptions allow the supplantation of mental processes in two capacities:

1. It can provide compensation for what the learner cannot execute mentally on his own, hence aiding him in attaining a particular instructional objective.

2. It can offer him an image of a situation or of a transformation to be internalized, stored, and made available for later use in a covert form. (p. 49)

Salomon (1970) cautions that the process of supplantation will occur only when the following two conditions are met:

1. The presented information is sufficiently explicit, thus providing enough supplantation of the mental processes necessary for an item to be learned, a concept to be obtained or a principle to be formulated. Here, then, we are concerned with the amount of supplantation, i.e., how much mental activity is left for the learner who has been given a specific learning task.
2. The presented information is sufficiently close, with respect to its semantic and contextual nature, to the learner's cognitive structure (p. 49-50).

The first condition stipulates that the amount of supplantation can range from very little to having the entire concept being totally supplanted for the learner. An instructional presentation may show only the beginning of the mental process in the hope that it will induce the necessary mental activities. The beginning state of a mental process may be shown along with the final state of the mental process after the transformation has occurred. This "short-circuit" does not show the transformation, and the learner is expected to possess the correct mental transformation. Finally, the entire transformation is shown to the learner with the hope that he/she will be able to incorporate the transformation for future use. The decision on how much supplantation to use is dependent upon the task to be performed by the learner (Salomon, 1970).

Salomon (1970) concludes that in order for the process of supplantation to be successful in allowing the learner to gain knowledge, the instructional designer must know the underlying task to be accomplished and the cognitive nature of the learner.

Summary

Bertoline's, et al. (1990) curriculum model defined visualization as one of the foundations for a technical drawing curriculum model, which is inclusive of engineering graphics. Although engineering graphics educators have noted the importance of spatial abilities, Miller (1990) reported that very little formal research had been undertaken by engineering graphics educators.

Spatial research began at the end of the nineteenth century. Although there are conflicting theories of spatial thought, spatial cognition seems to be the underlying mental process. Researchers have noted the existence of two distinct spatial abilities: spatial orientation and spatial visualization (McGee, 1979). Various spatial tests have been classified (Eliot & Smith, 1983) and used to measure spatial abilities although many may
not be valid measures of this ability. Zimowski (1986) claims that many tests measure nonanalog processes or other abilities that are not spatial abilities. She notes many test attributes that characterize the nonanalog components of spatial tests.

Vandenberg’s (1978) Mental Rotation Test seems to possess all of the requirements that Zimowski (1986) theorizes make a spatial relations test valid. This test has been widely used in educational and psychological testing.

Researchers (Piaget & Inhelder, 1967; Hart & Moore, 1973) advocate that spatial cognition develops in various age independent stages. Other researchers (Liben, 1981; McGee, 1979) contend that individual difference characteristics are a major source of variance in spatial cognition.

Individuals may possess different amounts of spatial abilities because they are at different developmental stages, or because they have been exposed to different environmental situations. Thus, instructors must consider that individuals possess different learning styles.

Perceptual aptitude theory is a subset of learning styles. Lowenfeld (1945) described different qualities of what he termed haptic and visual learners. Visual learners use their eyes as their major means of information gathering while haptic individuals prefer the sense of touch. Lowenfeld (1945) claims the most important difference between visual and haptic individuals is the ability to be able see a whole, break it up, see its component details, and then resynthesize the details back into a whole. If this is the difference between the learning styles of individuals, then it has major implications for engineering graphics education.

Several tests have been developed to measure visual/haptic learning style, but of all the tests reviewed, only the Successive Perception Test I (United States Army Air Corps, 1944) has been shown to possess both face validity (Wiggin, 1951) and, reliability (Gibson, 1947; L. A. Ausburn, 1975, 1979; F. B. Ausburn, 1975, 1979), and can be administered in a large group setting.
The supplantation theory of Salomon (1975) contends that the psychological requirements of a task must be matched to the characteristics of the learner if learning is to occur successfully. He contends that many times the learner will not possess the mental capabilities required to complete the task successfully. These processes must supplant the learner's mental process for the required task to be learned successfully by the individual. Thus, if the learner does not have the mental abilities to perform a certain task, it can be supplanted or be executed explicitly for the learner. Further, if engineering graphics students do not possess the mental abilities to spatially rotate or orientate themselves, then supplantation could be used to perform this process for them.

In conclusion, spatial abilities have been shown to be a central part of the engineering graphics curricula. Not all students possess spatial abilities that allow them to understand the concepts of engineering graphics and thus allow them to become successful design engineers. Because these students may possess different mental capabilities, they will possess varying learning styles. If students can be classified as possessing a certain learning style and this learning style has historically had low spatial abilities, then instructional material may be developed that supplants for these students mental activities that they do not possess. This may allow these students to grasp these concepts and to advance their spatial abilities.
CHAPTER III

METHODOLOGY

This chapter discusses the procedures that were followed to conduct the study. The instructional setting in which the study was conducted and the instruments used to measure the subjects' visual/haptic learning styles and spatial abilities are described. The next section gives a detailed description of the major methodological activities that were performed prior to and during the study. These activities include selection of the software, development of the instructional materials, training the laboratory instructors, consent for participation, administration of the pretest, selection of the sample, administration of the treatment, and administration of the posttest. The last section describes the research design and data analysis procedures that were used to test the hypotheses.

Instructional Setting for the Study

Technical Graphics 108 during Fall Semester 1990 was a one-hour course that consisted of a one-hour lecture and one-hour laboratory weekly meeting. The course was segmented into three sections, each consisting of eight divisions. A lecture presentation was one section, and each laboratory was a division. The lecture presentation for section one met Monday at 7:30 a.m. The eight one-hour laboratory divisions also met Monday from 9:30 a.m. to 4:30 p.m. This same schedule was followed for section two on Wednesday and section three on Friday.

Technical Graphics 108 during Fall Semester 1990 was a traditional sketching-based engineering graphics course. Offered to all freshman engineering students, it covered the topics of visualization, orthographic multiview sketching, pictorial isometric sketching, and
orthographic reading (see Appendix A). All formal instructional content was presented
during the one-hour lecture. The one-hour laboratory did not introduce any new
instructional content but was designed so that students were able to work on homework
assignments and receive additional help from an undergraduate teaching assistant.

Technical Graphics 108 is a service course for the Schools of Engineering at Purdue
University. The course is a requirement for civil, astrological/aeronautical, and freshman
engineering. The typical class is approximately 85 percent male and 15 percent female with
a broad range of spatial abilities. The majority have had little, if any, formal exposure to
instruction in techniques used to develop spatial abilities (Miller & Bertoline, 1989).

Instrumentation

Two standardized instruments were used in this study: The Successive Perception
Test I (United States Army Air Corps, 1944) and the Mental Rotations Test (Vandenberg &
Kruse, 1978). The Successive Perception Test I was used to determine the visual/haptic
learning styles of the subjects in the population; and thus was used to assign subjects to the
treatment groups.

The Successive Perception Test I (SP1) contains 38 items. Three items are practice
items and 35 are actual test items. The SP1 is a film version of the Test of Successive
Impressions. The Test of Successive Impressions consists of black abstract line drawing
symbols drawn on separate pieces of white cardboard. The white cardboard pieces on
which the symbols were drawn (symbol cards) are then placed, one at a time, into a white
opaque cardboard cover plate in which a horizontal rectangular window had been cut. The
SP1 film shows the symbol cards as they are pulled through the cover plate, thus exposing
small sections of the symbol until the entire symbol has been displayed. The entire symbol
is shown through the window in one and one-half seconds. The subject can see only that
part of the symbol that is displayed inside the window. As the symbol passes through the window, the subject must remember the entire design and pick the corresponding symbol from five alternatives (see Figure 6).

![Figure 6](image)

Lowenfeld (1945) theorized that 47 percent of the population are visual, 23 percent are haptic, and the remaining 30 percent are not identifiable. Based on this theory only subjects who were clearly visual or haptic as determined by the Successive Perception Test I were used in this study. L. A. Ausburn (1979), in a study that used volunteer undergraduate students enrolled in Education 4160, Media and Technology in Teaching at the University of Oklahoma, classified subjects by the Successive Perception Test I. Those students who scored 60 percent or more of the items correct (scores of 21 to 35) were classified as visuals and subjects who scored 60 percent or more incorrect (scores of 0 to 14) were classified as haptic. The procedure that Ausburn used in her study to define visual and haptic individuals was based on procedures Viktor Lowenfeld used with his Test of Integration of Successive Impressions. This is a pen-and-paper test from which the Successive Perception Test I was developed. Because Ausburn’s procedure was based on
Lowenfeld's theories and because her research involved undergraduate university students, this same procedure was attempted to determine visual and haptic individuals for this study.

F. B. Ausburn (1979) notes that the Successive Perception Test I has been used extensively by the United States Air Force and in various educational situations with students ranging from seventh grade to university level (Erickson, 1966, 1969; Clark, 1971; Bruning, 1974). The reliability of the Successive Perception Test I has been reported to be .56 by Gibson (1947) and .68 by F. B. Ausburn (1979). L. A. Ausburn (1979) notes that although the reported reliability coefficients are somewhat low, prior research results were consistent with the theory-based hypotheses. L. A. Ausburn (1979, p. 9) adds further, "The Successive Perception Test I is the only currently available instrument for assessing visual/haptic learning style for which reliability has been established empirically." Face validity has also been shown by Wiggin (1951) for the Integration of Successive Impressions Test (Lowenfeld, 1945) from which the Successive Perception Test I was developed. The Successive Perception Test I is the only currently available group-administered test for the measurement of visual/haptic learning style that provides both face validity and reliability.

The Mental Rotations Test (see Appendix B) was used to measure the spatial ability of the subjects. Although there are various measures of spatial ability, Zimowski (1986) notes that all spatial tests are not valid measures of spatial ability. The Mental Rotations Test was selected for use in this study because it had the following desirable characteristics not found in other spatial tests. First, this test has been used extensively in psychological and educational studies and in studies that are directly or closely related to the concepts of engineering graphics (Zavotka, 1985; Wells, 1987; McCuistion, 1990). Second, this test has been proven empirically to be a valid and reliable test of spatial ability. The Directory of Unpublished Experimental Mental Measures shows validity correlations with other spatial tests to range from .31 to .68 (Goldman & Osborne, 1985, p. 238). Vandenberg and Kruse (1978) report that this test has shown low correlations only with tests of verbal
ability. The Directory of Unpublished Experimental Mental Measures reports that this test has reliability ratings of .88 with the Kuder-Richardson 20 technique and the one-year test-retest correlations were .83 (Goldman & Osborne, 1985, p. 238). Finally, this test is readily available as compared to the other spatial tests and could be considered as an accepted benchmark against which other spatial tests are compared.

**Major Methodological Activities**

**Selection of the Software for the Study**

Selection of the software for the study was a compromise between availability, the researcher's experience using the software, ease of use for the subjects, and ability of the software to produce color surface-rendered three-dimensional representations of objects. The software also had to allow the user the option of rotating the objects to be viewed from any direction. Microcomputer-based CADD software was selected over mainframe and minicomputer software because of cost, amount of time necessary to learn the software, and greater use of micro-based CADD in schools of engineering and technology.

A review of available software revealed that several packages claimed the capability to produce three-dimensional color surface-rendered objects, which could be rotated by the user. This list of software packages then was limited to software packages that could be run on either a Macintosh or IBM microcomputer platform. The software package selected was SilverScreen version 1.11 and it ran on the IBM platform. The selection of this package was based upon the following criteria. First, this package allowed the researcher to produce accurate three-dimensional models in a time efficient manner. Second, once the models were developed, this package allowed them to be color surface rendered. Third, this package allowed the user to rotate the objects 360 degrees in any direction. Fourth, this package could be programmed so various objects would be automatically loaded into the computer and then be rotated in any direction by the use of a two-keystroke macro.
Finally, this software package was the only solid modeling software package that met the above requirements and that the Department of Technical Graphics at Purdue University had a site license.

Development of the Instructional Materials

Instructional materials were developed during the Fall, Spring, and Summer semesters of 1989-90. The computer-generated and real-models were produced on a limited scale during Fall Semester 1989. These models were pilot tested in two sections of Technical Graphics 108 during Spring Semester 1990. One class pilot tested the wooden blocks, and the second class pilot tested the use of the computer-generated models. Strengths and weaknesses of both wooden and computer-generated models were evaluated.

From the experiences of the pilot tests and from prior research (Zavotka, 1985), it was decided that at least four hours of treatment would be required to demonstrate differences in treatment effects. This required four weeks of laboratory exposure in Technical Graphics 108. For each hour of class, four objects were developed. These were chosen from the textbook Introduction to Engineering Drawing (Luzadder & Duff, 1989) used in Technical Graphics 108.

During Summer Semester 1990, all teaching materials were developed. Both wooden and computer-generated models were produced at double scale from selected traditional pictorials from the textbook Introduction to Engineering Drawing (Luzader & Duff, 1989) (see Figure 7). Selection of these problems was based on the literature review of engineering graphics, the opinions of an engineering graphics panel of experts (Dr. Gary R. Bertoline, Dr. Jon M. Duff, and Professor William A. Ross of the Department of Technical Graphics, Purdue University), and prior experiences of the researcher.
Sixteen color-rendered computer-generated objects were developed from the textbook pictorials. A programmed macro (see Appendix C) also was developed that would allow the user to select an object and rotate it in any direction with the use of two keystrokes.

Sixteen sets of twenty-five wooden blocks of the figures were also developed. The real-models were solid wooden blocks. The surfaces were painted to match the computer-generated models, and they were the same size as the computer-generated models.

The line drawing pictorials then were transferred from the textbook illustrations to separate sheets that contained orthographic grids upon which the solution was to be sketched. These assignment sheets also contained a scoring section at the top (see Appendices D-G). The scoring section of the assignment sheets allowed the instructors to
record any questions or problems that the students might have had with the specific problem. This allowed the researcher to acquire data about the nature of the questions and problems that students had on each problem.

**Training the Laboratory Instructors**

Before the study could be undertaken, all laboratory instructors had to be informed of the procedures they were to follow during laboratory sessions. A two-hour meeting was held two days before classes began. This meeting informed the laboratory instructors of the purpose and significance of the study. They were instructed on recording and scoring of the laboratory sheets. The researcher, throughout the study, had a formal weekly meeting with the laboratory instructors and many unscheduled meetings to answer questions concerning the study and to make sure teaching assistants were recording all laboratory activities.

**Consent for Participation**

During the first lecture meeting of Technical Graphics 108 during Fall Semester 1990, students were given an informed consent form (Appendix H) to read. They also were verbally informed that they might have the opportunity to participate in a research study. It was explained to the students that they would be selected randomly to participate in the study based on the results of the *Successive Perception Test I*. It was explained also to the students that the results of the *Successive Perception Test I* would not count toward their course grade and that they should do as well as possible on this test. Lastly, it was explained to the students that participation in this study was purely on a voluntary basis and that if they chose not to participate, this decision would not affect their grade in the course. Also, a blind was used so that the researcher did not know who chose or did not choose to participate in the study. Human subjects’ approval was granted by both Purdue University and The Ohio State University (Appendix I).
Administration of the Successive Perception Test I

The entire population of Technical Graphics 108 was administered the *Successive Perception Test I* during the first laboratory session. From test results, students were to be classified as either visual or haptic. L. A. Ausburn (1979) classified individuals who scored 21 or higher as visuals and those who scored 14 or lower as haptics. She based these scores on Lowenfeld’s (1945) theory of visual/haptic learning style.

Because of schedule limitations of Technical Graphics 108 and the time limitation of 24 hours before receiving data back from the Center for Instructional Services at Purdue University, results of the administration of the *Successive Perception Test I* of the Monday section were used to determine if L. A. Ausburn’s (1979) classification of visual/haptic learning style would be found in this population. It was necessary to use Monday’s results as a standard for both Wednesday and Friday sections, because Friday’s results would not be available until Monday afternoon. Thus, the study would have had to begin the third week of the semester if the combined data from each day were used and then randomly assigned to the treatment groups. Waiting until the third week was not feasible because too much material would not be covered throughout the semester.

The results of the Monday administration were recorded; and 10 students scored 14 or less and 102 scored 25 or greater out of 165 students who participated in the Monday administration of the *Successive Perception Test I*. These results showed that the Technical Graphics 108 population was skewed toward being visual. Ausburn’s definition of visual/haptic was not accurate for this population and her classification would not allow this study to be executed as originally planned. The sample that Ausburn (1979) used was college of education majors and the sample determined for this study was college of engineering majors. The engineering majors as a whole seemed to be more visual, or defining them as visuals or haptics required a different scale based upon the results of the *Successive Perception Test I* from this population.
After reviewing the data of the Monday administration of the *Successive Perception Test I*, a decision was made to redefine visual/haptic learning style for this study based on the Monday section data. The mean score for the Monday administration of the *Successive Perception Test I* was 21.370, with a standard deviation of 3.859. One standard deviation from the mean yielded a break in the score distribution with a low score of 17 and a high score of 25. This defined 27 (16%) of the students as haptics, 31 (19%) of the students as visuals, and 107 (65%) of the students as indefinites (see Figure 8). Although these percentages did not match Lowenfeld's theoretical percentages, the population from which his theoretical percentages were based was never clearly defined but Lowenfeld's research was conducted in art education and it did not involve engineering students.

![Histogram of the Monday section administration of the *Successive Perception Test I*.](image)

The mean score for the Wednesday administration of the *Successive Perception Test I* was 21.583 with a standard deviation of 4.062. One standard deviation from the mean also yielded a lesser break in the score distribution with a low score of 17 and a high score of 25 compared to the Monday section. This defined 29 (17%) of the students as haptics, 40 (23%) of the students as visuals, and 99 (60%) of the students as indefinites (see Figure 9). The mean score for the Friday administration of the *Successive Perception Test I* was
21.524 with a standard deviation of 3.964. One standard deviation from the mean resulted in a low score of 17 and a high score of 25. This defined 26 (16%) of the students as haptics, 38 (23%) of the students as visuals, and 100 (61%) of the students as indefinites (see Figure 10). The combined mean for all three administrations of the *Successive Perception Test I* was 21.493 with a standard deviation of 3.956 (see Figure 11). Because these values were relatively consistent throughout the population, a haptic was defined as scoring a 17 or below, and a visual was defined as scoring a 25 or higher on the *Successive Perception Test I*.

![Graph](Image)

**Figure 9.** Histogram of the Wednesday section administration of the *Successive Perception Test I*. 
Figure 10. Histogram of the Friday section administration of the Successive Perception Test I.

Figure 11. Histogram of the combined sections of the administration of the Successive Perception Test I.
Selection of the Sample

The population (497 subjects) from which the sample was drawn consisted of freshman engineering students enrolled in Graphics for Engineers (Technical Graphics 108) during the Fall Semester 1990 at the West Lafayette, Indiana, campus of Purdue University. The sample selected for the study was based upon the adjusted visual/haptic scale as determined by the Successive Perception Test I. The sample (150 subjects) involved students who were identified as possessing strong visual (75 subjects) or haptic (75 subjects) learning styles. Individuals classified as visuals (25 or higher on the Successive Perception Test I) were placed randomly into either the traditional exercise (n=25), the computer-generated model group (n=25), or the real-model group (n=25). This same procedure was also used to assign randomly the haptic subjects (17 or lower on the Successive Perception Test I) into the traditional exercise (n=25), the computer-generated model group (n=25), or the real-model group (n=25).

