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The Correlation Between a Pre-Engineering Student's Spatial Ability and Achievement in an Electronics Fundamentals Course

Mark E. Smith
Utah State University

THE CORRELATION BETWEEN A PRE-ENGINEERING STUDENT'S SPATIAL ABILITY AND ACHIEVEMENT IN AN ELECTRONICS FUNDAMENTALS COURSE

by

Mark E. Smith

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Approved:

_____	_____
Dr. Gary Stewardson Major Professor	Dr. Edward Reeve Committee Member
_____	_____
Dr. Leijun Li Committee Member	Dr. Ward Belliston Committee Member
_____	_____
Dr. Scott DeBerard Committee Member	Dr. Byron R. Burnham Dean of Graduate Studies

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Logan, Utah

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ABSTRACT

The Correlation Between a Pre-Engineering Student's Spatial Ability

and Achievement in an Electronics Fundamentals Course

by

Mark E. Smith, Doctor of Philosophy

Utah State University, 2009

Major Professor: Dr. Gary Stewardson
Department: Engineering and Technology Education

Though there is ample evidence showing a positive relationship between a student's spatial ability and achievement in many fields of science, technology, and engineering, this study was seeking evidence that a relationship exists between a pre-engineering student's spatial ability and achievement in an electronics fundamentals course.

The importance of spatial ability to mentally design, develop, and manipulate images has been linked to measures of practical and mechanical abilities that are quite useful in technical occupations. Spatial abilities are frequently attributed to creative and higher order thinking skills in science and mathematics. Spatial imagery is tremendously important in art and creative thinking, and has an important role in abstract engineering disciplines such as electronics.

This study included 154 students enrolled in two sections of a fundamentals electronics course. The average age of the students enrolled in this course was 22.64 years old. The majority (89.6%) of the students was male, and 59.1% of the students majored in mechanical engineering. The average GPA of the participants was 3.4. The participants scored well on the spatial ability test (avg. 17.5, out of a possible 20), and the average grade received in the course was a B (avg. 85.6, out of a possible 100).

This study showed a highly significant (.000 alpha 1-tailed level) and near medium (Pearson's *r* of .29) correlation strength between spatial ability and achievement in the course. There was significant positive correlation between GPA and spatial ability—corroborating that pre-engineering students with high GPAs also have high spatial ability. When controlling for GPA in a partial correlation, it was found that spatial ability accounted for a significant amount of the variance in the semester scores, which suggests that spatial ability provides some good prediction of doing well in an electronics fundamentals course above and beyond what GPA predicts alone.

Many STEM subjects are at the atomic level and require using mental models that are created in the mind's eye and necessarily require spatial reasoning ability. The understanding of a given aspect of the physical world is best conceptualized with a mental model.

(100 pages)

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Mark E. Smith

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LIST OF ACRONYMS

ASEE – American Society for Engineering Education

DAT:SR – Differential Aptitude Test: Space Relations

CAD – Computer Aided Design/Drafting

ETE – Engineering and Technology Education

IEEE – Institute of Electrical and Electronic Engineers

KR-20 – Kuder-Richardson equation number 20 for reliability coefficient

MTU – Michigan Technological University

NAS – National Academies of Science

PSVT:R – Purdue Spatial Visualization Test: Rotations

PSVT:V – Purdue Spatial Visualization Test: Visualizations

SIA – Semiconductor Industry Association

STEM – Science, Technology, Engineering, and Mathematics

USU – Utah State University

WLT – Water Level Task

CHAPTER I

INTRODUCTION

Unlike the mechanical, architectural, manufacturing, and other disciplines that deal with three-dimensional (3-D) objects, electronics design deals in the "mysterious," "abstract," and "invisible realm." These former disciplines have actual physical objects to aid students in their understanding of the concepts; therefore, the need for spatial ability (mental visualization and manipulation of objects) in students designing in this realm is commonly acknowledged. In the realm of electronics, however, there exist only conceptual models of the inherent properties and characteristics. Traditionally, instructors in electronics have resorted to analogies to help students grasp the concept of electricity. They rely on the students' mental grasp of these analogies' inference to the properties of electricity. If a student is to construct a mental model of these properties, they should have the ability to visualize them. Spatial thinking is used to visualize abstract concepts, metaphors, and analogies (Committee on Support for Thinking Spatially, 2006).