Before the second laboratory session the students identified as being either visuals (n=109) or haptics (n=82) were assigned randomly to a treatment group for participation in the study. During the second laboratory session they were asked to sign the informed consent form if they volunteered to participate in the study. Eight visual and five haptic subjects chose not to participate in the study and 26 visual and two haptic subjects were not selected to participate in the study. The subjects then were asked to sign up for a computer-generated or real-model laboratory time slot that would fit their schedule. They then left their traditional laboratory session.

The experimental laboratory sessions were in place of their regularly scheduled one-hour laboratory sessions. The experimental laboratories were offered at alternative times to the regular laboratory sessions necessary because of the logistical constraints of laboratory space being available during the study. Although the students had to attend a laboratory session at a different time than their normal laboratory time, all laboratory sessions, both traditional and experimental, were 50 minutes in length and a student could attend only one
laboratory session each week. The size of the traditional laboratories ranged from nine to nineteen students. This was determined by how many students volunteered for the study and left the traditional classroom session.

The size of the experimental laboratories ranged from five to eighteen students. This was determined by how many students volunteered to participate in one of the experimental laboratories at a given time. The experimental laboratories were offered at various times during the day and in the evening. The computer-generated model laboratories were offered from 9:30 a.m. to 4:30 p.m., 6:00 p.m., and 8:00 p.m. on Monday. Computer-generated model laboratories were also offered on Tuesday and Thursday at 7:00 p.m. and 9:00 p.m., and Wednesday and Friday at 6:00 p.m. and 8:00 p.m. The real-model laboratories were offered from 9:30 a.m. to 4:30 p.m., 7:00 p.m., and 9:00 p.m. on Tuesdays. Real-model laboratories were also offered on Tuesday and Thursday at 6:00 p.m. and 8:00 p.m., and Wednesday and Friday at 7:00 p.m. and 9:00 p.m. A student could attend only one of these laboratory meetings per week during the study. They were not allowed to attend any other laboratory session. The experimental laboratory sessions were not divided by visual/haptic learning style, thus each laboratory section contained students who were haptics and visuals.

Administering the Treatment

Throughout this study all students received the same laboratory problems and the same amount of time in the laboratory sessions. The differences between the control group for the study and the two experimental groups were the instructor, the treatment, and the time laboratory sessions were held. The control group received the traditional laboratory sessions with their assigned undergraduate teaching assistant, while the experimental groups were supplemented with either the real or computer-generated models during the laboratory sessions. Because of logistical constraints the experimental sessions were directed by the researcher. Again because of logistical factors the experimental groups and
the control groups had different laboratory meeting times as discussed earlier. Because the researcher conducted all experimental laboratories extreme care was taken not to make the presentation of the concepts different from the traditional laboratories. One possible confounding variable was that the time the experimental labs were available was different then the normal labs. But students had the opportunity to choose a time from over twenty possible experimental labs, thus the researcher hoped that this reduced time as a confounding variable.

The administration of the treatment for this study lasted four weeks. During each week of the study, students in all treatment groups were given drawing problems that contained a pictorial sketch of a real-model and an orthographic grid on which they were to sketch a three-view orthographic representation of the object (see Appendices D-G). Four problems were to be completed during each week. The students had to determine the most descriptive view of the object and sketch this as the front view. They then had to sketch the top view and one side view of the object. The grades for the exercises were based upon the correct visualization of the object and the accuracy of the sketched orthographic representation based on engineering graphics standards.

One problem was due at the conclusion of each laboratory session. The students were required to stay in laboratory the full length of the laboratory session unless they completed all four problems and turned them in to their instructor. If they did not complete all four problems, they were allowed to work on them outside of laboratory and these problems were due at the beginning of the next laboratory session. They were asked to record the amount of time on each problem and if they did the problem outside of laboratory.

During the first week of the treatment, the students were required to complete four drafting assignments (see Appendix D). The first four exercises were introductory. The purpose of these exercises was to introduce the students to the concepts of orthographic projection. The geometry of these problems consisted of only normal rectangular and
normal cylindrical solids. The students were required to sketch each view according to orthographic standards, including hidden features and lines of symmetry.

The geometry of the problems used during the second week (see Appendix E) was more complex than the geometry of the problems used during the first week. These problems, like the first week of problems, contained normal rectangular and normal cylindrical solids. In addition, they introduced inclined rectangular solids. The purpose of these problems was to reinforce the standards and theory of orthographic projection by showing how an inclined surface is different from a normal surface and how inclined surfaces must be represented on a two-dimensional drawing plane.

During the third week (see Appendix F) of the treatment, the complexity of the geometry of the problems was increased. The problems contained normal rectangular, normal cylindrical, and inclined surfaces. The purpose of these problems was to reinforce further orthographic projection theory and standards and to give the students more problems to develop further their spatial and sketching abilities. No new concepts were introduced during this week.

During the fourth week (see Appendix G) the complexity of the geometry of the problems increased. During this week oblique surfaces were introduced to the students. The problems also included normal and inclined surfaces. The problems containing oblique surfaces were the most complex drawings that the students had to visualize and sketch. These problems progressed from simple to complex oblique surfaces. The students then were informed that the treatment portion of the study was complete and that they should report to their regular laboratory the following week.

The week following the last treatment, the entire population of students was administered the Mental Rotations Test and the Successive Perception Test I. The Mental Rotations Test was used to measure the spatial abilities of the students and the Successive Perception Test I was used to determine the visual/haptic learning styles of the students. The students then were informed that the study was completed. During the remainder of
During the final laboratory meeting of the semester, the subjects who participated in the study were asked to complete a questionnaire concerning the study (see Appendix J). The purpose of this questionnaire was to determine if the subjects felt that the treatment they received helped or hindered them throughout the semester, and specifically if it helped them to develop and advance their visualization abilities.

Research Design

For this study the research design consisted of two major sections that were used to test specific hypotheses of the study. The main objective of the study was to determine the effects of visual/haptic learning style and instructional treatment upon the spatial ability of the subjects. To determine if visual/haptic learning style, instructional treatment, or an interaction between visual/haptic learning style and treatment significantly affected the subjects' spatial abilities, a 2 x 3 factorial experimental design, the posttest-only control group design was used to test the hypotheses 5 through 18 (see Figure 12). This overall design meets the criteria for being an experimental study by having individual students randomly selected from two matched pools of attribute variables (visual/haptic learning style) to three levels of the independent variable (traditional, real-model supplemented, or computer-supplemented instructional approaches). This experimental design allows the researcher to determine the main effects of visual/haptic learning style and instructional treatment and any interaction between these variables on the dependent variable of spatial ability. This design controls for the sources of internal validity of history, maturation, testing, instrumentation, regression, selection, mortality, and the interaction between them. The weakness of this design is in controlling for external validity concerns of interaction of selection and treatment and reactive arrangements (Campbell & Stanley, 1963).
Figure 12. Experimental design for the study

To determine if an individual changed visual/haptic learning style because of treatment effects, a pretest-posttest design was used. This design compared the mean of the subjects on the \textit{Successive Perception Test I} pretest score with the mean scores of the subject on the posttest score of the \textit{Successive Perception Test I} that was administered after the experiment.

\textbf{Data Analysis}

Different types of tests are appropriate for different sets of data. The following set of procedures was used for the statistical analysis for this study. First, the Cronbach Alpha Reliability statistic was used to determine if the \textit{Successive Perception Test I} was a reliable instrument for predicting visual/haptic learning style. This analysis was performed on both the pretest and posttest administration of the \textit{Successive Perception Test I}.

Second, a Chi-square goodness-of-fit was used to determine if Lewenfeld's prediction that 47 percent of the population are visuals, 30 percent of the population are indefinites, and 23 percent of the population was true for the population used in this study as stated by \( H_0 : 1 \).

Third, an analysis of variance was used to determine the decision to be reached concerning \( H_0 : 2 \) through \( H_0 : 17 \). These hypotheses are concerned with the main effects of visual/haptic learning styles of the subjects and instructional treatment and any interaction that might occur between them. A two-factor ANOVA was used to test for the main effects
of visual/haptic learning style and treatment and any interactions between them. The one
factor ANOVA test was used to compare specific visual/haptic learning styles and treatment
types against other visual/haptic learning styles and treatment combinations.

The ANOVA was chosen because it is extremely robust when violations of normality
and unequal numbers occur (Hopkins, et. al., 1987). It also is recommended to determine
if there is a significant difference between two or more groups. However, four
assumptions must be met before the ANOVA is used. One is that the variable is normally
distributed in the population. Gay (1981) reports that most variables studied in educational
settings are distributed normally. A second assumption is that the data is interval or ratio.
For this study, the posttest scores of the Successive Perception Test I are interval. The
third assumption is that the subjects are selected independently, which they were for this
study. The fourth assumption is that the variance of the groups is equal.

Fourth, the Pearson Correlation Coefficient was utilized to determine the correlation
between the posttest administration of Successive Perception Test I and the posttest
administration of the Mental Rotations Test as stated by HO: 18.

Finally, the percentages of subjects who were classified as visual, haptic, or indefinite
learning style types from the pretest administration of the Successive Perception Test I
were compared to the posttest administration of the Successive Perception Test I.

Summary

Chapter 3 described the procedures that were followed for this study. The instruments
and instructional setting for the study were reported. The methods used to perform the
study were reported, including selection of the software and exercises, development of the
instructional materials, training of the laboratory instructors, development and
administration of the consent for participation form, administration of the pretest, selection
of the sample, administration of the treatment, and administration of the posttest. The
research design and data analysis were the last topics covered.
CHAPTER IV
ANALYSIS OF THE DATA

Results of the Study

This chapter presents the analysis of data for the study. Null hypotheses were tested and results are presented in five major sections based on the research hypotheses of the study. Each section, except the first and last, begins with the appropriate null hypotheses, reports the analysis of data, and presents conclusions about the rejection or the failure to reject the null hypotheses. Each hypothesis was tested at the 0.05 level of probability.

Cronbach Alpha Test of Reliability on the Successive Perception Test I

The first section is concerned with a quality control check of the reliability of the Successive Perception Test I. Because this test has previously inconsistently high reliability ratings, the reliability of the Successive Perception Test I was examined for the population used in this study.

The procedure used to determine the reliability of the Successive Perception Test I involved the use of the Cronbach Alpha Test of Reliability. Table 1 presents the Cronbach Alpha data for the pretest and posttest administration of the Successive Perception Test I. The Successive Perception Test I shows a somewhat low reliability coefficient for both administrations. Thorndike and Hagen (1969) note that reliability of a test must be considered in terms of other procedures with which it competes. In the case of the Successive Perception Test I, no other group measure of visual/haptic learning style currently is available. They note further that the accuracy of conclusions drawn from a test with low reliability is greater with group data than with individual data. Thorndike and Hagen (1969) state, “A test with relatively low reliability will permit us to make useful
Table 1

Cronbach Alpha Test of Reliability of the *Successive Perception Test I*

<table>
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<th>Administration</th>
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<th>Posttest</th>
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</tbody>
</table>

studies of and draw accurate conclusions about groups, especially groups of substantial size, but quite high reliability is required if we are to speak with confidence about individuals (p. 95).” Therefore, because a large group administration of the *Successive Perception Test I* was used, it was considered a reliable measure for use in this study.

**Chi-square Goodness-of-Fit of Lowenfeld’s Theory**

The first hypothesis was concerned with whether Lowenfeld’s theory of visual/haptic learning style was reflected in the population used for this study. A Chi-square goodness-of-fit compared Lowenfeld’s theoretical percentages with actual percentages of the population used in this study.

**HO1:** The proportion of visual/haptic learning style types in the population for this study will not differ significantly from the 47 percent visuals, 23 percent haptics, and 30 percent indefinites found in the research of Lowenfeld.
The procedure used to test this hypothesis was the Chi-square goodness-of-fit statistic. This statistic compared Lowenfeld’s theoretical prediction of visual/haptic percentages with the actual percentages found from the pretest administration of the *Successive Perception Test I* to the population of this study. This statistical analysis was conducted on the adjusted visual/haptic learning style scale used for this study which defined a haptic as scoring 17 or below, a visual as scoring 25 or higher, and an indefinite as scoring between 18 and 24 on the *Successive Perception Test I*. Table 2 shows the descriptive breakdown of the actual percentages of the population. Table 3 reports the Chi-square goodness-of-fit statistics.

A significant difference was found indicating that Lowenfeld’s prediction that 47 percent of the population are visual, 30 percent of the population are indefinite, and 23 percent of the population are haptic was incorrect for the population used in this study. The calculated probability of 0.00 was less than the established 0.05 alpha level. Therefore, Hypothesis 1 was rejected.

Lowenfeld’s visual/haptic theoretical percentages differed significantly from the actual visual/haptic learning style percentages found in the population even with the adjusted scale used to define visual/haptic learning style used in this study. This adjusted scale changed the cutoff points for a haptic from 14 to 17, an indefinite from 15 to 18, and a visual from 21 to 25.

All of the prior visual/haptic research (Lowenfeld, 1939, 1945; Wiggin, 1951; Erickson, 1963, 1966, 1969; Clark, 1971) was conducted with elementary, middle school, or high school students. College age students used in visual/haptic research studies were education majors (F. B. Ausburn, 1975; Ausburn, 1975, 1979). Because engineering students in the population from this study scored higher on the *Successive*
Table 2

Descriptive Data for the Chi-Square Goodness-of-fit Test

<table>
<thead>
<tr>
<th>Learning Style</th>
<th>Frequency</th>
<th>%</th>
<th>Cumulative Frequency</th>
<th>Cumulative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haptic</td>
<td>82</td>
<td>16.50</td>
<td>82</td>
<td>16.5</td>
</tr>
<tr>
<td>Indefinite</td>
<td>306</td>
<td>61.57</td>
<td>388</td>
<td>78.07</td>
</tr>
<tr>
<td>Visual</td>
<td>109</td>
<td>21.93</td>
<td>497</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Note: Based on the adjusted visual/haptic learning style scale of 17 or less is a haptic and 25 or greater is a visual.

Table 3

Chi-Square Goodness-of-fit Test of Lowenfeld’s Theoretical Visual/Haptic Learning Style Values with the Actual Population Values from the Study

<table>
<thead>
<tr>
<th></th>
<th>Lowenfeld’s theoretical population values</th>
<th>Actual population values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haptic</td>
<td>114</td>
<td>82</td>
</tr>
<tr>
<td>Indefinite</td>
<td>149</td>
<td>306</td>
</tr>
<tr>
<td>Visual</td>
<td>234</td>
<td>109</td>
</tr>
<tr>
<td>Probability Value</td>
<td>0.00*</td>
<td></td>
</tr>
</tbody>
</table>

Note: Based on the adjusted visual/haptic learning style, scale of 17 or less is a haptic and 25 or greater is a visual.

*p<.05
Perception Test I, it was clearly a different population than those used in prior research studies. Thus, it is logical that Hypothesis 1 was rejected, and that engineering majors as a whole are self-selected and seem to be predominately indefinite followed by visual learning style types.

**Testing for Interaction Between Visual/Haptic Learning Style and Treatment**

The second research hypothesis investigated if the experimental instructional methods and media (traditional supplemented by real-models, and traditional supplemented by computer-generated surface models) interacted with the learning style (visual/haptic) of the students, allowing for a greater increase in spatial abilities than would have occurred with the traditional engineering graphics instructional methods or media. The results of this research hypothesis is divided into two sections. The posttest scores of the *Mental Rotation Test* were analyzed using one and two factor ANOVAs to determine if there was a significant difference between visual/haptic learning style, treatment, and interaction of these variables. The second section gives the results of the summative evaluation administered at the conclusion of the course. These results are presented in percentage form for each set of problems and are divided by visual/haptic learning style and treatment.

First, the posttest scores of the *Mental Rotation Test* were analyzed using one and two factor ANOVAs to determine if there were significant differences between visual/haptic learning style, treatment, and interaction between these variables. But before the results of the ANOVA statistic could be evaluated, three assumptions needed to be considered.

**Testing the Assumptions of the ANOVA**

The assumptions of the ANOVA are normality, homogeneity of variance, and independence of samples. These assumptions must be accounted for to determine if the statistics are valid. Bartlett's test was used to determine the homogeneity of variance of the
ANOVA of the Mental Rotations Test mean scores. The Chi-square goodness-of-fit test was used to determine if the ANOVA of the Mental Rotations Test mean scores was distributed normally. Because the sample was a random independent sample, the independence of samples assumption was met. Both Bartlett’s test and the Chi-square goodness-of-fit test were tested at the 0.05 probability level.

The hypothesis of the Bartlett’s test is that the variance of the residuals is constant. The calculated probability of 0.61 was greater than the established 0.05 alpha level. Therefore, the hypothesis for assumption of homogeneity of variance was not rejected.

The hypothesis for the Chi-square goodness-of-fit test is that the ANOVA of the Mental Rotations Test mean scores are distributed normally. The calculated probability of 0.00 was less than the established 0.05 alpha level. Therefore, Hypothesis 1 was rejected. The mean scores for the Mental Rotations Test were not distributed normally, thus the assumption of normality was not satisfied. Although the mean scores for the Mental Rotations Test were not distributed normally, Hopkins et. al. state, "that the violation of the assumption of normality has almost no practical consequences" (p. 166). Thus, the significance of this assumption is not important because both other assumptions were met and because it will not adversely affect the statistical analysis.

Two-factor ANOVA on the Mental Rotations Test Scores

The first test investigated if there were significant interactions between visual/haptic learning style and treatment on spatial ability as measured by the Mental Rotations Test. This information was analyzed using a two-factor analysis of variance to determine if there were significant interactions occurring. The hypothesis listed below refers to the interaction between visual/haptic learning style and treatment.

H02: There will be no significant interaction between visual/haptic learning style and instructional treatment of the group mean scores on the Mental Rotations Test.
This hypothesis was tested using a two-factor ANOVA on group mean test scores. Table 4 shows the descriptive statistics for the *Mental Rotations Test* scores by treatment. Table 5 shows the descriptive statistics for the *Mental Rotations Test* scores by visual/haptic learning style. Table 6 reports the data from the two-factor ANOVA on the data in Tables 4 and 5.

The ANOVA suggests that there is no significant interaction between visual/haptic learning style and treatment on the *Mental Rotations Test*. The calculated probability of 0.6955 was greater than the established 0.05 alpha level. Therefore, Hypothesis 2 was not rejected.

Because interaction effects did not significantly occur, the main effects of treatment and visual/haptic learning style were examined. The two-factor ANOVA was used to determine if there were significant differences on the main effects of the mean scores of visual/haptic learning style and the mean scores of treatment on the *Mental Rotations Test*.

**H03:** There is no significant difference between group mean scores on the *Mental Rotations Test* between subjects who have been classified as being visual or haptic learning style.

**H04:** There is no significant difference between group mean scores on the *Mental Rotations Test* between subjects who used the traditional exercises and students who used the real-model exercises.

**H05:** There is no significant difference between group mean scores on the *Mental Rotations Test* between subjects who used the traditional exercises and students who used the computer-generated model exercises.

**H06:** There is no significant difference between group mean scores on the *Mental Rotations Test* between subjects who used the computer-generated model exercises and students who used the real-model exercises.
Table 4

**Descriptive Data for the Mental Rotations Test by Treatment**

<table>
<thead>
<tr>
<th>Treatment groups</th>
<th>Traditional</th>
<th>Real-model</th>
<th>Computer-generated model</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>49</td>
<td>46</td>
<td>47</td>
</tr>
<tr>
<td>M</td>
<td>11.53</td>
<td>12.97</td>
<td>11.85</td>
</tr>
<tr>
<td>SD</td>
<td>4.40</td>
<td>4.16</td>
<td>4.33</td>
</tr>
<tr>
<td>SE</td>
<td>0.63</td>
<td>0.61</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Table 5

**Descriptive Data for the Mental Rotations Test by Visual/Haptic Learning Style**

<table>
<thead>
<tr>
<th>Learning style</th>
<th>Visual</th>
<th>Haptic</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>74</td>
<td>68</td>
</tr>
<tr>
<td>M</td>
<td>13.88</td>
<td>10.18</td>
</tr>
<tr>
<td>SD</td>
<td>3.57</td>
<td>4.25</td>
</tr>
<tr>
<td>SE</td>
<td>0.41</td>
<td>0.52</td>
</tr>
</tbody>
</table>
Table 6

ANOVA Data for the Mental Rotations Test

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F value</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning style</td>
<td>1</td>
<td>472.52</td>
<td>472.52</td>
<td>30.84</td>
<td>0.0001</td>
</tr>
<tr>
<td>Treatment</td>
<td>2</td>
<td>41.32</td>
<td>20.66</td>
<td>1.35</td>
<td>0.2630</td>
</tr>
<tr>
<td>Learning style x treatment</td>
<td>2</td>
<td>11.16</td>
<td>5.58</td>
<td>0.36</td>
<td>0.6955</td>
</tr>
<tr>
<td>Error</td>
<td>136</td>
<td>2083.48</td>
<td>15.32</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These hypotheses were tested using a two-factor ANOVA on group mean test scores. Table 4 shows the descriptive statistics for the Mental Rotations Test scores by treatment. Table 5 shows the descriptive statistics for the Mental Rotations Test scores by visual/haptic learning style. Table 6 reports the data from the two-factor ANOVA on the data in Tables 4 and 5.

The ANOVA suggests that a significant difference is present. First, the ANOVA suggests that there is a significant difference between the group means of visual and haptic learning style. To reject the null hypothesis, the probability associated with the calculated value of the test statistic must be equal to or less than the 0.05 alpha level. Because the calculated probability was 0.0001, Hypothesis 3 was rejected. Thus, visual learning style group mean score of 13.88 on the Mental Rotations Test was higher and significantly different from the group mean score of 10.18 for haptic subjects.

Second, the ANOVA suggests that there are no significance differences between the treatment groups. To reject the null hypothesis, the probability associated with the
calculated value of the test statistic must be equal to or less than the 0.05 alpha level. Because the calculated probability was 0.26, Hypotheses 4, 5, and 6 were not rejected. Thus, the mean scores of 11.85 for the computer-generated model group, 12.98 for the real-model group, and 11.53 for the control group were not significantly different.

Thus, results of the two-way ANOVA show a significant difference between visual and haptic learning style individuals’ spatial abilities as measured by the *Mental Rotations Test*. The two-way ANOVA results also show that there were no significant differences between the treatment groups. The significant difference between visual and haptic subjects on the *Mental Rotations Test* was consistent with Lowenfeld’s theories and prior research in this area. Visual subjects should score higher than haptic subjects on a visual format test.

The second finding of no significant difference between the treatment groups is less clear. In prior research on the use of models in engineering graphics, some researchers claim models are helpful (Vanderwall, 1981; Young, 1952; Rowe, 1938, 1945), while others (French, 1913; Orth, 1941) claim that they hinder the students to advance their spatial abilities. Zavotka’s (1985) research showed that computer models did help students to advance their spatial abilities. While the visual/haptic learning style research of Lowenfeld (1945) would advocate the use of real-models for haptic subjects, the experimental instructional treatments would not be necessary for visual subjects. The next set of hypotheses examined if a specific treatment would benefit a visual or haptic learning style and allow individuals to advance their spatial abilities more than one of the other treatment types.

**One-factor ANOVA on the *Mental Rotations Test* Scores by Visual Learning Style**

The research design included specific treatment and visual/haptic learning style group comparisons using a one-factor ANOVA to determine significant statistical differences. This statistical technique was used to determine if significant differences occurred in spatial ability development as measured by the *Mental Rotations Test*. The following hypotheses
tested how the different treatments affected the *Mental Rotations Test* mean scores for visual subjects.

**H07:** There is no significant difference between group mean scores on the *Mental Rotations Test* for visual subjects using traditional exercises and visual subjects using real-model exercises.

**H08:** There is no significant difference between group mean scores on the *Mental Rotations Test* for visual subjects using traditional exercises and visual subjects using computer-generated model exercises.

**H09:** There is no significant difference between group mean scores on the *Mental Rotations Test* for visual subjects using computer-generated model exercises and visual subjects using real-model exercises.

**H010:** There is no significant difference between group mean scores on the *Mental Rotations Test* for visual subjects by treatment.

These hypotheses were tested using a one-factor ANOVA on group mean test scores of the *Mental Rotations Test*. Table 7 shows the descriptive data for the *Mental Rotations Test* by the visual learning style group. Table 8 reports the data from the one-factor ANOVA on the data in Table 7.

To reject the null hypothesis, the probability associated with the calculated value of the test statistic must be equal to or less than the 0.05 alpha level. After contrasting the mean scores between visual subjects with traditional treatment and visual subjects with real-model treatment, the probability value was 0.33. Thus, Hypothesis 7 was not rejected.

After contrasting the mean scores between visual subjects with traditional treatment and visual subjects with computer-generated model treatment, the probability value was 0.67. Thus, Hypothesis 8 was not rejected.

After contrasting the mean scores between visual subjects with real-model treatment and visual subjects with computer-generated model treatment, the probability value was 0.16. Therefore, Hypothesis 9 was not rejected.
Table 7

Descriptive Data for the *Mental Rotations Test* by Visual Learning Style

<table>
<thead>
<tr>
<th>Visual treatment groups</th>
<th>Traditional</th>
<th>Real-model</th>
<th>Computer-generated model</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>24</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>M</td>
<td>13.67</td>
<td>14.76</td>
<td>13.20</td>
</tr>
<tr>
<td>SD</td>
<td>3.57</td>
<td>3.53</td>
<td>3.54</td>
</tr>
<tr>
<td>SE</td>
<td>0.73</td>
<td>0.71</td>
<td>0.71</td>
</tr>
</tbody>
</table>

After contrasting the mean scores between visual learning style subjects between all three treatments, the probability value was 0.07. Thus, Hypothesis 10 was not rejected.

For visual subjects no significant differences in spatial ability as measured by the *Mental Rotations Test* was found between the three treatment groups. Thus, for visual subjects, the mean scores of 13.20 for the computer-generated model group, 14.76 for the real-model group, and 13.20 for the control group were not different significantly from each other.

These results seem to support Lowenfled's theory that visual subjects should be capable of working with visual images naturally, and they should not benefit from additional treatment methods. Any additional treatment methods seem unnecessary by the visual subjects to help visualize.

**One-factor ANOVA on the *Mental Rotations Test* Scores by Haptic Learning Style**

The one-factor ANOVA statistical technique was used also to determine if significant differences occurred in spatial ability development for haptic subjects by treatment.
Spatial ability was measured by the *Mental Rotations Test*. The following hypotheses tested how the different treatments affected the *Mental Rotations Test* mean scores for haptic subjects.

HO11: There is no significant difference between group mean scores on the *Mental Rotations Test* for haptic subjects using traditional exercises and haptic subjects using real-model exercises.

Table 8

ANOVA Data for the *Mental Rotations Test* by Visual Learning Style

<table>
<thead>
<tr>
<th>Source/Contrast</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F Value</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1 vs G2</td>
<td>1</td>
<td>14.64</td>
<td>14.64</td>
<td>0.96</td>
<td>0.33</td>
</tr>
<tr>
<td>G2 vs G3</td>
<td>1</td>
<td>30.42</td>
<td>30.42</td>
<td>1.99</td>
<td>0.16</td>
</tr>
<tr>
<td>G1 vs G3</td>
<td>1</td>
<td>2.67</td>
<td>2.67</td>
<td>0.17</td>
<td>0.68</td>
</tr>
<tr>
<td>G1 vs G2 vs G3</td>
<td>2</td>
<td>31.01</td>
<td>16.01</td>
<td>1.04</td>
<td>0.35</td>
</tr>
<tr>
<td>Error</td>
<td>136</td>
<td>2083.48</td>
<td>15.32</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

G1 = Visual Learning Style with Traditional Treatment

G2 = Visual Learning Style with Real-model Treatment

G3 = Visual Learning Style with Computer-Generated Model Treatment

HO12: There is no significant difference between group mean scores on the *Mental Rotations Test* for haptic subjects using traditional exercises and haptic subjects using computer-generated model exercises.

HO13: There is no significant difference between group mean scores on the *Mental Rotations Test* for haptic subjects using computer-generated model exercises and haptic subjects using real-model exercises.
HO14: There is no significant difference between group mean scores on the Mental Rotations Test for haptic subjects by treatment.

These hypotheses were tested using a one-factor ANOVA on group mean test scores of the Mental Rotations Test. Table 9 shows the descriptive data for the Mental Rotations Test by the haptic learning style. Table 10 reports the data from the one-factor ANOVA on the data in Table 9.

Table 9

Descriptive Data for the Mental Rotations Test by Haptic Learning Style

<table>
<thead>
<tr>
<th>Haptic treatment groups</th>
<th>Traditional</th>
<th>Real-model</th>
<th>Computer-generated model</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>25</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>M</td>
<td>9.48</td>
<td>10.86</td>
<td>10.32</td>
</tr>
<tr>
<td>SD</td>
<td>4.19</td>
<td>3.90</td>
<td>4.70</td>
</tr>
<tr>
<td>SE</td>
<td>0.84</td>
<td>0.85</td>
<td>1.00</td>
</tr>
</tbody>
</table>

To reject the null hypothesis, the probability associated with the calculated value of the test statistic must be equal to or less than the 0.05 alpha level. Contrasting the mean scores between haptic subjects with real-model treatment and haptic subjects with computer-generated model treatment, the probability value was 0.65. Thus, Hypothesis 13 was not rejected.

Because there was no difference in the mean scores between haptic subjects with real-model treatment and haptic subjects with computer-generated model treatment, haptic subjects with traditional treatment were contrasted against the mean score of these two
groups. The probability value was 0.26. Therefore, Hypotheses 11 and 12 were not rejected.

Table 10

**ANOVA Data for the Mental Rotations Test by Haptic Learning Style**

<table>
<thead>
<tr>
<th>Source/Contrast</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F Value</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>G5 vs G6</td>
<td>1</td>
<td>3.12</td>
<td>3.12</td>
<td>0.20</td>
<td>0.66</td>
</tr>
<tr>
<td>G4 vs G5 &amp; G6</td>
<td>1</td>
<td>19.39</td>
<td>19.39</td>
<td>1.27</td>
<td>0.26</td>
</tr>
<tr>
<td>G4 vs G5 vs G6</td>
<td>2</td>
<td>22.98</td>
<td>11.15</td>
<td>0.73</td>
<td>0.48</td>
</tr>
<tr>
<td>Error</td>
<td>136</td>
<td>2083.48</td>
<td>15.32</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Key:

- G4 = Haptic Learning Style with Traditional Treatment
- G5 = Haptic Learning Style with Real-model Treatment
- G6 = Haptic Learning Style with Computer-Generated Model Treatment

After contrasting the mean scores between haptic subjects across all three treatments, the probability value was 0.48. Thus, Hypothesis 14 was not rejected.

For haptic subjects, no significant differences in spatial ability as measured by the Mental Rotations Test were found between the three treatment groups. Thus, the mean scores of 10.32 for the computer-generated model group, 10.86 for the real-model group, and 9.48 for the control group were not different significantly.

These results seem to lead to unclear conclusions. First, if Lowenfeld's theories are correct, it would seem that haptic individuals would benefit from being exposed to the real-model treatment. But, because the haptic students did not have any models available when
they took the *Mental Rotations Test*, they did not have the benefit of a model to help visualize the objects on this test. Lowenfeld also theorized that a haptic individual will always be haptic. Thus, the various treatments would not change an individual's visual/haptic learning style. This would explain why there were no differences on the *Mental Rotations Test* because all of these individuals are haptic and no matter what type of treatment they receive, they will always have trouble with visual material.

**One-factor ANOVA on the Mental Rotations Test Scores by Visual/Haptic Learning Style**

After determining that there were not any significant interactions between visual/haptic learning style and treatment, a one-factor ANOVA was used also to determine if significant differences in spatial ability occurred between treatment type by visual/haptic learning style. The following hypotheses tested how visual/haptic learning style affected the *Mental Rotations Test* mean scores for the different treatments. The following hypotheses were tested:

**HO15:** There is no significant difference between group mean scores on the *Mental Rotations Test* for haptic subjects using traditional exercises and visual subjects using traditional exercises.

**HO16:** There is no significant difference between group mean scores on the *Mental Rotations Test* for haptic subjects using real-model exercises and visual subjects using real-model exercises.

**HO17:** There is no significant difference between group mean scores on the *Mental Rotations Test* for haptic subjects using computer-generated exercises and visual subjects using computer-generated exercises.

These hypotheses were tested using a one-factor ANOVA on group mean test scores of the *Mental Rotations Test*. Tables 11, 12, and 13 show the descriptive statistics for the *Mental Rotations Test* scores with treatment by visual/haptic learning style. Table 14 reports the data from the one-factor ANOVA on the data in Tables 11, 12, and 13.
To reject the null hypothesis, the probability associated with the calculated value of the test statistic must be equal to or less than the 0.05 alpha level. Contrasting the mean scores between haptic subjects with traditional treatment and visual subjects with traditional treatment, the probability value was 0.0003. Thus, Hypothesis 15 was rejected.

After contrasting the mean scores between visual subjects with real-model treatment and haptic subjects with real-model treatment, the probability value was 0.0010. Therefore, Hypothesis 16 was rejected.

Table 11

<table>
<thead>
<tr>
<th>Learning Style</th>
<th>Haptic traditional</th>
<th>Visual traditional</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>M</td>
<td>9.48</td>
<td>13.67</td>
</tr>
<tr>
<td>SD</td>
<td>4.19</td>
<td>3.57</td>
</tr>
<tr>
<td>SE</td>
<td>0.84</td>
<td>0.73</td>
</tr>
</tbody>
</table>

After contrasting the mean scores between visual subjects with computer-generated treatment and haptic subjects with computer-generated model treatment, the probability value was 0.0129. Thus, Hypothesis 17 was rejected.

For each treatment, significant differences in spatial ability as measured by the *Mental Rotations Test* were found between visual and haptic subjects.
### Table 12

**Descriptive Data for the Mental Rotations Test with Real-Model Exercises by Visual/Haptic Learning Style**

<table>
<thead>
<tr>
<th></th>
<th>Haptic real-model</th>
<th>Visual real-model</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>21</td>
<td>25</td>
</tr>
<tr>
<td>M</td>
<td>10.85</td>
<td>14.76</td>
</tr>
<tr>
<td>SD</td>
<td>3.90</td>
<td>3.53</td>
</tr>
<tr>
<td>SE</td>
<td>0.85</td>
<td>0.71</td>
</tr>
</tbody>
</table>

For the traditional treatment the visual subjects' mean score of 13.67 was different significantly and higher than the mean score of 9.48 of the haptic subjects. For the real-model treatment the visual subjects' mean score of 14.76 was different significantly and
higher than the mean score of 10.85 of the haptic subjects. For the computer-generated model treatment the visual subjects' mean score of 13.20 was different significantly and higher than the mean score of 10.31 of the haptic subjects.

Table 14

ANOVA Data for the Mental Rotations Test by Treatment Groups

<table>
<thead>
<tr>
<th>Source/Contrast</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F Value</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1 vs G4</td>
<td>1</td>
<td>214.63</td>
<td>214.63</td>
<td>14.01</td>
<td>0.0003*</td>
</tr>
<tr>
<td>G2 vs G5</td>
<td>1</td>
<td>173.85</td>
<td>173.85</td>
<td>11.35</td>
<td>0.0010*</td>
</tr>
<tr>
<td>G3 vs G6</td>
<td>1</td>
<td>97.18</td>
<td>97.18</td>
<td>6.34</td>
<td>0.0129*</td>
</tr>
<tr>
<td>Error</td>
<td>136</td>
<td>2083.47</td>
<td>15.32</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p<.05

Note. Key: G1 = Visual Learning Style with Traditional Treatment  
G2 = Visual Learning Style with Real-Model Treatment  
G3 = Visual Learning Style with Computer-Generated Model Treatment  
G4 = Haptic Learning Style with Traditional Treatment  
G5 = Haptic Learning Style with Real-Model Treatment  
G6 = Haptic Learning Style with Computer-Generated Model Treatment

The results of these hypotheses also support Lowenfeld's visual/haptic theories. Because the Mental Rotations Test is a visual test and because a person's visual/haptic learning style does not change over time or as a result of different experiences, the visual subjects should have outperformed the haptic subjects on the Mental Rotations Test.
Results of the Summative Evaluation

A summative questionnaire (see Appendix J) was used to measure whether students positively or negatively viewed the instructional treatment they received during the study and to see if they might have preferred one or a combination of the treatments to which they might not have been exposed. This information is informal in nature and should be considered as data that would justify future follow-up or related studies. The questionnaire was administered during the final laboratory meeting of Technical Graphics 108. Before the questionnaire was administered, the entire study was explained to each laboratory section by the investigator. Each laboratory section also was shown the real-model, computer-generated model, and traditional treatments. The students had the chance to question the investigator concerning each treatment during this session.

The following paragraphs list the questions on the questionnaire that were directly related to the study, followed by the subjects’ response data. Questions two, three, and nine gathered data for a different study, which was not related to this study, thus the data from these questions is not reported. On all questions except number five, a score of five meant that the subject agreed with the statement and a score of one meant that the student disagreed with the statement. Also, space was provided below each question so students could write comments about each question. The list of these comments can be found in Appendix K.

The descriptive data for each question consists of the median, the range, and the maximum and minimum scores. On question five the data is given by a frequency distribution. The response data is broken down by visual/haptic learning style and instructional treatment, by visual/haptic learning style, and by the overall response data of the sample.

Because this questionnaire was administered on the last day of each laboratory section, many of the students involved in the study skipped this final laboratory session. The
reader is advised that the results of the data are not of the entire sample, and these results should be read and considered with a note of caution.

The first question asked the subjects to rate on a five point scale (5 = agree, 1 = disagree) whether the instructional setting they had during the study helped them to visualize problem solutions. Table 15 presents the results of question one by visual/haptic learning style and instructional treatment. Table 16 presents the results of question one by visual/haptic learning style and the overall results of question one.

The median overall score of four was the same for both the treatment totals and by learning style totals. It would seem that the students agreed that the treatment they were exposed to during the study helped them to visualize solutions to problems.