The field of electronics is viewed as more abstract than many other engineering disciplines and content areas (Smith, 2008). Teachers and students of electronics describe the instruction of electronics as "nonsensical" and "incomprehensible" (the same sort of descriptors as used for quantum mechanics). However, most electronic engineers can describe electronics with visual analogies at the atomic and molecular level.

To predict success in engineering programs, universities look at standard achievement indictors such as high grade point average (GPA) and college entrance exam scores in math and science. Many studies have shown a positive correlation between high

spatial ability and an inherent ability in most fields of engineering, chemistry, medical surgery, architecture, and others. Several universities, including Purdue and Michigan Technological, now test for spatial ability of their freshman engineering students.

Problem Statement

Though there is ample evidence showing a positive relationship between a student's spatial ability and achievement in many sciences, technology, and fields of engineering; there was no evidence for a relationship between a pre-engineering student's spatial ability and achievement in an electronics fundamentals course.

Research Questions

There were several questions to be investigated in this study.

1. To grasp the overall makeup of this population, what were the summary statistics of participant demographics (i.e., gender, age, major, GPA)?
2. To grasp the overall makeup of the focus data, what were the summary statistics of the spatial ability test and the course grade measurements?
3. To determine which variables were factors, what were the core correlations for all variables to the pre-engineering student's achievement in an electronics fundamentals course?
4. To verify the appropriateness of the PSVT:R test for measuring spatial ability, what was the reliability coefficient of analysis for the spatial ability test for this cohort?
5. Calculating partial correlations, while controlling for GPA, was the spatial

ability variable a statistically significant amount of the variance and a predictor of a pre-engineering student's achievement in an electronics fundamentals course?

Purpose of the Study

The purpose of this study was to examine the correlation between the spatial ability test score and a pre-engineering student's cumulative score for the semester in an electronics fundamentals course. Other variables such as gender, major, age, and GPA were included in the data set for consideration. Since no study of spatial ability specifically in the field of electronics had been done, a relationship between spatial ability and achievement in electronics was currently unknown.

Need for the Study

The need for this study became apparent due to the lack of data examining the relationship between spatial ability and achievement in electronics. Most seminal work regarding the correlations between spatial ability and achievement in subject areas deemed requiring spatial intelligence had been investigated within the last decade. However, the importance of spatial ability has been noted far longer.

The importance of spatial ability has been linked to measures of practical and mechanical abilities that are quite useful in technical occupations (Smith, 1964). A link was also established between spatial ability and abstract reasoning abilities. Spatial imagery is tremendously important in art, creative thinking (Shepard, 1978), and may have an important role in abstract engineering disciplines such as electronics. Spatial

abilities are frequently attributed to creative and higher order thinking skills in science and mathematics.

The positive correlation between measured spatial ability and measured achievement, rank, or achievement was found consistently in all of the studies reviewed for this study—across a multitude of disciplines and areas of concern. Many science, technology, engineering, and mathematics (STEM) subjects are at the atomic level and require using mental models that are created in the mind's eye and necessarily require spatial reasoning ability. The understanding of a given aspect of the physical world is best conceptualized through a mental model. Therefore, if a correlation could be found between spatial ability and achievement in learning electronics, instruction to improve spatial ability could be given to new students to improve their achievement in the study of electronics.

Procedure Summary

Students participating in this study completed a 20-item spatial visualization test of rotations. The score from the rotations test was then correlated with each participating student's cumulative score from the entire semester to determine the degree of relationship while controlling for gender, age, major, and GPA. The following steps were performed in this study.

1. A problem was presented regarding no data that showed a relationship between spatial ability and ability to understand electronics.
2. A review of the literature was performed to verify the problem. No studies

were found that specifically investigated the relationship posited in the problem statement.

3. A reliable test to measure relevant spatial ability was identified (the PSVT:R) and the right to use it in this study was procured.

4. The student sample of the population was identified as those in an electronics fundamentals course at Utah State University (USU).

5. Approval to perform the research study was granted from the Institutional Review Board for the protection of human participants at USU (see Appendix A).

6. A dissertation proposal was completed, presented, and approved by the candidate's committee.

7. The modified PSVT:R test was administered at the beginning of the Fall 2008 semester to the participating students.

8. The cumulative scores for each participating student were compiled at the end of the semester and matched to each students PSVT:R score.

9. The data, which consisted of each participants age, gender, major, GPA, the compiled semester scores, and the PSVT:R scores, were reviewed for completeness, accuracy, and anomalies were noted.