These statistical results also were reflected in the comments that the subjects made concerning question one (see Appendix K). The haptic subjects' median score on question one was 4.0 and their comments were almost all favorable toward the instructional setting that they were exposed to during the study. The median score for the haptic real-model group was 4.0 and only two subjects from the haptic real-model group gave written responses to question one. Their responses reflected the median score in that the responses were positive toward the use of real-models in helping them to visualize problem solutions. One subject stated, "The physical blocks were helpful because of the views I was able to observe," while a second subject was not as positive but wrote he used the real-models for "only the most difficult problems." The haptic control group median score was also 4.0 and these subjects' written comments were not entirely positive toward the use of traditional exercises for the development of their visualization abilities. One subject commented that the exercises were "too easy," while a second subject claimed that the traditional exercises helped him with his visualization ability "to some extent." The haptic subjects who were exposed to the computer-generated models had a median score of 4.0. There were only positive responses from the haptic subjects who used the computer-generated models except for one subject who stated, "The computer was not used on most
of the problems because it was of little help." One subject stated, "I thought it was very
helpful to me and believe I would have had a great deal of problems without the computer."
Additional haptic computer-generated model subjects' comments included: "It might have
been more helpful to use computers longer" and "When I had problems seeing the figure, it
was good to be able to rotate the figure."

The overall median score for visual subjects was 4.0. The visual subjects who gave
comments about question one were again almost entirely positive with the visual control
group not responding to question one. Although visual control group members did not
give any written comments concerning question one, their median score of 4.0 seemed to
show that these individuals were positive toward using traditional engineering exercises in
the advancement of their spatial abilities. The only negative comments came from the
visual computer-generated model group although the median score for this group was 4.0.
Comments included: "It was difficult to manipulate at times" and "It was kind of slow."
Other visual computer-generated subjects were extremely positive toward the use of the
computer-generated models. One subject stated, "It really helped on those problems that I
had a hard time with." A second subject wrote, "I have really good skill concerning
visualization of objects. If the computer exercises did not help me visualize better, then it
did help me to become faster. But I feel that on larger and more complex models, it can be
very helpful." The median score for visual real-model group was 5.0 and their comments
were also positive. One subject wrote, "These things should be integrated ASAP! They
were extremely helpful in visualization and in determining hidden lines, etc." Other
comments included: "The blocks were a good help when I couldn't visualize the object
from the drawing" and "The three-dimensional models were extremely helpful."

Question four asked the subjects to rate on a five point scale (5 = agree, 1 = disagree)
whether they felt that too much time was spent on this study. Table 17 presents the results
of question four by visual/haptic learning style and instructional treatment. Table 18
presents the results of question four by visual/haptic learning style and the overall results of question four.

Table 15

**Summative Evaluation Data for Question One by Learning Style and Treatment**

<table>
<thead>
<tr>
<th>Haptic</th>
<th>Visual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer</td>
<td>Real</td>
</tr>
<tr>
<td>N</td>
<td>17.0</td>
</tr>
<tr>
<td>Median</td>
<td>4.0</td>
</tr>
<tr>
<td>Range</td>
<td>3.0</td>
</tr>
<tr>
<td>Minimum</td>
<td>2.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>5.0</td>
</tr>
</tbody>
</table>

The median overall score of two was the same for both the treatment totals and by learning style totals. In general it would seem that students did not think too much time was spent on this study.

The written comments concerning question four also seemed to support the notion that students did not seem to think too much time was spent on the study (see Appendix K). The haptic subjects' median score on question four was 2.0 and their comments did not entirely agree with the median score. The haptic traditional group median score was 3.0, which would tend to be a neutral score, not agreeing or disagreeing with the statement that too much time was spent on this study. Only one student made a written comment which would tend to favor spending more time in the introductory portion of the course. The comment was, "There should have been more time spent on the last section." The median score for the haptic real-model group was 1.0 and written comments supported this
Table 16

Summative Evaluation Data for Question One by Learning Style Type and the Combined Overall Data

<table>
<thead>
<tr>
<th></th>
<th>Haptic</th>
<th>Visual</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>70.0</td>
<td>56.0</td>
<td>106.0</td>
</tr>
<tr>
<td>Median</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Range</td>
<td>3.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Minimum</td>
<td>2.0</td>
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<td>1.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Table 17

Summative Evaluation Data for Question Four by Learning Style and Treatment

<table>
<thead>
<tr>
<th></th>
<th>Haptic</th>
<th>Visual</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Computer</td>
<td>Real</td>
<td>Traditional</td>
</tr>
<tr>
<td>N</td>
<td>17.0</td>
<td>16.0</td>
<td>23.0</td>
</tr>
<tr>
<td>Median</td>
<td>1.0</td>
<td>1.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Range</td>
<td>3.0</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>4.0</td>
<td>4.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>
median score. The haptic real comments included: "I thought it was very helpful." and "Time spent on it was enough to help students 'get the hang of' doing the problems." The median score for the haptic computer-generated model group was also 1.0. Their comments also reflected that generally not too much time was spent on the study. Comments included: "Put more time toward the computer" and "Not enough time was spent." One subject felt that, "...this section was fairly easy," while another student commented, "It was a good way to view the objects."

The visual subjects' median score for question four was also a 2.0. The visual real-model median score was 2.0 and these subjects' written comments also supported the statement that not too much time was spent on this study. One subject commented, "Although I didn't need to use the blocks for most of the models, when I did have a problem though, the models helped." A second subject simply stated, "It's a good idea." The visual control group's median score was also a 2.0. Only one visual traditional exercise subject commented on question four, "It seems orthographic is fairly important to visualizing." The visual computer-generated model group median score was 1.0 and some
of their comments are: "An additional couple of weeks would have been great;" "No! This was a very good study. It shows how with a little help mental visualization can become a lot easier;" "The study should be implemented into TG 108 permanently;" "No, because the computer could really help the people who are having difficulties visualizing the blocks;" and "I wish I could have had more."

Question five asked the subjects to choose one type of instructional treatment that they thought would have helped them to advance their spatial abilities. Their choices were computer-generated models, real-models, traditional exercises, or a combination of all three. Before the questionnaire was administered, the entire study was explained to each laboratory section by the investigator. Each laboratory section also was shown what was involved with the real-model, computer-generated model, and traditional treatments. The students had the opportunity to question the investigator concerning each treatment during this session.

Tables 19 presents the results of question five by visual/haptic learning style and instructional treatment. Table 20 presents the results of question five by visual/haptic learning style and presents the overall results of question five.

The overall results for question five showed that the subjects would choose a combination of real-models, computer-generated models, and traditional exercises if they were given that choice followed by real-models, computer-generated models, and traditional exercises. The visual and haptic learning style responses on question five were very similar to the overall results, with the subjects choosing a combination of all three treatments followed by real-models, computer-generated models, and traditional exercises.

When examining the results of the haptic traditional group, the subjects again chose a combination of all three treatments followed by real-models, but these subjects preferred traditional exercises over the computer-generated models. Haptic subjects with traditional exercises responses to question five also supported a combination of all three treatments (see Appendix K). One student commented, "By using the combination of all three, the real-model would have made the last section easier. The computer models would have
made the last test easier." Another student commented, "I think that the computer models should definitely be used for the latter part of the course (missing view, etc.). This is where most students need help in visualization." One subject thought that the exercises "proposed much thought."

Unlike the overall results or the total haptic results, fifty percent of the haptic subjects who were exposed to real-model exercises favored real exercises over any other option including a combination of all three treatments. Forty-four percent favored a combination of all three treatments followed by six percent favoring traditional treatments. No subjects from the haptic real group chose the computer-generated model group as a stand-alone treatment. Only one haptic real subject commented on question five, stating, "Real-models would have been even more helpful as the class progressed."

The haptic computer-generated model group again felt as if a combination of all three treatments would be most beneficial to them (50%). These subjects felt equally toward real-models (29%) and computer-generated models (29%). None of the students in this group chose the traditional treatment. The comments that the haptic computer-generated model group gave were mostly negative. One subject commented, "With the computer you couldn't hold the real-model and it wouldn't give one view." A second subject stated, "The computer model was of little help." Another subject wrote, "I think that if I could have held the model and seen it as a real object, I would have done better." Other comments were positive including, "I believe the computer greatly helped me," and "Use a combination of computer and real-models."

A majority of visual subjects who used traditional exercises favored a combination of all three treatments (74%), followed by both the real-model and traditional model treatments (13% each). No subject in the visual traditional treatment group chose computer-generated models but some of the subjects' written comments supported them in combination with the other exercises. Written comments for the visual traditional group were positive but with some reservations (see Appendix K). One subject wrote, "I picked a combination of all
three just because seeing something three different ways would probably help, but there should be an emphasis on regular assignments; the only way to really learn it is to do it."

Another subject wrote, "Both computer and real-model can help a tremendous amount but also might really limit the amount of visualization the student would need to do. If there could be a way to have models for the really 'hard' problems or made available after the students have tried to visualize it in their mind."

The visual subjects who used the computer-generated models also favored a combination of all three treatments (42%) followed by real-models (33%), computer-generated models (17%), and traditional exercises (8%). Their comments also supported this data (see Appendix 0). One subject wrote, "It was great, because at first it is hard to grasp concepts of TG. But the computer established a good foundation." A second subject advocated a combination of all three treatments and wrote, "I think having all three resources available would help future classes. I benefited from the assignments and the computer, and though I didn't use real-models, I think they would be a further benefit." A couple of students commented that the computer models could be improved. One student commented, "The only vice that I have with computers is that they took too long to switch a view." A second subject stated, "The perspective that was involved with the computer sometimes made it harder. The real-models would have been faster, too." Finally one subject commented that "It would be very easy to visualize something you're actually holding that's a 3D object."

The visual subjects who used the real-models favored a combination of treatments (48%) over any one single treatment but they also favored real-models almost equally (43%). Visual real-model subjects' comments reflected the data. One subject wrote, "I think it would be a good idea to allow students access to both real-models and computer models." A second student wrote that a combination of all three treatments "would give diversity and encourage finding new ways to solve problems." These subjects also showed strong support for the implementation of real-models. One subject commented,
Table 19

**Summative Evaluation Data for Question Five by Learning Style and Treatment**

<table>
<thead>
<tr>
<th>Learning Style</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Computer-Generated Model</strong></td>
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<td></td>
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<tr>
<td>Haptic/Traditional</td>
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<td>4</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>35</td>
</tr>
<tr>
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<td>52</td>
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<tr>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Haptic/Real</td>
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<td>0</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>50</td>
</tr>
<tr>
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<td>44</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Haptic/Computer-Generated Model</td>
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<td>29</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>29</td>
</tr>
<tr>
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<td>0</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
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<tr>
<td><strong>Visual/Traditional</strong></td>
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<td></td>
</tr>
<tr>
<td>Frequency</td>
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<td>0</td>
</tr>
<tr>
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</tr>
<tr>
<td>17</td>
<td>23</td>
<td>100</td>
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<td><strong>Visual/Real</strong></td>
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<td></td>
</tr>
<tr>
<td>Frequency</td>
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</tr>
<tr>
<td>%</td>
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<td>43</td>
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<td>11</td>
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</tr>
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<td><strong>Visual/Computer-Generated Models</strong></td>
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</tr>
<tr>
<td>Frequency</td>
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<td>17</td>
</tr>
<tr>
<td>%</td>
<td>8</td>
<td>33</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>42</td>
</tr>
<tr>
<td>10</td>
<td>24</td>
<td>100</td>
</tr>
</tbody>
</table>
Table 20

Summative Evaluation Data for Question Five by Learning Style and the Overall Summative Data

<table>
<thead>
<tr>
<th></th>
<th>Computer-Generated Model</th>
<th>Real-Model</th>
<th>Traditional</th>
<th>Combination</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visual</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
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<tr>
<td>%</td>
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<td>54</td>
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<td><strong>Haptic</strong></td>
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<td></td>
</tr>
<tr>
<td>Frequency</td>
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<tr>
<td>%</td>
<td>11</td>
<td>37</td>
<td>5</td>
<td>47</td>
<td>100</td>
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<tr>
<td><strong>Overall</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
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<tr>
<td>%</td>
<td>10</td>
<td>33</td>
<td>6</td>
<td>51</td>
<td>100</td>
</tr>
</tbody>
</table>

"Real allows manipulation, which is totally governed by the user - move it how you want it." Two other subjects also commented that it was important to be able to hold the object physically: "because you can feel the real-model in your own hand, relating hand to eye" and "It helps to hold something physically in your hands."

The frequency distribution of the data indicates that by visual/haptic learning style, treatment, visual/haptic learning style by treatment, and for the overall data, the subjects favored a combination of computer-generated models, real-models, and traditional exercises, followed by real-models, computer-generated models, and finally by traditional exercises. The exception was the haptic real group who favored real-models followed by a combination of all three exercise options. The treatment least favored by all of the groups,
except the visual traditional group, was the traditional exercise treatment. The visual traditional group favored the computer-generated models the least.

Lowenfeld's theory would agree with portions of these findings but not all of them. His theory agrees with the finding that the haptic real group favored the use of the real-models over any other treatment possibility. Had all the haptic subjects been exposed to the real-model treatment, these same results might be expected. The other haptic groups thought a combination of treatments would have helped them most. This would tend to agree with Lowenfeld's theory that the computer-generated models would allow the haptic students to supplant by the computer the need to retain the visual images. His theory would disagree with the findings of the visual groups who chose a combination of treatments, because the visual subjects should not need the additional treatment to help them to supplant their visualization ability.

Question six asked the subjects to rate on a five point scale (5 = agree, 1 = disagree) if they felt that real-model exercises should be integrated into the course throughout the semester. Table 21 presents the results of question six by visual/haptic learning style and instructional treatment. Table 22 presents the results of question six by visual/haptic learning style and the overall results of question six.

The overall median score of 5.0 indicated that the subjects strongly agreed that real-model exercises should be integrated into the course. The median score of 5.0 also indicated that haptic individuals strongly agreed that real-model exercises should be integrated into future courses. The 5.0 median score was consistent for all treatment groups. The median score of 5.0 by haptic subjects who received the real-model treatment also strongly agreed with the integration of real-models into future classes although these individuals did not write any comments to support this median score (see Appendix K).

Almost all of the haptic subjects who received the traditional exercises also agreed with the implementation of real-models into the curriculum (see Appendix K). One subject wrote, "It would help visualization immensely." Another commented, "Yes, it would help
a lot." Finally one subject commented, "They would be cheap, easy to distribute, especially for hard problems." One subject did not agree commenting, "I don't think that it really matters."

Haptic computer-generated subjects also commented on the use of real-models and with the median score of 5.0, supported their future implementation (see Appendix K). One subject wrote, "I definitely believe this would be a good thing to help visualize the objects better." Another commented that it would be a "good idea." One subject disagreed, commenting that, "None should be used throughout the whole course."

The median score for question six for the visual subjects was a 4.0. This still shows strong support for the implementation of real-models into the curriculum. Visual subjects who were exposed to the real exercises showed the strongest support for the implementation of real-models into the curriculum with a median score of 5.0. This support also was reflected in the written comments (see Appendix K). One subject wrote, "I strongly believe that real-models should be used in the whole course." Another subject commented, "When you can see an object in 3D, it immensely helps visualization." One subject supported their use but added a note of caution, "They could be used occasionally, but not to the point where the student is dependent upon them." Finally one subject was straight to the point in his analysis of future implementation of real-models and stated, "Yes, Yes, Yes."

Visual subjects who were exposed to the computer-generated model exercises and had median score of 4.0 also were supportive of the implementation of real-models into the curriculum. Their written responses also support the high median score in support of real-model integration (see Appendix K). Two subjects' comments generally reflected how visual subjects who used computer-generated exercises felt toward the use of real-models. The first one wrote, "I think having all three resources available would help future classes. I benefited from the assignments and the computer, and though I didn't use real-models, I think they would be a further benefit." The second subject also added a note of caution by
stating, "They should not be used throughout the entire course because they could become a crutch. But they could be very useful in explaining some of the more complex parts of the course or in helping us visualize complex objects (i.e., inclined planes)."

The median score for visual subjects who used the traditional exercises was 4.0 for question six. Thus, these subjects also supported the implementation of real-models into the curriculum and their written comments supported the data (see Appendix K). One subject wrote, "It makes visualization of hard problems easier. Maybe it should be integrated just for the harder problems." A second student commented that real-models should be used, "especially during missing view problems."

Question seven asked the subjects to rate on a five point scale (5 = agree, 1 = disagree) if they felt that computer-generated model exercises should be integrated into the course throughout the semester. Table 23 presents the results of question seven by visual/haptic learning style and instructional treatment. Table 24 presents the results of question seven by visual/haptic learning style and the overall results of question seven.

Table 21

**Summative Evaluation Data for Question Six by Learning Style and Treatment**

<table>
<thead>
<tr>
<th></th>
<th>Haptic</th>
<th>Visual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Computer</td>
<td>Real</td>
</tr>
<tr>
<td><strong>N</strong></td>
<td>17.0</td>
<td>16.0</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>
The median score for all subjects on question seven was 4.0. Thus, overall the subjects involved in the study felt that computer-generated models should be integrated into the curriculum. Visual subjects also felt that the integration of computer-generated models into the curriculum would be beneficial. With the median score of 5.0 visual subjects who were exposed to the computer-generated models highly supported their implementation into the curriculum. Subjects' comments also supported the implementation of computer-generated models into the curriculum (see Appendix K). One subject commented that the computer-generated models, "seemed helpful to those near me." Another subject simply stated, "Definitely." One subject added a note of caution and stated, "Only if it is in a case where someone is having a lot of trouble on the assignments even with the real-models."

The visual real group subjects were neutral towards the implementation of computer-generated models into the curriculum. The median score of 3.0 also was reflected in written comments that did not support the implementation of computer-generated models into the curriculum (see Appendix K). One subject wrote, "It wouldn't be as easy to do as
real-models" and that "the computer is still in 2-D." One subject reflected a neutral median score by stating, "It would have been interesting to use them at least once."

The visual control group median score of 4.0 supported the implementation of computer-generated models into the curriculum. Only two subjects gave written comments concerning question seven (see Appendix K). The first comment supported the implementation of computer-generated models into the curriculum, "Yes, they would be extremely helpful when visualizing the object," while the second subject stated, "I think the computer would not help simply because the screen cannot represent that third dimension."

The haptic real-model group was the least receptive to the notion of implementation of computer-generated models into the curriculum. The median score for this group was a 3.5 which gave some support but was more neutral. The haptic subjects' comments (see Appendix K) on this question were neutral in support of the use of computer-generated models. Only one subject made a comment, "I don't know."

The haptic computer-generated model group data showed that these subjects supported computer-generated models into the curriculum. The median score was 5.0 but only two subjects gave written responses. Both comments were positive with the first subject stating, "I feel they should be used in the course throughout the semester." The second subject commented that all assignments should "start with this form."

The haptic control group median score was 4.0 indicating support for the implementation of computer-generated models into the curriculum. Comments from the haptic control group (see Appendix K) were not as supportive toward computer-generated models. Comments included, "I think the real-model is better because you can examine it more." A second comment was, "It would take too much time to accomplish too little, and it would be too much trouble." But some of the comments also were positive as one subject added, "would be helpful." Another comment also supported their use, "if everybody could use their own computer and work at their own pace."
Table 23

Summative Evaluation Data for Question Seven by Visual/Haptic Learning Style and Treatment

<table>
<thead>
<tr>
<th></th>
<th>Haptic</th>
<th></th>
<th>Visual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Computer</td>
<td>Real</td>
<td>Traditional</td>
</tr>
<tr>
<td>N</td>
<td>17.0</td>
<td>16.0</td>
<td>23.0</td>
</tr>
<tr>
<td>Median</td>
<td>5.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Range</td>
<td>4.0</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.0</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Question eight asked the subjects to rate on a five point scale (5 = agree, 1 = disagree) if they felt that a combination of real-model exercises and computer-generated model exercises should be integrated into the course throughout the semester. Table 25 presents the results of question eight by visual/haptic learning style and instructional treatment. Table 26 presents the results of question eight by visual/haptic learning style and the overall results of question eight.

The overall median score of 5.0 for question eight seemed to show strong support for the implementation of a combination of traditional, real-model, and computer-generated models into the curriculum. Overall, visual subjects' median score of 5.0 also strongly supported a combination of treatments. The median score for the visual computer-generated model group was also 5.0. A large portion of subjects gave written comments concerning question eight (see Appendix K) and a majority of these subjects agreed that a combination of all three treatments would work best. One subject wrote, "I think having all
three resources available would help future classes. I benefited from the assignments and
the computer, and though I didn't use real-models, I think they would be a further benefit." Another subject added, "Using all three would make this class much easier, as well as more compatible." One of the subjects did not feel as positive towards using all three treatments, "I don't think both would have worked together."

The median score for the visual real-model group was 4.0. The data from this group seemed to show support of the implementation of all three treatments in the future, and questionnaire comments also supported their implementation but not without reservations. One subject commented, "Yes, but used to help develop a sense of perception, then only as an aid for harder problems. They could result as a crutch - shouldn't be used throughout the course." Another student added, "Students still need to visualize without models." Another student fully supported their implementation and wrote, "I think a combination would be most helpful."

The visual control group had a median score of 5.0 for question eight, thus these subjects were highly supportive of the implementation of all three instructional treatments into the curriculum. The written comments (see Appendix K) that these subjects gave also showed strong support for the implementation of all three treatments. One subject wrote, "It's sometimes hard to see and understand the views just from the drawings (computer and real-model exercises will make the course more exciting as well)." Another commented, "All three would give a student the opportunity to see the objects correctly instead of perhaps visualizing an incorrect object and continuing without knowing of his/her mistakes."

The overall median score of 5.0 for the haptic subjects also showed strong support for the implementation of a combination of all three treatments into the curriculum. The median score of 5.0 for the haptic computer group also reflected strong support for question eight. The written comments (see Appendix K) by haptic computer subjects also supported question eight. One subject wrote, "Use computer then real-models," while a second
Table 24

Summative Evaluation Data for Question Seven by Visual/Haptic Learning Style and the Combined Overall Data

<table>
<thead>
<tr>
<th></th>
<th>Haptic</th>
<th>Visual</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>70.0</td>
<td>56.0</td>
<td>106.0</td>
</tr>
<tr>
<td>Median</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Range</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

subject thought real-models should be emphasized, "More, much more use of real-models though."

The real-model group also strongly supported the utilization of a combination of all three treatments and was reflected in a median score of 4.0. Only one subject gave written comments (see Appendix K) and they were neutral in stating, "I don't know, but I liked the real-models a lot."

The haptic control group was not as receptive to a combination of all three treatments but still strongly supported their implementation with a median score of 4.0. Their written comments (see Appendix K) were supportive of question eight but some favored one treatment over another. One subject wrote, "More emphasis should be placed on computer-models." But the second comment was supportive of real-models and the subject wrote, "I think the real-model is better because you can examine it more."

Question ten asked the subjects to rate on a five point scale (5 = agree, 1 = disagree) if they felt that the instructional treatment (real-model, computer-generated model, or traditional exercises) used during the study helped them to receive a better grade in the
Table 25

Summative Evaluation Data for Question Eight by Learning Style and Treatment

<table>
<thead>
<tr>
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<th>Haptic</th>
<th></th>
<th></th>
<th>Visual</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Computer</td>
<td>Real</td>
<td>Traditional</td>
<td>Computer</td>
<td>Real</td>
<td>Traditional</td>
</tr>
<tr>
<td>N</td>
<td>17.0</td>
<td>16.0</td>
<td>23.0</td>
<td>24.0</td>
<td>23.0</td>
<td>23.0</td>
</tr>
<tr>
<td>Median</td>
<td>5.0</td>
<td>5.0</td>
<td>4.0</td>
<td>5.0</td>
<td>4.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Range</td>
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<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.0</td>
<td>3.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Maximum</td>
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<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

course. Table 27 presents the results of question ten by visual/haptic learning style and instructional treatment. Table 28 presents the results of question ten by visual/haptic learning style and the overall results of question ten.

The overall median score for question 10 was 4.0, thus the subjects felt as if the instructional treatment they received helped them to receive a better grade in the course. This overall median score for visual subjects was also 4.0 so visual subjects likewise agreed with the overall sample of subjects. Visual subjects exposed to the computer-generated model exercises had a median score 4.0 and their written comments were supportive of question ten (see Appendix K). One subject wrote, "Using the computers helped initiate me. I had never had this type of course and the computer helped show me what I needed to be doing." A second subject also agreed, "Either you saw the views or you didn't, I feel that the computer aids helped you to see the views." One subject felt the computer would have been more helpful later in the course and stated, "My problem was with the end of the semester stuff. If we had the models then it would have been great."
Visual subjects who were exposed to the real-model exercises also had a median score of 4.0 and their written responses (see Appendix K) supported the idea that exposure to real-models helped them to receive a better grade in the course. One subject commented, "The real-models probably helped me improve my grade on the tests." A second subject stated that the models, "allowed me to check my drawings for error easier and faster than without them." One subject thought that background experience was a greater factor and wrote, "I had a mechanical drafting class in high school which I believe gave me enough of the skills, mental and otherwise, to be able to picture most of the objects in my mind and put them on paper."

The median score of 4.0 for visual subjects who were in the traditional exercise group reflected the concept that traditional exercises help them with their grade in the course although none of these subjects gave written comments either supporting or refuting this data.

The overall score for haptic subjects was again 4.0. Haptic computer subjects also reflected the support of question ten with a median score of 4.0. The written comments of the haptic computer-generated model group (see Appendix K) were supportive of the concept that exposure to computer-generated models helped them to receive a better grade in the course. One comment was, "The computer models helped me to visualize some of the strange shapes that we were assigned to draw." A second comment was, "They helped me to start to think in 3-D."

The haptic real-model group also had a median score of 4.0 and their written comments also supported this data. One subject commented, "The models helped, I think, because I was lost at the beginning." A second subject also claimed that the real-models helped him improve his grade and wrote, "The real-model section seemed to bring my grade up; it helped me a lot." Finally one subject wrote, "It helped me during that time, when I went back to my regular lab, my grade went down."
The haptic control group also had a 4.0 median score but written comments were not as positive (see Appendix K). One subject wrote, "I think I would have done better with real-models." But another subject commented that, "I think that they helped."

Table 26

Summative Evaluation Data for Question Eight by Visual/Haptic Learning Style and the Combined Overall Data

<table>
<thead>
<tr>
<th></th>
<th>Haptic</th>
<th>Visual</th>
<th>Overall</th>
</tr>
</thead>
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<tr>
<td>N</td>
<td>70.0</td>
<td>56.0</td>
<td>106.0</td>
</tr>
<tr>
<td>Median</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Range</td>
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<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Minimum</td>
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<td>1.0</td>
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</tr>
<tr>
<td>Maximum</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Table 27

Summative Evaluation Data for Question Ten by Learning Style and Treatment

<table>
<thead>
<tr>
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<th>Haptic</th>
<th>Visual</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Computer</td>
<td>Real</td>
<td>Traditional</td>
<td>Computer</td>
<td>Real</td>
</tr>
<tr>
<td>N</td>
<td>17.0</td>
<td>16.0</td>
<td>23.0</td>
<td>24.0</td>
<td>23.0</td>
</tr>
<tr>
<td>Median</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Range</td>
<td>4.0</td>
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<td>2.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>3.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Maximum</td>
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<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>
Table 28

Summative Evaluation Data for Question Ten by Visual/Haptic Learning Style and the Combined Overall Data

<table>
<thead>
<tr>
<th></th>
<th>Haptic</th>
<th>Visual</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>70.0</td>
<td>56.0</td>
<td>106.0</td>
</tr>
<tr>
<td>Median</td>
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<td>4.0</td>
<td>4.0</td>
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<tr>
<td>Range</td>
<td>1.16</td>
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<tr>
<td>Minimum</td>
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<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Results of the Exercise Scoring Sheets

Exercise scoring keys (see Appendices D-G) were designed to record problems that students encountered while completing their orthographic drawing exercise sheets. Information on the amount of time and various errors were recorded on these keys by the laboratory instructors. This data was recorded from the study but will not be reported because of problems that were associated with it.

The main cause for problems with this data was how the data was recorded by the instructors of the subjects in the control groups. The subjects in the control group were scattered among the twenty-four sections of Technical Graphics 108 during Fall Semester 1990. Each of these sections included at least one, and up to five, control subjects. The fourteen different instructors were undergraduate teaching assistants. Eight were teaching for the first time. Because of the instructors' inexperience, many of the problems that the control group students might have had were not recorded on the scoring keys. If a control group student had a problem, he/she could have gotten help from a classmate and this data
might have gone unrecorded. Although these exercise sheets could have been scored at a later date, many of the student questions could have been answered, thus making the problem correct but never have been marked in the scoring key. Thus, the accuracy and validity of this data was questionable, so the researcher decided that this data was not valid for statistical analysis and eliminated it. This suggests that if future studies use a scoring key similar to this one, only the researcher or a very small number of individuals use it so that the data will be valid.

Pearson Correlation Coefficient Between The Successive Perception Test I and the Mental Rotations Test

Hypothesis eighteen was concerned with the correlation between the posttest administration of the Successive Perception Test I and the Mental Rotations Test. This data was important to determine if these two instruments were measuring different perceptual attributes. Theoretically, the Successive Perception Test I should be measuring visual/haptic learning style, the Mental Rotations Test should be measuring visualization ability, and very little correlation should exist between them.

HO18: The posttest Successive Perception Test I results will not significantly correlate with the results of the Mental Rotations Test.

The procedure used to test this hypothesis was the Pearson Correlation Coefficient. This procedure was used because it compared the results of the posttest administration of the Successive Perception Test I, which are interval data, with the results of the Mental Rotations Test, which also are interval data. Table 29 shows the descriptive data for each test. Table 17 reports the Pearson Correlation Coefficient.

A significant difference was found that indicated a relationship of 0.3298 between the Successive Perception Test I and the Mental Rotations Test. To reject the null hypothesis, the probability associated with the calculated value of the test statistic must be equal to or
less than the 0.05 alpha level. Because the calculated probability was 0.0001, Hypothesis 18 was rejected.

Table 29

Descriptive Data for the Posttest Administration of the *Successive Perception Test I* and the *Mental Rotations Test*

<table>
<thead>
<tr>
<th></th>
<th>SP-1</th>
<th>MRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>497.00</td>
<td>497.00</td>
</tr>
<tr>
<td>M</td>
<td>23.64</td>
<td>12.25</td>
</tr>
<tr>
<td>SD</td>
<td>3.68</td>
<td>4.03</td>
</tr>
<tr>
<td>SE</td>
<td>0.17</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Although there was a significant correlation between these two instruments, the correlation of 0.33 is a low to moderate correlation. Davis (1971) contends that a correlation between 0.30 to 0.49 is low to moderate correlation. Thus, it appears as if these two instruments are measuring different psychological attributes.

Percentage Comparison between the Pretest and Posttest Administration of the *Successive Perception Test I*

The last statistical analysis was concerned with determining if individuals classified with certain visual/haptic learning style on the pretest administration of the *Successive Perception Test I* would be classified as the same visual/haptic learning style on the posttest administration of the *Successive Perception Test I*. 
Table 30

Pearson Correlation Coefficient Between the Successive Perception Test I and the Mental Rotations Test

| SP-1   |  
|--------|---------------------------------------------------
| Correlation Coefficient | 0.32998  
| MRT Probability          | 0.0001*  
| N                  | 497.0  

Note. Prob > |R| under H0: Rho =0

*p<.05

The procedure used to review this data involved the development of a special type of frequency table to determine what percentages of visual/haptic learning style classification from the pretest administration of the Successive Perception Test I were found in the posttest administration of the Successive Perception Test I. Table 31 shows the frequency table of the descriptive statistics of this comparison.

Reviewing the overall statistics of individuals classified as haptics between the pretest and posttest administrations of the Successive Perception Test I, the percentage of haptic individuals decreased from 16.50% to 11.07%. Between the pretest and posttest administrations of the Successive Perception Test I overall statistics of individuals classified as indefinites increased from 61.57% to 64.99%, while visual subjects increased from 21.93% to 23.94%. Thus, it might seem probable that experiences in a visual realm, such as the treatments administered in this study, changed and improved an individual's chance of becoming more visual. Thus, the overall percentages would indicate that a haptic might tend to become more visual, and defined as an indefinite after treatment. This same
occurrence would appear to make indefinites tend to be visual. However, upon further study, these overall results tend to be misleading.

Haptic individuals can only improve, which the data reflected. Of the individuals who were considered haptic on the pretest, only 14.63% remained classified as haptics, while 73.17% of the haptic individuals were classified as indefinites on the posttest administration of the *Successive Perception Test I* and 12.20% were classified as visuals.

Comparing indefinites between pretest and posttest administration of the *Successive Perception Test I*, 72.22% of the indefinites were classified as indefinites on both test administrations, while 13.07% were classified as indefinites on the pretest and as haptic on the posttest. Between the pretest and posttest administrations of the *Successive Perception Test I*, 14.71% indefinite individuals were classified as visuals.

Of the subjects who were classified as visual on the pretest of the *Successive Perception Test I*, 58.72% were again classified as visuals on the posttest administration, 38.53% were classified as indefinites, and 2.75% changed from visual to haptic classification.

It might be concluded from these results that the instructional treatment caused many individuals to change their visual/haptic learning style, but to change from haptic to visual or the opposite does not support Lowenfeld's theories. He claims that a person would either have a visual or haptic learning style and that he/she should not change. He also claims that a large percentage of individuals cannot be classified as either and that this indefinite population could be closer to being either visual or haptic learning style types. But it could be that the instructional treatment did somehow change a person's visual/haptic learning style. Even if there was a small correlation between the *Successive Perception Test I* and the *Mental Rotations Test*, the instructional treatment could have prepared the individuals to do better on the second administration of the *Successive Perception Test I*. But this conclusion does not account for the small percentage of subjects (2.75%) who changed from visual to haptic classification.
Table 31

Comparison of Visual/Haptic Learning Style from the Pretest to the Posttest Administration of the *Successive Perception Test I*

<table>
<thead>
<tr>
<th></th>
<th>Haptic</th>
<th>Indefinite</th>
<th>Visual</th>
<th>Total</th>
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<tr>
<td><strong>Haptic</strong></td>
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</tr>
<tr>
<td>Frequency</td>
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<tr>
<td>%</td>
<td>2.41</td>
<td>12.07</td>
<td>2.01</td>
<td>16.50</td>
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<tr>
<td>Row %</td>
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<td>12.20</td>
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<td>Column %</td>
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<tr>
<td>Frequency</td>
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<td>497</td>
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<td>%</td>
<td>11.07</td>
<td>64.99</td>
<td>23.94</td>
<td>100.00</td>
</tr>
</tbody>
</table>

*Note.* How to read Table 18: The rows are the visual/haptic learning style categories for the pretest administration of the SP-1. The columns are the visual/haptic learning style categories for the posttest administration of the SP-1. Thus, reading across the visual row and down the indefinite column gives you the number 42. Therefore, 42 individuals changed from visual to indefinite visual/haptic learning style between the pretest and posttest administration of the SP-1.
The reliability of the *Successive Perception Test I* also must be questioned. In both administrations, the reliability was between 0.53 and 0.54. Thus, this test might not have classified visual and haptic subjects correctly thus leading to the questionable data. Finally, it could be that the adjusted scale on the *Successive Perception Test I* caused data errors. Because engineers seemed to be visual by nature and selection, the classification used in this study could be faulty. Although some of the percentages refute Lowenfeld's theories and support the use of instructional treatment as a factor in changing a person's visual/haptic learning style, these conclusions must be viewed with skepticism.

**Summary**

This chapter, which dealt with the analysis of data, was organized into five main sections. The first section investigated the reliability of the *Successive Perception Test I*. It was determined that the reliability of the *Successive Perception Test I* was 0.54 for the pretest measurement and 0.53 for the posttest measurement. The statistical analysis used on this data was the Cronbach Alpha reliability statistic.

The next four sections of the analysis of the data were concerned with the research hypotheses of the study. The first research hypothesis was concerned with whether Lowenfeld's claim that 47 percent of the population are visuals, 23 percent are haptics, and the remaining 30 percent are indefinites would hold true for the population drawn for use in this study. A Chi-square goodness-of-fit compared Lowenfeld's theoretical percentages with the actual percentages of the population used in this study. A significant difference was found indicating that Lowenfeld's prediction that 47 percent of the population are visuals, 30 percent of the population are indefinites, and 23 percent of the population are haptics was not found in the population used in this study.

The second research hypothesis was concerned with whether the experimental instructional methods and media (traditional supplemented by real-models, and traditional supplemented by computer-generated surface models) interacted with the learning style
of the students, allowing for a greater increase in spatial abilities than would have occurred with the traditional engineering graphics instructional methods or media.

First, a two-factor ANOVA was used to determine significant interactions between learning style (visual/haptic) and instructional treatment (real-models, computer-generated models, and traditional exercises). The results of the ANOVA suggested there were no significant interactions between visual/haptic learning style and treatment on the results of the Mental Rotations Test. Thus hypothesis two failed to be rejected.

Second, a two-factor ANOVA also was used to determine significant differences between the main effects of learning style (visual/haptic) and instructional treatment (real-models, computer-generated models, and traditional exercises). The results suggested no significant differences occurred between the different treatments (real-models, computer-generated models, and traditional exercises), thus hypotheses four through six failed to be rejected. A significant difference between learning style (visual/haptic) was found and hypothesis three was rejected.

Third, one-factor ANOVAs were used to determine significant differences between specific instructional treatment learning style combinations (i.e. haptic computer-generated model subjects vs. visual real-model subjects). The results of these ANOVAs suggested no significant differences occurred between any of these combinations, thus hypotheses seven through seventeen failed to be rejected.

Fourth, the results of the summative questionnaire were presented. Seven questions asked the subjects to rate and give comments concerning the various instructional treatments. Although statistical significance was not found that would support future implementation of the two experimental instructional treatments, student responses on the summative supported their implementation. Generally, median scores supported by verbal comments showed that a majority of the students felt that the instructional setting in which
they participated helped them to improve their spatial abilities. This also occurred when the subjects were asked if the instructional setting helped them to receive a higher grade in the course. The questionnaire also determined that a majority of the students did not feel that too much time was spent on the study. And finally, the subjects strongly felt that each of the experimental exercises should be implemented in future courses and that a combination of these treatments would give them an added advantage in the development of their spatial abilities.

The results of the scoring keys of these exercises were dropped from data analysis because of validity concerns. Because many of the instructors did not accurately and completely keep track of this data, it was not considered valid data.

The third research hypothesis investigated whether the measurement of visual/haptic learning style would or would not correlate with the measure of spatial ability. The Pearson Correlation Coefficient was used to determine if any correlation existed between the posttest administration of the Successive Perception Test I and the Mental Rotation Test. A significant difference was found that indicated there was a relationship of 0.3298 between the Successive Perception Test I and the Mental Rotations Test.