10. The data were then entered into the SPSS statistical software. Central tendencies, frequencies, correlation analyses, and controlled partial correlation analyses were done. Visual graphs and plots were generated for analysis.

11. Conclusions were drawn from the review and analysis of the data.

12. Recommendations were conceived and proposed in the final chapter.

Definition of Terms

Correlation: A relation between phenomenon not normally associated with each other.

g: A factor of measured intelligence common to all mental tests.

Pre-engineering: First 2 years of lower-division general courses prior to specific upper-division engineering courses, in a BS program.

Spatial ability: The ability to mentally design, develop, and manipulate images.

Visual comprehension: The ability to understand an object simply by examining it.

CHAPTER II

REVIEW OF LITERATURE

Spatial ability, sometimes referred to as spatial intelligence or spatial visualization, can be described in multiple ways. Common definitions of spatial ability are: being able to view, conceive, and manipulate objects or ideas within the "mind's eye"; the capacity to perceive the visual world accurately, perform transformations and modifications upon one's initial perception; and being able to recreate aspects of one's visual experiences even in the absence of relevant stimuli. Additionally, spatial intelligence goes beyond simple "visual" intelligence as it is the ability to perceive a form or object—the most elementary form (with examples of blind humans having this ability)—to the manipulation of the object or form in the "spatial realm" of thought.

Historical Examples of Spatial Ability

The ability to mentally model objects has long been recognized as a valuable skill in the fields of engineering, particularly when dealing with design and graphical representations. Recently, spatial ability has been acknowledged for its relevance in areas such as surgery, chemistry, physics, and even mathematics. As noted in a course on spatial intelligence at Purdue University (Benes, 2005, pp. 2-13), a variety of people use their spatial ability in everyday life, research, and leisure. For example, Albert Einstein often mentioned that he frequently used mental models rather than pure mathematical lines of reasoning and that verbal processes did not seem to play a part in his creativity.

Nikola Tesla used his spatial ability to visualize the many machinery inventions

he was responsible for as well as the important electrical discoveries he is credited with. Until the helical structure of DNA was spatially realized, it was not explainable. Friedrich Kekule explained how he visualized the Benzene ring in his sleep prior to developing the chemical model of its properties. Chess players, cartographers, artists, and even Gikwe bushmen in Africa have been tested for and exhibit high spatial intelligence. Indeed, even Piaget's early work was testing children to determine their spatial development (Piaget & Inhelder, 1948). The famous Water Level Task (WLT) used to test the concept that water will always seek a level horizon in respect to the Earth's surface, was developed by Piaget for testing the spatial ability in children. For example, their testing revealed that young students invariably drew the water level parallel to the base of the glass and were not able to discern the difference until they were older. During the late 1970s, it was discovered that there was a gender difference in accuracy in performing the WLT and it was adopted by cognitive psychologists for testing, and experiments in, the gender differences seen in spatial ability (Liben & Golbeck, 1980).

The importance of spatial ability has been linked to measures of practical and mechanical abilities that are quite useful in technical occupations (Smith, 1964), but what about a link to abstract reasoning abilities? Spatial imagery is tremendously important in art, creative thinking (Shepard, 1978), and may have an important role in abstract engineering disciplines such as electronics. Spatial abilities are frequently attributed to creative and higher order thinking skills in science and mathematics.

The Cognitive Nature of Spatial Ability

Cognitive psychology has made important contributions to the understanding of how people encode, remember, and transform visual images. Roger Shepard (1978) and his students conducted seminal research in the 1970s, which posed interesting questions for cognitive scientists regarding two basic findings that were found relevant. The first, that time played a factor in determining whether two figures could be rotated into congruence which suggests that mental rotation is an analog process that has a one-to-one correspondence to actual physical rotation, and second, that the rotation process is a mental representation that somehow preserves information about the objects' structure during the rotation transformation itself. However, most agree that spatial knowledge can be represented in more than one way.