The fourth research hypothesis investigated whether the instructional methods and media had any effect on an individual's visual/haptic learning style type as measured by the Successive Perception Test I. A comparison of visual/haptic learning style type percentage changes between the pretest and posttest administrations of the Successive Perception Test I was used to determine if the instructional methods and media had any effect on an individual's visual/haptic learning style type. The results showed that, in part of the cases, an individual's learning style type did not change, but many times the individual's learning style type did change and in limited cases learning style type changes were totally unexpected (i.e., haptic to visual). These results led the researcher to question if Lowenfeld's theories that contend that a subject will never change learning style type are
valid or if the *Successive Perception Test I* is a valid and reliable measurement instrument in the classification of visual/haptic learning style.

The next chapter will present a more thorough discussion of these findings as well as ideas for the implementation of future studies.
CHAPTER V
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This chapter briefly summarizes the problem studied and the research procedures followed. It presents the study's findings and conclusions along with recommendations for further research in spatial abilities, learning styles, and the integration of real- and computer-generated models and other forms of instructional media.

Summary

The problem of this study was to determine if the use of nontraditional (computer-generated and real- models) instructional approaches develop and advance the spatial abilities of engineering students who possess different learning styles (visual/haptic). A review of the literature revealed that many introductory engineering graphics courses use traditional instructional approaches that are not based upon spatial research findings. The literature review also indicated that many factors determine that students possess various levels of spatial abilities. It was also determined that students may use different learning styles to solve spatial problems.

One specific learning style is visual/haptic. Victor Lowenfeld advocated visual/haptic theory after extensive research in art education in Europe and the United States. Lowenfeld (1945) identified two characteristics of learners: the visual and the haptic. He contended that these two learning styles fall on opposite ends of a continuum of how individuals perceive the external world. The visual type is a perceptual observer or spectator who normally approaches objects from their visual appearance, uses the eyes to discover the surrounding environment, and transforms kinesthetic and tactile experiences into visual ones. On the other hand, a haptic individual does not have the tendency visually to see a
whole object, break it up into its component parts, and then reassemble it into a whole (Lowenfeld & Brittain, 1987).

The review of literature also disclosed that computer technology, specifically 3D CADD technology, can be integrated into instruction to help students advance their spatial abilities (Zavtoka, 1985). Other studies (Vanderwall, 1987) recommended the use of real-models to help students advance their spatial abilities. Although research studies advocated the use of 3D computer-generated models and real-models, contradicting research questioned the validity of using models to help students to visualize (Orth, 1941; French, 1913).

Finally, media research by Gavriel Salomon contended that instructional media can be used to supplant or bridge the gap between learners' abilities and their cognition of abstract concepts. If supplantation does help students of different learning styles grasp abstract concepts, then computer-generated or real-models could be used as supplantation tools. It was the hope of the researcher that through the use of real- and computer-generated models, more students would be able to advance their spatial abilities farther than possible through traditional instructional methods.

Therefore, the main problem of the study was that traditional instructional approaches used to advance the spatial abilities of engineering students frequently do not match individual learning styles. The main purpose of this study was to determine if certain instructional approaches (real-models or computer-generated models) were more effective than traditional instructional approaches in the advancement of spatial abilities of engineering students who were classified as visual or haptic individuals. A secondary purpose of this study was to determine if Victor Lowenfeld's visual/haptic theories were supported by the results of this study and if his evaluation instruments were valid and reliable to measure and classify the visual/haptic learning style. More specifically, the research hypotheses of the study were to determine if:
1. Lowenfeld’s claim that 47 percent of the population are visuals, 23 percent are haptics, and the remaining 30 percent are indefinites will hold true for the population drawn for use in this study.

2. The experimental instructional methods and media (traditional supplemented by real-models, and traditional supplemented by computer-generated surface models) will allow students with different learning styles (visual/haptic) a greater chance of advancing their spatial abilities than would have occurred with the traditional engineering graphics instructional methods or media.

3. The measurement of visual/haptic aptitude will correlate with the measure of spatial ability.

4. The instructional methods and media will change an individual’s visual/haptic learning style as measured by the Successive Perception Test I.

Methodology

This section describes major methodological activities performed prior to and during the study. The instructional setting for the study was Purdue University, Fall Semester 1990. Technical Graphics 108, a one-credit-hour traditional sketching-based engineering graphics course that met weekly for a one-hour lecture and one-hour laboratory. Offered to all freshman engineering students, the course covered the topics of visualization, orthographic multiview sketching, pictorial isometric sketching, and orthographic reading.

This study used two standardized instruments: the Successive Perception Test I (United States Army Air Corps, 1944) and the Mental Rotations Test (Vandenberg & Kruse, 1978). The Successive Perception Test I was used to determine the visual/haptic learning style of the subjects in the population and thus to assign subjects to the treatment groups. The Mental Rotations Test was used to measure spatial abilities of the subjects.

The entire population of Technical Graphics 108 was administered the Successive Perception Test I during the first laboratory session. From test results, students were to be
classified as either visual or haptic. L. A. Ausburn (1979) classified individuals who scored 21 or higher as visuals and those who scored 14 or lower as haptics. She based these scores on Lowenfeld's (1945) theory of visual/haptic learning style.

After reviewing scores of the *Successive Perception Test I*, a decision was made to redefine visual/haptic learning style for this study because the number of haptic students present in the population was insufficient to draw a sample. The mean score of the *Successive Perception Test I* was 21.493 with a standard deviation of 3.956. Because these values were relatively consistent throughout the population, a haptic was defined as scoring 17 or below and a visual was defined as scoring 25 or higher.

The sample selected for the study was based upon the adjusted visual/haptic scale as determined by the *Successive Perception Test I*. The sample (150 subjects) involved students who were identified as possessing strong visual (75 subjects) or haptic (75 subjects) learning styles. Individuals classified as visuals (25 or higher on the *Successive Perception Test I*) were placed randomly into either the traditional exercise (n=25), the computer-generated model group (n=25), or the real-model group (n=25). This same procedure also was used to assign randomly the haptic subjects (17 or lower on the *Successive Perception Test I*) into the traditional exercise (n=25), the computer-generated model group (n=25), or the real-model group (n=25).

Experimental laboratory sessions replaced regularly scheduled one-hour laboratories. The experimental laboratories were offered at alternative times to the regular laboratory sessions. This was necessary because of the logistical constraints of laboratory space available during the study. All laboratory sessions, both traditional and experimental, were 50 minutes in length; a student could attend only one laboratory session each week.

The size of the traditional laboratories ranged from nine to nineteen students, determined by the number of students who volunteered for the study and left the traditional classroom session. The size of the experimental laboratories ranged from five to eighteen students, determined by how many students volunteered to participate in one of the
experimental laboratories at a given time. The experimental laboratories were offered at various times during the day and in the evening.

Throughout the study, all students received the same laboratory problems and the same amount of time in the laboratory sessions. The only differences between the control group for the study and the two experimental groups were the instructor, the treatment, and the time when the laboratory sessions were held.

The administration of the treatment for this study continued four weeks. Each week students in all treatment groups were given drawing problems (Appendix D-G) that contained a pictorial sketch of an object and an orthographic grid. They were assigned to sketch a three-view orthographic representation of the object according to orthographic standards, including hidden features and lines of symmetry. The purpose of these exercises was to introduce students to basic concepts of orthographic projection and to advance their spatial abilities. Four problems were to be completed each week. The students had to determine the most descriptive view of the object and sketch this as the front view. Next they had to sketch the top view and one side view of the object. Grades were based upon correct visualization of the object and the accuracy of the sketched orthographic representation based on engineering graphics standards. Students were required to stay in the laboratory the full length of the session unless they completed and turned in all four problems to their instructor. If they did not complete all four problems, they were allowed to work on them outside of the laboratory. These problems were then collected at the beginning of the next laboratory session. The complexity of the geometry of these problems increased from week to week.

The main objective of the study was to determine the effects of learning style and instructional treatment upon the spatial abilities of the subjects. To determine if the learning style instructional treatment, or an interaction between visual/haptic learning style and treatment significantly affected the subjects' spatial abilities, a 2 x 3 factorial experimental design, the posttest-only control group design was used. This overall design meets the
criteria for being an experimental study by having individual students randomly selected from two matched pools of attribute variables (visual/haptic learning style) to three levels of the independent variable (traditional, real-model supplemented, or computer-supplemented instructional approaches). Secondly, a summative questionnaire was used to determine how students reacted to the instructional treatment to which they were exposed.

To determine if an individual changed visual/haptic learning style because of treatment effects, a pretest-posttest design was used. This design compared the mean scores of the subjects on the Successive Perception Test I pretest with the mean scores of the subjects on the posttest Successive Perception Test I.

Findings

The findings of this study are based on the four research hypotheses. Where statistically possible, each hypothesis was tested at the 0.05 level of probability. The following paragraphs present the findings of each research question.

Before the research hypotheses were investigated, the reliability of the Successive Perception Test I was determined on both the pretest and posttest administration. On the pretest administration of the Successive Perception Test I, the reliability coefficient was 0.53. On the posttest administration Successive Perception Test I, the reliability coefficient was 0.54.

The first research hypothesis focused on the visual/haptic theory of Victor Lowenfeld that states the proportion of visual/haptic learning style in the population is 47 percent visuals, 23 percent haptics, and 30 percent indefinites. Specifically, would these values hold true for the population that the sample was to be drawn from for this study? Data from the experiment did not support this hypothesis. Thus, Lowenfeld's visual/haptic theoretical percentages differed significantly from the actual visual/haptic learning style percentages found in the population.
The second research hypothesis was to determine if experimental instructional methods and media (traditional supplemented by real-models and traditional supplemented by computer-generated surface models) would allow students with different learning styles (visual/haptic mode) a greater chance of advancing their spatial abilities than would have occurred with the traditional engineering graphics instructional methods or media. Two different research methods were used to gather information concerning this research question. The first type of data, experimental, was collected through the use of a posttest-only-control group design, which utilized both one- and two-factor ANOVAs for statistical analysis of the data gathered from the *Mental Rotations Test*. The second form of data, qualitative, was gathered through the use of a summative questionnaire.

The first statistical analysis involved the use of a two-factor ANOVA to determine statistically significant interactions between instructional methods and media (traditional supplemented by real-models and traditional supplemented by computer-generated surface models) and learning style (visual/haptic) of the students as measured by the *Mental Rotations Test*. No statistical interactions were found between the instructional treatment and learning style variables. Because no interactions were found, the main effects of instructional treatment and visual/haptic learning style were examined to determine if any of the instructional treatments were more beneficial in helping the subjects to advance their spatial abilities.

The second statistical review of research hypothesis two was involved in statistically analyzing, through the use of a two-factor ANOVA, the main effects of instructional treatment and learning style. The statistical analysis determined that there were no significant differences between the three instructional treatments. A significant difference was found between the learning styles of visual and haptic with the visual subjects having a significantly higher mean score on the *Mental Rotations Test*.

The statistical analysis of research hypothesis two also included specific treatment and visual/haptic learning style group comparisons using a one-factor ANOVA, to determine if
specific instructional treatments were equally effective in the advancement of spatial abilities of visual or haptic subjects. Specifically, every instructional treatment and learning style combination was compared against each other to determine if significant statistical differences occurred.

No significant statistical interactions were found when haptic subjects were contrasted against haptic subjects exposed to a different instructional treatment. Likewise, no statistical significant differences were found when visual subjects were contrasted against visual subjects who were exposed to a different instructional treatment. Statistical significance was found contrasting specific visual and haptic subjects who were exposed to the same instructional treatment.

The results of the summative questionnaire were as follows. The subjects agreed that the instructional setting to which they were exposed helped them to visualize problem solutions and helped them to receive a better grade in the course. They also did not think that too much time was spent on the study. If the subjects could select an instructional treatment, they would have chosen a combination of all three treatments followed by real-models. The subjects felt that real- and computer-generated models should be integrated into the curriculum and they also agreed that a combination of traditional curricular approaches with real- and computer-generated models would be extremely helpful in allowing them to advance their spatial abilities.

The third research hypothesis was concerned with the correlation between visual/haptic learning style and spatial ability. The data from this study did not support the hypothesis that there is no correlation between visual/haptic learning style and spatial ability. A low correlation (0.32) was found between the Successive Perception Test I and the Mental Rotations Test.

The fourth research hypothesis investigated whether instructional treatments would change the individual’s visual/haptic learning style. Results showed that overall the
percentage of haptics was reduced while the percentages of indefinites and visuals increased from the pretest to the posttest administration of the Successive Perception Test I.

Discussion of the Findings

Although data from this study does not totally support Lowenfeld's theoretical visual/haptic learning style percentages, it does not totally invalidate his theories. Three major factors that support this statement: the population used to gather this data, the use of the Successive Perception Test I to classify individuals as visuals or haptics, and the cognitive strategies used by the subjects to solve the test problems.

The first factor in support of Lowenfeld's theories was the population used in this study to classify persons as visuals or haptics. Prior visual/haptic research (Lowenfeld, 1939, 1945; Wiggin, 1951; Erickson, 1963, 1966, 1969; Clark, 1971) used either elementary, middle school, or high school students. College age students used in visual/haptic research studies were education majors (F. B. Ausburn, 1975; Ausburn, 1975, 1979). Engineering students in this study scored higher on the Successive Perception Test I and seemed to be a different population than those used in prior research studies.

Engineering majors at Purdue University may not be a true representation of the general population. These students are either self-selected or through admissions standards seem to be visuals. Entrance requirements are rigid for being accepted into the engineering programs at Purdue University. The lowest possible requirements for Indiana residents are SAT verbal score of 400 and math score of 500 (Purdue University, 1992). The average scores for admission into engineering for Indiana residents are SAT verbal score of 520, SAT math score of 640, and a rank of 91 percentile in class graduation (Gant, 1992). Out-of-state admissions requirements are even higher, and only the most qualified students are selected for the 500 open slots available (Purdue University, 1992).
Finally, subjects might have been misclassified as haptics when they could have been visuals because of the cognitive processes they used to answer the questions on the Successive Perception Test I. If these subjects used verbal linguistic strategies or other flawed cognitive processes to answer the test questions, they may have been misclassified. However, this would seem to be a rare occurrence because if individuals were truly visuals, logically they would use visual strategies to solve problems on the Successive Perception Test I.

Therefore, three possible outcomes might have happened. The first is that most Purdue engineering students are visuals and that haptic individuals already were removed from consideration through self-selection or the admissions process. This would account for the fact that very few haptic individuals were found in the population when the Successive Perception Test I was administered, thus causing the need to revise visual/haptic classification scores. This adjustment of Lowenfeld/Ausburn's visual/haptic classification would have had the effect of classifying individuals, who in the general population were indefinites, as being haptic. Therefore, many of the haptic individuals used in the treatment and control groups may not have been haptic. This could have led to the unexpected results in the statistical analysis of the experimental data.

Secondly, the reliability of the Successive Perception Test I must also be questioned. Because this test had not previously had consistently high reliability ratings, the reliability of the Successive Perception Test I was examined for both the pretest and posttest administrations. The procedure used to determine the reliability of the Successive Perception Test I involved the use of the Cronbach Alpha test of reliability. The pretest reliability coefficient was 0.54 and the posttest was 0.53. Both of these reliability coefficients were low, but there was no other group measure of visual/haptic aptitude available to use in this study. The Successive Perception Test I was deemed reliable for use in this study because Thorndike and Hagen (1969) stated, "A test with relatively low reliability will permit us to make useful studies of and draw accurate conclusions about
groups, especially groups of substantial size, but quite high reliability is required if we are to speak with confidence about individuals (p. 95).” Given the low reliability of the Successive Perception Test I on the posttest administration, its reliability also must be questioned. If the Successive Perception Test I is not reliable, it could cause individuals to be misclassified, especially visual or haptic subjects who were very close to being classified as indefinites. If individuals were classified falsely as haptics or visuals when they were really indefinites, these misclassifications would also affect the statistical results of the study.

Third, if students used various cognitive strategies to determine answers to the Successive Perception Test I, this could have caused them to be misclassified as being haptics. If a large proportion of the sample was so misclassified, results of the statistical analysis would be invalid.

Either of these situations causes the researcher to suggest caution in using the Successive Perception Test I as a visual/haptic classification instrument. Unless this instrument through thorough statistical analysis can be proven reliable for classification of individuals as visuals or haptics, it should not be used. Even if the Successive Perception Test I accurately classifies individuals as visuals or haptics, this validity is useless unless it can do so reliably.

Also, further research of Lowenfeld's visual/haptic classification instruments as a whole should be undertaken. The Successive Perception Test I is only one of many measurement instruments that Lowenfeld developed for the classification of individuals as visuals or haptics. The reliability and validity of each of these instruments should be determined. Of these evaluation instruments, any which show high reliability should be statistically analyzed to determine if it is then valid. Once the reliability and validity are determined to be acceptable, other research could be undertaken.

One area of research would be to test a representative sample of the general population to determine if Lowenfeld's theoretical percentages are valid. Other studies could involve
the development of a new visual/haptic instrument that would replace the Successive Perception Test I for use in group administrations. Finally, if a new group-administered visual/haptic classification instrument is developed that is both reliable and valid, this study could be replicated to determine if the same or different results are found. If haptic subjects would benefit from the experimental instructional approaches, students identified as haptics should be advised to enroll in special sections of engineering graphics courses that specifically utilize real- and computer-generated models.

Results of the two-factor ANOVAs showed no statistically significant interactions between instructional treatment and learning style variables. These results were not totally unexpected based on prior visual/haptic learning style and instructional media research theories. Visual/haptic research theories by Lowenfeld would agree with these results. But, the supplantation theory of Salomon would not agree entirely with the results, especially if real- and computer-generated models are valid supplantation tools that would allow for the advancement of spatial abilities.

The basis for using visual and haptic subjects in this study was Lowenfeld's claim that visual and haptic individuals are at extreme opposites in the way they process information. Lowenfeld postulated that visual individuals, unlike haptics, have the ability to see an object, break it up, see its component details, and resynthesize the details back into a whole. Thus, visual individuals have the ability to manipulate and maintain visual imagery, where haptics do not. Secondly, visual individuals would rather "see" or visualize experiences; haptic individuals would rather "feel" or use tactile experiences to process information.

Because of Salomon's supplantation theories, the researcher felt that the use of computer-generated and real-models would act as supplantation tools that would especially help haptic individuals to visualize objects. The assumption was that real- and computer-generated models would allow haptic individuals to maintain the visual image of the object until they could form the mental image for themselves. The computer-generated models
would allow the subject to see selected views of the object by being able to rotate the computer-generated image and would supplant for them the retention of visual images. This would not be possible through the use of traditional pictorial representation of objects. While real-models would allow the same advantages of visual imagery as the computer-generated models, real-models would also have the distinct advantage of allowing the student to have tactile interaction and manipulation of the object, which Lowenfeld claims is so important. Visual subjects, according to Lowenfeld's theories, should not need these learner experiences that supplant the spatial ability development that is so vital to haptic individuals.

Thus, it was the expectation of the researcher that there would be an interaction between treatment and learning style. Because of the presumed supplantation effects of both real- and computer-generated models, haptic subjects who received these experimental treatments were expected to have significantly higher spatial ability scores than haptic individuals who were exposed to the traditional treatments. Conversely, visual subjects who were exposed to the experimental treatments should not have scored significantly different from visual subjects who were exposed to traditional treatments. This was expected because Lowenfeld's theories suggest that visual subjects possess the ability to manipulate visual imagery and thus should not need the experimental treatments.

Data from the statistical analysis for the main effects of learning style and instructional treatment somewhat, but not entirely, reflected the expectations of the researcher based upon visual/haptic learning style research and media research. First, it seemed logical that significant differences would have occurred between the instructional treatment variables. Specifically, it seemed that haptic subjects would have benefited from exposure to one of the experimental treatments as opposed to the use of traditional exercises. Because haptic subjects supposedly cannot maintain visual imagery, both the computer-generated and real-models would have allowed these individuals through supplantation to maintain the visual imagery necessary to solve the problems. Further haptic subjects who were exposed to the
real-model treatment should have benefited more because they had exposure to tactile experiences. Thus if haptics’ spatial abilities were advanced because of the instructional treatment, this might have caused a significant difference between the experimental variables of real-models and computer-generated models and the control group who were exposed to traditional exercises. Because of the expected improvement of the spatial abilities of the haptic subjects, a significant difference was expected even if visual subjects were not helped by the exposure to the experimental treatments.

The second finding of statistical difference between visual and haptic subjects was expected by the researcher. Lowenfeld contends that visual individuals possess the ability to manipulate mentally visual images while haptic individuals do not. Because the *Mental Rotations Test* is a spatial ability test that requires mental manipulation of visual images, visual individuals should have mean scores significantly different than haptic subjects. Secondly, if it is a reliable and valid test for classifying visual/haptic learning style, the *Successive Perception Test I* should have separated these two groups. If it did not, then no significant differences should have been found.

But, a few considerations must be made about these data. Two are concerned with the measurement instruments that were used to classify subjects and to gather data for this study. First, as was discussed previously, the *Successive Perception Test I* may not have correctly classified subjects as being truly haptic or visual. Together with the revised visual/haptic classification scheme used in this study, this may have lead to unexpected results.

Second, when the students' spatial abilities were measured with the *Mental Rotations Test*, they did not have the advantage of using the real- or computer-generated models to help them with this test. Without the advantage of the supplantation tool to help maintain the visual imagery needed to solve the problems, haptic subjects may not have scored well on the *Mental Rotations Test*. This would have affected the statistical results so that no statistical significance would be found. If this occurred, then Lowenfeld's visual/haptic
claim that an individual's visual/haptic learning style cannot be changed is supported. Thus, without the help of the supplantation tool, haptic individuals do not have the spatial abilities necessary to visualize problem solutions.

If this is indeed the case, it should be determined what causes a person to become either visual or haptic. Research in cognitive psychology contends that there are several sources of variance in spatial cognition. Individuals could be at different developmental stages when they are exposed to environmental, social, or emotional factors that influence the development of a particular learning style. These factors could account for sex differences in spatial abilities that McGee (1979) notes. Longitudinal or case studies should be undertaken to determine what factors might cause an individual to become either visual or haptic. With this knowledge, parents and elementary and secondary school curricula could include activities to allow individuals to advance their spatial abilities.

It also should be determined how subjects, who are exposed to instructional treatment that through supplantation allows them to visualize an object, can advance their spatial abilities without the aid of the supplantation tool. This would be necessary for subjects to function in their chosen professions. If individuals cannot visualize without the aid of the supplantation tool, they should be encouraged to seek alternate career choices where spatial abilities are not a central concern.

The external validity factors of selection, treatment, and reactive arrangements might have affected the study and should be considered in future studies. Had statistical significance been found, these factors might have questioned the results of the study. Future studies that have smaller groups might allow the researcher to control for all of these factors especially the possible interaction of treatment and reactive arrangements.

Although statistical significance was not found, results of the summative evaluation supported the use of a combination of real- and computer-generated models supplementing the traditional exercises. Because students felt so strongly in favor of using these instructional approaches, the quantitative results of the study must be questioned further.
Future qualitative studies should examine in greater detail the use of the experimental instructional treatments. If this research confirms that students do feel that these instructional approaches are indeed helpful, then it must be determined how much treatment is needed and who needs the treatment. Students who do not need the special instructional treatments should be allowed to progress at their own rate or be placed into special sections that allows them to progress rapidly. This same procedure should be developed for students who need the special instructional approaches. Thus special sections of the course could be developed to allow these students to advance their spatial abilities at a slower rate.

As mentioned previously, placing students into special sections of a course means that these students must be classified correctly as visuals or haptics. Thus, the need for a valid and reliable visual/haptic measurement cannot be overemphasized. But future research should not concentrate in just this area. Other areas of learning styles and teaching styles must be considered. Many times spatial abilities might not be developed because the teaching styles of the instructors do not match the learning styles of the students. Instructors of engineering graphics must remember that students do not have their level of advanced spatial abilities. Thus engineering graphics educators must think like a beginning engineering graphics student. They cannot mistakenly assume that the students possess advanced spatial abilities and their instructional approaches must reflect this fact. Miller, Wiley, and Bertoline (1989) contend that engineering graphics students should be exposed to realistic objects then work toward abstract line drawings. Thus the student should be given the object first then progress toward engineering drawings. It is hoped that with practice students then could visualize a design and be able to draw its abstract representation.

Also, the advancement of computer technology must be considered by engineering graphics educators. Within the next few years, the use of traditional two-dimensional engineering drawings may become obsolete. The influx of 3D solid modeling could replace 2D drawings. Thus, the engineering graphics educator must be prepared to develop
instructional approaches that will allow students to possess the cognitive abilities to work with this technology. Spatial abilities will become even more important for the engineer. The visualization of primitive objects and their spatial orientation in Euclidian three-dimensional space will become a necessity for all engineers. Thus the principles of engineering graphics and descriptive geometry will still be important but will have to be approached in a radically different manner.

Finally, advances in computer technology also will require the engineering graphics instructor to utilize all available technology. Every effort will have to be made to work with colleagues in computer science and related areas to utilize all high-end technology. Starting with computer animation, the development of new and advanced computer technology must be tested and integrated into the curriculum.

The results of the correlation between the posttest administration of the *Successive Perception Test I* and the *Mental Rotations Test* was significant but very low (0.32). Thus it would seem that these visual/haptic and visualizer/non-visualizer learning style areas are different. If reliable and valid visual/haptic measurement instruments are found or can be developed, a future in-depth study comparing these two learning style theories would benefit the literature.

Finally, the effects on an individual's visual/haptic learning style type, as measured by the *Successive Perception Test I*, was investigated. A comparison of visual/haptic learning style type percentage changes, between the pretest and posttest administrations of the *Successive Perception Test I*, was used to determine if the instructional methods and media had any effect on an individual visual/haptic learning style type. Results showed that in part of the cases an individual's learning style type did not change. However, many times the individual's learning style type did change, and in limited cases learning style type changes were totally unexpected (i.e., haptic to visual). These results led the researcher to question if Lowenfeld's theories that contend that a subject will never change learning style
type are valid or if the *Successive Perception Test I* is a valid and reliable measurement instrument in the classification of visual/haptic learning style.

It might be concluded from these results that the instructional treatment caused many individuals to change their visual/haptic learning style, but to change from a haptic to a visual or visa versa does not support Lowenfeld's theories. He claims that persons would either have a visual or haptic learning style and that they should not change. He also claims that a large percentage of individuals cannot be classified as either and that this indefinite population could be closer to having either visual or haptic learning styles. But it's possible the instructional treatment somehow changed a person's visual/haptic learning style. Even if a small correlation existed between the *Successive Perception Test I* and the *Mental Rotations Test*, the instructional treatment could have prepared the individual to do better on the second administration of the *Successive Perception Test I*. But this conclusion does not account for the small percentage of subjects (2.75%) who changed from visual to haptic classification.

The reliability of the *Successive Perception Test I* also must be questioned again. Thus, this test might not have classified correctly visual and haptic subjects, thus leading to the questionable data. Finally, it could be that the adjusted scale on the *Successive Perception Test I* caused data errors. Because engineers seemed to be visual by nature and selection, the classification used in this study could be faulty. Although some of the percentages refute Lowenfeld's theories and support the use of instructional treatment as a factor in changing a person's visual/haptic learning style, these conclusions must be viewed with skepticism.

**Conclusions**

The conclusions of this study are related to the four research hypotheses of the study. The following conclusions were based upon the statistical analysis and findings found in Chapter Four. It can be concluded that:
1. The reliability of the *Successive Perception Test I* was consistently low on both of its administrations. Because of the low reliability of the *Successive Perception Test I*, it might not classify subjects correctly as being visual or haptic learning style types, thus possibly invalidating the statistical analysis.

2. The population from which this sample was drawn was statistically significantly different from Lowenfeld’s theoretical claim that 47 percent of the population are visuals, 23 percent are haptics, and the remaining 30 percent are indefinites.

3. Statistically, the experimental instructional treatments (real- and computer-generated models) did not help the subjects to advance their spatial abilities.

4. Statistically, visual subjects possessed higher spatial abilities than did haptic subjects.

5. Qualitatively, the subjects strongly believed that the instructional treatments helped them to visualize better and to receive a higher grade in the course.

6. Qualitatively, the subjects believed that a combination of traditional exercises supplemented by real- and computer-generated models, would be more advantageous in helping them to advance their spatial abilities. The subjects also felt that real-models by themselves would be helpful. Computer-generated models were selected also as being good instructional media to advance spatial abilities but were not favored as highly.

7. Although there was a significant correlation between visual/haptic learning style as measured by the *Successive Perception Test I* and spatial ability as measured by the *Mental Rotations Test*, the correlation was too low to consider these different learning styles are the same.

8. Although many individuals changed visual/haptic learning style from the pretest to the posttest administration of the *Successive Perception Test I*, this data should not suggest that an individual can change visual/haptic learning style. This conclusion is based upon the unreliability of the *Successive Perception Test I*. 
9. The reliability of the *Successive Perception Test I* is so low that statistical results of this study should be viewed with skepticism. Results of the qualitative questionnaire should be considered earnestly for further studies.

**Recommendations**

The review of the literature, experiences of the researcher in conducting the study, and the statistical results of the study serve as a basis for several recommendations. These recommendations are directed to teachers and to future researchers in spatial abilities advancement, learning styles, and instructional media.

1. Because of the low reliability of the *Successive Perception Test I* in this study and prior studies (Ausburn, 1979, Gibson, 1947), the use of this test instrument to classify visual/haptic learning styles is discouraged.

2. Because the use of the *Successive Perception Test I* to classify visual/haptic subjects is not recommended, a new group administered visual/haptic measurement instrument should be developed, statistically analyzed, and implemented.

3. Because Lowenfeld's theoretical visual/haptic learning style classification percentages were not found in an engineering population, this study should be replicated to determine if these findings would be found again in a different engineering population.

4. Because Lowenfeld's theoretical visual/haptic learning style classification percentages were not found in this study, it should be replicated using different populations of subjects.

5. Because Lowenfeld's theoretical visual/haptic learning style classification percentages were not found in this study, his other visual/haptic learning style classification instruments should be examined to determine if they are reliable and valid in the classification of visual/haptic learning styles.

6. Because the statistical findings that determined the experimental treatments did not advance the spatial abilities of either the visual or haptic subjects, and conflicted with the
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qualitative findings that showed the subjects felt that the experimental instructional
treatments were beneficial, this study should be replicated to try to determine the cause of
this discrepancy.

7. Because of the amount of time necessary to develop real-models and the hardware
and software expenses of computer-generated models, future studies should try to
determine how much time should be spent using these models.

8. Because students may have had trouble visualizing without the aid of the real- or
computer-generated models, future studies should determine how students can gradually
reduce their dependency upon these instructional approaches and still advance their spatial
abilities.

9. Because of the amount of time necessary to develop real-models and the hardware
and software expenses of computer-generated models, future studies should try to
determine the learning style characteristics of subjects who need to use real-models,
computer-generated models, or no models at all.

10. Because the theories of visual/haptic learning style and visual/nonvisual learning
style are very similar and because there was a small correlation between these two areas in
this study, future studies should investigate if these are separate or the same learning style.

11. Because subjects changed visual/haptic classification from the pretest to the posttest
administration of the Successive Perception Test I, future studies should determine if a
person's visual/haptic learning style can be changed by exposure to specific instructional
treatments.

12. Because theoretical differences exist as to the factors that contribute to the
development of spatial abilities longitudinal and case studies should be undertaken to
investigate what factors cause individuals to differ in spatial ability.

13. Because the students felt that both real-and computer-generated models were helpful
in advancing their spatial abilities these instructional approaches should be integrated in
engineering graphics curricula.
14. If a valid and reliable measurement can be developed that can predict spatial ability, then students should be assigned to special course sections that will match their spatial abilities.

15. Engineering graphics educators must use all existing instructional technologies and be prepared to implement new technologies that help students to advance their spatial abilities.

16. Because of the rapid influx of 3D solid modeling technology and other advanced graphical technologies, the engineering graphics curriculum will have to make substantial revisions to reflect and implement these technologies.

17. It is the expressed hope that education professionals who teach and research in visual disciplines, especially individuals in engineering and technical graphics, will undertake more research in the aforementioned and related visual areas to build a solid research base. With such a base, visual disciplines can develop a justified body of knowledge. Without this research-based body of knowledge, visual disciplines' respectability, growth, and very existence are threatened.
APPENDIX A

TECHNICAL GRAPHICS 108 SYLLABUS AND COURSE OUTLINE
Course Description

Basic graphical methods taught with emphasis on visualization and freehand sketching. Lectures and laboratory assignments are intended to develop a broad understanding of representational and descriptive graphics and an ability to read and analyze engineering documents. Multiview, isometric, and sectional views, and dimensioning topics are covered as well as creative design sketching and the design process. The reading and visualization of engineering drawings and documents in the areas of mechanical design, piping, electronics, construction, and assembly is stressed.

Course Objectives

1. To develop the ability to visualize the spatial relationships of points, lines, and surfaces.
2. To understand the theory of geometric primitives as applied to spatial and projected relationships.
3. To develop the ability to present clearly identified solutions useful in graphic communication.

Textbook


Workbook


Equipment

TG 108 equipment set available at bookstores.

Grading Scale

1. Final letter grades are calculated as follows:
   4 Performance Tests 50%........ Performance tests are graded from 1 to 100, in increments of 1.
   Lab Exercises 25%........ Lab exercises are graded from 1 to 4, in increments of .5
   Unannounced quizzes 15%........ Unannounced quizzes are graded from 1 to 10, in increments of 1.
   Final Examination 10%........ Final examination is graded from 1 to 100, in increments of 1.

2. Regardless of the above percentages, any student who completes (1 pt. or higher) less than 80% of the lab assignments will receive an F for the course.

3. One lab assignment may be collected during lecture and will count as a quiz grade. These lab assignments will be collected by the teaching assistants or the professor. Each individual can only turn in his/her lab assignment. Students will not be allowed to turn in other students work. One assignment will be collected and graded at the end of each lab period. All remaining lab assignments will be due at the beginning of the class following the day they were assigned. Late drawings will not be accepted.

4. Performance tests are 48 minutes in length and are offered only during the regularly scheduled lab period. A unit laboratory test will be administered during "dead week" before finals.

5. Unannounced quizzes may be given either during lecture or lab periods.

6. The final examination will be held during finals week at the officially scheduled time and location. No excuses will be accepted for missing the final examination.
### Technical Graphics 108 Schedule of Instruction Fall Semester 1990 Monday Sections

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<th>Topics</th>
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APPENDIX B

THE MENTAL ROTATIONS TEST
PLEASE NOTE

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University Microfilms International
APPENDIX C

THE SILVERSCREEN MACRO
Using the SilverScreen Drawings and Macro

Note: These were developed using version 1.11

Loading the drawings into SilverScreen:

From the C:
1. Change directory to Silver (CD Silver, enter).
2. Change to the DWG directory under Silver (CD DWG, enter).
4. Copy all files to the C drive (Copy *.* C:, enter).
5. Change the drive back to the C drive (C:, enter).
6. Change directory to Silver (CD.., enter).

Loading the macro (toronto.mac) into the Silver directory:

From C/Silver:
1. Change to the A drive (A:, enter).
2. Copy the file Toronto.mac to the C drive (Copy Toronto.mac C:, enter).
3. Change back to the C drive (C:, enter).
4. Load SilverScreen (Silver, enter).
5. Enter Utility/Startup/Standard (U enter, S enter, S enter).
6. Scroll down to the Menus and Prompting area (press the down directional key)
   A. Change Command Macro Mode to automatic (press right directional key)
   B. Change Macro File to Toronto (type toronto, enter)
7. Enter F10 to quit the Startup menu (enter F10).
8. Enter F10 to quit SilverScreen (enter F10).

Now everytime that you enter SilverScreen the macro 'toronto' will automatically be loaded.

Using the Macro:
1. Enter SilverScreen.
2. Hit the 'tab' key.
3. Choose a drawing and press enter.
4. Hit the 'ESC' key.
5. Enter Swing (enter S).
6. Use the up/down and the right/left directional keys to choose a view direction for the object and press enter.
7. Use the F9 key to repeat the last move if you want to repeat that move.
8. Repeat the above steps for different viewing positions.
9. Enter 'E' to exit this object in order to quit or load a new drawing.
APPENDIX D

WEEK ONE PROBLEM SHEETS
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Time on task

![Diagram](image-url)
Time on task

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INTRODUCTION TO ENGINEERING DRAWING

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[Diagram of a 3D object with various lines and annotations]

**INTRODUCTION TO ENGINEERING DRAWING**

**DRAWN BY:**

**LAB**

**CLASS/SEC.: DATE SCALE**
APPENDIX E

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**CLASS/SEC.:**

**DATE:**

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APPENDIX G

WEEK FOUR PROBLEM SHEETS
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**Standards/Conventions**

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**INTRODUCTION TO ENGINEERING DRAWING**

**DRAWN BY**

**CLASS/SEC.**

**DATE**

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**Introduction to Engineering Drawing**

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INTRODUCTION TO ENGINEERING DRAWING

DRAWN BY, LAB
CLASS/SEC. DATE SCALE
APPENDIX H

CONSENT FOR PARTICIPATION FORM
Technical Graphics 108 Research Consent Form

This is a study to determine if different engineering graphics instructional approaches help specific individuals to develop and advance their spatial abilities.

This study will last for the first six weeks of the semester. If you agree to participate in this study you will be randomly assigned to a special section of Technical Graphics 108 based on your scores on the Successive Perception Test I. The special sections will take the place of your regular one-hour laboratory section. They will meet at either 6:00 p.m., 7:00 p.m., 8:00 p.m., or 9:00 p.m. in the evening Monday thru Friday depending on your schedule. The special laboratory sections will be one hour in length and will cover the exact same material as the traditional laboratory sections. The only difference between the experimental sections and the regular laboratory sections will be how the instructional material is presented. You will be randomly placed into one of the following sections: (1) a traditional section where the instruction is the regular laboratory section, (2) a laboratory section that will supplement the traditional laboratory instruction with real models, or (3) an laboratory section that will supplement the traditional laboratory instruction with computer-generated models. You will be expected to attend the regularly scheduled lecture sections and complete all assignments, quizzes, and examinations.

At the conclusion of the experiment you will be administered the Mental Rotations Test and the Successive Perception Test I. The following week you will meet in your regular laboratory section and will do so for the remainder of the semester.

All information that you give us during this study will be kept confidential. The records will be available only to persons working on or auditing the project.

If you have any problems during the study or wish to ask questions concerning the study, call Craig L. Miller at (317) 494-8207 during working hours (8:00 a.m.-5:00 p.m.).

Taking part in this study is completely up to you. You can refuse to be in the study. You may also withdraw from the study at any time. If you withdraw or refuse to be in the study, you will not lose anything or be penalized in any manner.

I have read the above information and understand it. I was given a chance to ask questions. Also, I am over eighteen years of age and I freely agree to participate in this study. A copy of this form will be given to me.

______________________________________________    ________________________
Subject's Signature                                     Date
APPENDIX I

HUMAN SUBJECTS PERMISSION FORMS
ACTION OF THE REVIEW COMMITTEE

With regard to the employment of human subjects in the proposed research protocol:

90B0135 THE EFFECTIVENESS OF USING REAL AND COMPUTER-GENERATED MODELS TO ADVANCE THE SPATIAL ABILITIES OF VISUAL-HAPTIC ENGINEERING STUDENTS, E. Keith Blankenbaker, Craig L. Miller, Educational Studies

THE BEHAVIORAL AND SOCIAL SCIENCES REVIEW COMMITTEE HAS TAKEN THE FOLLOWING ACTION:

X APPROVED

DISAPPROVED

APPROVED WITH CONDITIONS*

WAIVER OF WRITTEN CONSENT GRANTED

* Conditions stated by the Committee have been met by the Investigator and, therefore, the protocol is APPROVED.

It is the responsibility of the principal investigator to retain a copy of each signed consent form for at least four (4) years beyond the termination of the subject's participation in the proposed activity. Should the principal investigator leave the University, signed consent forms are to be transferred to the Human Subjects Review Committee for the required retention period. This application has been approved for the period of one year. You are reminded that you must promptly report any problems to the Review Committee, and that no procedural changes may be made without prior review and approval. You are also reminded that the identity of the research participants must be kept confidential.

Date: August 14, 1990

Signed: [Signature]

(Chairperson)
Research Protocol:

90B0135  The Effectiveness of Using Real and Computer-Generated Models to Advance the Spatial Abilities of Visual-Haptic Engineering Students, E. Keith Blankenbaker, Craig L. Miller, Educational Studies

Presented for review by the Behavioral and Social Sciences Review Committee to ensure proper protection of the rights and welfare of the individuals involved with consideration of the methods used to obtain informed consent and the justification of risks in terms of potential benefits to be gained, the Committee action was:

- X APPROVED *
- _____ APPROVED WITH CONDITIONS
- _____ DISAPPROVED
- _____ NO REVIEW NECESSARY

*CONDITIONS/COMMENTS:

Subjects were deemed NOT AT RISK and the protocol was unanimously APPROVED.

COMMENT: The written script to subjects (as written in the Summary Sheets, Item #10), should be explained to subjects in more simplistic terms and deleting cited references.
COMMITTEE ON THE USE OF HUMAN RESEARCH SUBJECTS

Approval Form

REF. # 90-064

1. Project Title: THE EFFECTIVENESS OF USING REAL AND COMPUTER-AIDED MODELS TO ADVANCE THE SPATIAL ABILITIES OF VISUAL-HAPTIC ENGINEERING STUDENTS

2. Principal Investigator: MILLER, CRAIG L.

3. Department/Head: TECHNICAL GRAPHICS (KNOY) / J. V. SMITH

4. Funding Agency: N/A

5. Committee Action: Approved X Denied _____ Date 8/28/90

R. Paul Abernathy, Chairman
Use of Human Subjects in Research Committee

1. Human subjects involved in the above-titled project are in one of the following classes:

____ Minors ____ Pregnant Women ____ Fetuses ____ Abortuses

____ Prisoners ____ Mentally Retarded ____ Mentally Disabled

X None of the above

2. The Institution Review Board (IRB) has determined:

X Human subjects will NOT be at risk.

_____ Human subjects WILL be at risk. ____ Low ____ Intermediate ____ High

These actions were taken by:

X Full Review Board X Expedited Review

All activities in this application have been reviewed by Purdue's IRB in accordance with the requirements of the Code of Federal Regulations on Protection of Human Subjects (45 CFR 46) and our General Assurance with HHS (Number M1162).

CC: C. L. MILLER/TECH GRAPH/KNOY
J. V. SMITH/TECH GRAPH/KNOY

HS-7
TG 108 Research Study Questionnaire

Your Name: _______________________ Computer/Real/Control Section: _________

1. Did the real/computer/exercises helped you to visualize the solution to the problems?

Agree ___ ___ ___ ___ Disagree

Comments:

2. Do you think real/computer/exercises were too easy in relation to the test problems?

Agree ___ ___ ___ ___ Disagree

Comments:

3. Do you think real/computer/exercises were too hard in relation to the test problems?

Agree ___ ___ ___ ___ Disagree

Comments:

4. Do you think that too much time was spent on this study?

Agree ___ ___ ___ ___ Disagree

Comments:
5. Which exercises would have helped you more?

Computer-Model  Real Model  Regular Assignments  Combination of all three

Comments:

6. Do you think that the real model exercises should be integrated into the course throughout the semester?

Agree __ __ __ __ Disagree

Comments:

7. Do you think that the computer-model exercises should be integrated into the course throughout the semester?

Agree __ __ __ __ Disagree

Comments:

8. Do you think that a combination of computer-model and real model exercises should be integrated into the course throughout the semester?

Agree __ __ __ __ Disagree

Comments:

9. How much time outside of class did you spend on homework assignments?

Time__________

Comments:

10. Do you think the exercises helped you receive a better grade in the course?

Agree __ __ __ __ Disagree

Comments:
APPENDIX K
SUMMATIVE QUESTIONNAIRE STUDENT COMMENTS
The first question asked the subjects to rate on a five point scale (5 = agree, 
1 = disagree) whether they felt that the instructional setting they were in during the study 
helped them to visualize problem solutions.

**VISUAL/COMPUTER (Comments)**

1. Difficult to manipulate at times
2. It really helped on those problems that I had a hard time with.
3. Some exercises were helped a great deal by the computer.
4. For certain problems where mental visualization fails, computer graphics help 
a lot.
5. For the most part, I didn’t require the computer in order to visualize the isometrics.
6. Yes, better than I could before, and better than a normal class.
7. On some of the more difficult problems, it helped to be able to look at a model to 
figure out the solution.
8. The computer helped, but the drawings at the beginning of the semester weren’t 
one’s I needed help on. It would have been better to be able to use the computer 
on the more difficult drawings.
9. Only used computer on a couple of assignments.
10. I have already good skill concerning visualization of objects. If the computer exercises 
did not help me visualize better then it did help me to become faster. But I feel that on 
larger and more complex models it can be very helpful.
11. It was kind of slow.
12. It is much easier to visualize an object if you have a model or computer 
generation.

**VISUAL/REAL (Comments)**

1. They helped until we moved back and took our first test without the aid of the models.
2. It sped things up.
3. They made it easier to do the problems quicker because I didn’t have to think it out in 
my head.
4. These things ought to be integrated ASAP! They were extremely helpful in 
visualization and in determining hidden lines, etc.
5. The blocks were a good help when I just couldn’t visualize the object from the 
drawing.
6. The three dimensional models were extremely helpful.

**VISUAL/CONTROL (Comments)**

1. No comments.

**HAPTIC/REAL (Comments)**

1. Only for the most difficult.
2. The physical blocks were helpful because of the views I was able to observe.

**HAPTIC/CONTROL (Comments)**

1. Too easy
2. To some extent.
HAPTIC-BUHRTER (Comments)

1. However, it only helped on a few of the problems. The computer was not used on most of the problems because it was of little help.
1. When I had problems seeing the figure it was good to be able to rotate the figure.
1. I believe that I would have done better with the real models.
1. It might have been more helpful to use computers a bit longer.
1. I thought it was very helpful to me and believe I would have had a great deal more problems without the computer.

Question four asked the subjects to rate on a five point scale (5 = agree, 1 = disagree) whether they felt that too much time was spent on this study.

VISUAL/BUHRTER (Comments)

4. It was interesting
4. An additional couple of weeks would have been great.
4. No! This was a very good study. It shows how with a little help mental visualization can become a lot easier.
4. The study should be implemented by the TG 108 class permanently.
4. No, it was long enough to see if would benefit, but short enough so that no problems were caused if a person was having trouble with either the computer or the real models.
4. No, because the computer could really help the people who are having difficulties visualizing the blocks.
4. I wish I could have done more.
4. This concerned basic drafting techniques, something the student will need a great understanding of.
4. Drawing a third view from only the other two (no model or isometric drawing) was the most difficult for me.
4. Time seemed reasonable.
4. Actually, no.

VISUAL/REAL (Comments)

4. Although I didn't need to use the blocks for most of the models, when I did have a problem though, the blocks helped.
4. It's a good idea.

VISUAL/CONTROL

4. It seems orthographic is fairly important to visualizing.

HAPTIC/REAL

4. That depends on the results but it didn't hurt my grade by doing the study.

HAPTIC/CONTROL

4. There should have been more time spent on the last section.
4. I think that I spent too much time on this course, and that the tests were too difficult for a one-credit course.
4. Too much for a one-credit hour course (2-3 hrs/wk).
HAPTIC-COMPUTER

4. Good way to learn how to view objects.
4. The experimental time took only the first 4-5 weeks of the semester during only the first section.
4. I feel as though enough was not really done with it - that I saw. I also would have liked to have been in a new group. One where the first half of the group was computer and the second half hand-held models. Just to see if I improved, no change, or worse.
4. I felt this first section was fairly easy.
4. Not enough time was spent.
4. Put more time towards the computer.

Question five asked the subjects to choose one type of instructional treatment that they thought would have helped them to advance their spatial abilities.

VISUAL/COMPUTER

5. Easier for me to visualize
5. It is what I did and I thought it helped me the most.
5. It was great, because at first it is hard to grasp concepts of TG. But computer establishes good foundation.
5. The only vice that I have with computers is that they took too long to switch a view.
5. I think having all three resources available would help future classes. I benefited from the assignments and the computer, and though I didn’t use real models, I think they would be a further benefit.
5. Maybe alternate what you use at different times during semester.
5. Combining these things could only help more. Computer can give a good side of top view.
5. The perspective that was involved with the computer sometimes made it harder. The real models would have been faster too.
5. It would be very easy to visualize something you’re actually holding that’s 3D.
5. Combining all three methods can help student to visualize objects given any one of the methods in the future.

VISUAL/REAL

5. I think it would be a good idea to allow students access to both real models and comp. models.
5. Real allows manipulation which is totally governed by user - move it how you want it.
5. Would give diversity and encourage finding new ways to solve problems.
5. It helps to be able to hold something physically in your hands.
5. Just because I do everything better on computer.
5. Because you can feel the real model in your own hand, relating hand to eye.
5. I had the Real Model section and it helped me to do the regular problems better. I would think that the same would be true for the computer model.
VISUAL/CONTROL

5. It would help to see the models and then draw them.
5. There are times when things need to be seen to help draw the views.
5. I picked a combination of all three just because seeing something three different ways would probably help, but there should be an emphasis on regular assignments; the only way to really learn it is to do it.
5. Both computer and real model can help a tremendous amount but also might really limit the amount of visualization the student would need to do. If there could be a way to have models for the really “hard” problems or made available after the students have tried to visualize it in their mind.

HAPTIC/CONTROL

5. By using the combo of all three, the real model would have made the last section easier. The computer model would have made the last test easier.
5. I think this is the best combination. It would have been nice to have a 3D model to look at and rotate.
5. I didn’t think any of the exercises proposed much great thought.
5. I think the computer models should definitely be used for the latter part of the course (missing view, etc.). This is where most students need help in visualization.

HAPTIC-COMPUTER

5. Computer you couldn’t hold the real model and it wouldn’t give one view.
5. Computer model was of little help.
5. I think that if I could have held the model and seen it as a real object, I would have done better.
5. Combination of computer/real models
5. I believe the computer helped me greatly.

HAPTIC/REAL

5. Real models would be even more helpful as the class progressed.

Question six asked the subjects to rate on a five point scale (5 = agree, 1 = disagree) if they felt that real model exercises should be integrated into the course throughout the semester.

VISUAL/COMPUTER

6. Yes, it would definitely help.
6. It might have helped those who couldn’t visualize the different problems.
6. Real model is easier to manipulate than computer.
6. It would be OK. to integrate real model but I think the computer is the best.
6. Definitely, they help just as well, if not more than pictorials.
6. I didn’t have any real model experience.
6. I think having all three resources available would help future classes. I benefited from the assignments and the computer, and though I didn’t use real models, I think they would be a further benefit.
6. Absolutely.
6. They should not be used throughout the entire course because they could become a crutch. But they could be very useful in explaining some of the more complex parts of the course or in helping us visualize complex objects (i.e., inclined planes)
VISUAL/REAL

6. I strongly believe that real models should be used in the whole course.
6. If the blocks are in the room then if someone needed them they could get them.
6. I think that if I can actually touch the object I can draw it easier.
6. At least at the beginning.
6. Yes it might help.
6. Yes! Yes! Yes!
6. Especially on oblique models.
6. When you can see an object in 3D, it immensely helps visualization.
6. They could be used occasionally, but not to the point where the student is dependent upon them.

VISUAL/CONTROL

6. It make visualization of hard problems easier. Maybe it should be integrated just for the harder problems.
6. Especially during missing view problems.
6. Yes, if everyone is given chance at each in an equal amount.

HAPTIC/CONTROL

6. I don’t think it really matters.
6. Yes, it helps a lot.
6. Cheap, easy to distribute, used especially on hard problems.

HAPTIC-COMPUTER

6. Good idea
6. I definitely believe this would be a good thing to help visualize the objects better.
6. None should be used throughout the whole course.

Question seven asked the subjects to rate on a five point scale (5 = agree, 1 = disagree) if they felt that computer-generated model exercises should be integrated into the course throughout the semester.

VISUAL/COMPUTER

7. It would have been nice, but for a beginning course it might have been too involved.
7. Yes they give an early taste of CAD.
7. It seemed helpful to those near me.
7. I think having all three resources available would help future classes. I benefited from the assignments and the computer, and though I didn’t use real models, I think they would be a further benefit.
7. Definitely.
7. Only if it is in a case where someone is having a lot of trouble on the assignments even with the real models.
7. No.
VISUAL/REAL

7. It would have been interesting to see them work at least once.
7. It wouldn't be as easy to do as the real models.
7. I don’t know.
7. The computer is still in 2D.

VISUAL/CONTROL

7. Yes, they would be extremely helpful when visualizing the object.
7. I think the computer would not help simply because the screen cannot represent that third dimension.

HAPTIC/REAL

7. Don’t know.

HAPTIC/CONTROL

7. I think the real model is better because you can examine it more.
7. It would take too much time to accomplish too little.
7. Computer models might help, but I think visualization is something that develops slowly regardless of the method used to improve it - at least in my case.
7. Would probably be prohibitively expensive, but otherwise would be good.
7. If everybody could use their own computer, to work at their own pace.
7. Too much trouble.
7. Would be helpful.

HAPTIC/COMPUTER

7. Start with this form.
7. Alternate lab groups on the computers.
7. I feel they should be used in the last half of the semester.

Question eight asked the subjects to rate on a five point scale (5 = agree, 1 = disagree) if they felt that a combination of real model exercises and computer-generated model exercises should be integrated into the course throughout the semester.

VISUAL/COMPUTER

8. I don’t think both would have worked together.
8. Being exposed to both, I feel, would be helpful.
8. Using all three would make this class much easier, as well as more compatible.
8. Both maybe, but computer is good enough.
8. It would be the best of both worlds.
8. The computers really seemed to help those sitting around me.
8. It would be totally helpful.
8. I think having all three resources available would help future classes. I benefited from the assignments and the computer, and though I didn’t use real models, I think they would be a further benefit.
8. It would be so much more helpful for the students to visualize and develop their visualizing skills. Use on homework, not for tests.
8. I found it faster not to use computer unless I got stuck on a difficult exercise.
8. Yes!

VISUAL/REAL

8. Yes, but used to help develop a sense of perception, then only as an aid for harder problems. They could result as a crutch - shouldn't be used throughout.
8. I think a combination would be most helpful.
8. I think the models are enough, and it would be more fair if everyone did the same thing.
8. Students still need to visualize without models.
8. I am doubtful about the merit of the computers. Simply because it is in 2D.

VISUAL/CONTROL

8. Because I would have liked to have done both to see which was better.
8. This would give everyone the chance to use tools that helped their need.
8. It's sometimes hard to see and understand the views just from the drawings (computer and real model exercises will make the course more exciting as well)
8. All three would give a student the opportunity to see the objects correctly instead of perhaps visualizing an incorrect object and continuing without knowing of his/her mistakes.

HAPTIC/REAL

8. Don't know, but I liked the real models a lot.

HAPTIC/CONTROL

8. More emphasis should be placed on computer-model, though.
8. I think the real model is better because you can examine it more.

HAPTIC-COMPUTER

8. Computer then real model
8. One or the other

Question ten asked the subjects to rate on a five point scale (5 = agree, 1 = disagree) if they felt that the instructional treatment (real model, computer-generated model, or traditional exercises) they used during the study helped them to receive a better grade in the course.

VISUAL/COMPUTER (Comments)

10. Somewhat. It did help in learning to visualize the objects.
10. Computers made it easy.
10. Using the computers helped initiate me. I had never had this type of course and the computer helped show me what I needed to be doing.
10. Slightly, they helped me on problems that I felt less sure of.
10. Overall, it added slightly to my skill level by working with the computers.
10. Either you saw the views or you didn't, I feel that the computer aids helped you to see the views.
10. It helped to visualize the blocks early on in the course.
10. My problem was with the end of the semester stuff. If we had the models then it would have been great.
10. I saw where the computer could be helpful but found that I was able to do a majority of the exercises without the computer.

VISUAL/REAL (Comments)

10. The real models probably helped me improve my grade on the tests.
10. More one on one learning.
10. Allowed me to check my drawings for error easier and faster than without them.
10. I had a mechanical drafting class in high school which I believe gave me enough of the skills, mental and otherwise, to be able to picture most of the objects in my mind and put them on paper.
10. When I couldn't see something, I was often able to visualize with the block.
10. Yep, they helped me to be sure of myself
10. The exercises (models) helped when I was stuck and couldn't visualize something in my head.
10. Yes, especially with oblique surfaces.
10. Even though it was difficult adjusting to 2-D from the real model, having worked with 3-D models helped me with visualizing shapes later on.

VISUAL/CONTROL (Comments)

None

HAPTIC/REAL (Comments)

10. The models helped I think because I was lost at the beginning.
10. The real model section seemed to bring my grade up; it helped me a lot.
10. It helped me during that time, when I went back to my regular lab my grade went down.

HAPTIC/CONTROL (Comments)

10. No it was really easy stuff
10. Yes, since my second test bombed me from an A.
10. I think they helped.
10. I think I would have done better with real models.

HAPTIC-COMPUTER (Comments)

10. They helped me to start to think in 3-D
10. The computer models helped me visualize some of the strange shapes that we were assigned to draw.
10. I feel that depending on the individual, that either computers or real models would be helpful.
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