Though there is much research and theory in cognitive psychology and artificial intelligence regarding the nature of spatial knowledge and processing, it does not address the source of the individual differences seen in spatial processing. The most popular hypothesis is the notion that spatial abilities can be explained by individual differences in the speed that subjects exhibit when performing mental rotations correctly. The most common and reliable tests are designed to measure this context. However, this cannot explain the gender difference, which consistently has shown a statistically significant preference for the male subjects scoring above the female subjects, nor can it explain the high correlation between time and correct answers on the most difficult of rotations for those that score near the median on the overall test. Although the rate of processing time and accuracy on rotations is confounded, the differences on the accuracy scores are much

higher than the differences on the time processing for those with high spatial ability versus those with low spatial ability. Perhaps it is a function of working memory space. In other words, those with low levels of working memory take more time for the rotations simply because they need more time to process the information though they have an equal amount of spatial ability as those who can process the information more rapidly within their working memory. Given enough time, nearly everyone can determine the answer to the problem: “If the minute and hour hands on an analog clock indicate the time is a quarter past noon, what time will it be if we swap the minute and hour hands on the clock?” Perhaps timed mental rotation problems are good measures of spatial ability because they not only require mental manipulation, but good use of mental memory storage as well. For this study, there was a 20-minute time limit to perform the 20-item mental rotations test. As Figure 1 illustrates, congruent lines of a 3-D model can be a bit confusing for some but many can perform the rotation in a few seconds.

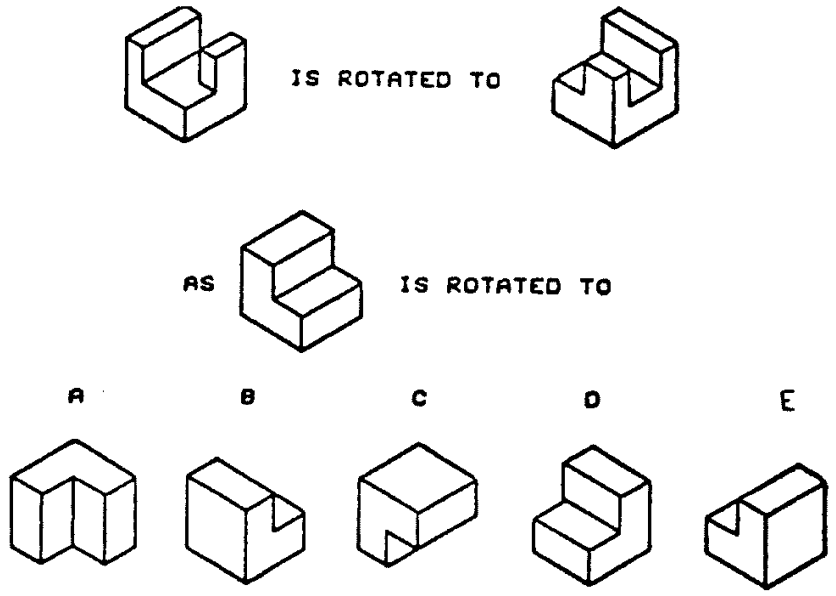

Figure 1. Sample rotation from the PSVT:R test.

High Versus Low Spatial Ability

A number of investigations have attempted to find a difference in the type of mental representations created by high and low spatial ability subjects (Cooper, 1982; Lohman, 1979). These studies show that the difference between high and low spatial ability is not so much the ability to remember stimuli as it is the ability to remember structured stimuli. Low spatial ability subjects find it difficult to construct structured images while those with high spatial ability appear to not have much difficulty. Furthermore, it has been shown that those subjects with high spatial ability remember complex polygons by breaking them into simpler geometric shapes. It may take a bit longer for memory processing, but the accuracy when asked to reassemble the complex polygon is much higher for the high spatial ability subjects. Contrarily, those subjects with lower spatial ability try to remember the complex polygons "as is" with a consequential lower accuracy when asked to reassemble the same polygons. Hence, subjects of different spatial ability tend to solve spatial tests in predictably different ways.

Factorial studies of spatial ability routinely show that spatial ability tests are good measures of "*g*"—the highest-order common factor that can be extracted in a hierarchical factor analysis from a large battery of diverse tests of various cognitive abilities. One example, from research on reading comprehension conducted by Kintsch and Greeno (1985), showed why many children fail to solve word problems in mathematics. What they discovered is that a model based simply on the text was not enough. The children also needed to construct a visual mental model that could be coordinated with the text model. They found also that as the complexity of the problem increased, the importance

of constructing a visual model became apparent. A good example would be trying to decipher the oftentimes confusing text that comes with a new toy that requires assembly. Though the words are in English, they can be very difficult to comprehend, “Put the hex nut R and lock washer P on tapered spindle Q-3 and tighten.” If one cannot visualize the assembly, then it may not be understood. Beginning books for children contain many pictures. As the books progress to only textual content, the child must now use language to construct visual models and images and hence coordinating the two. This is depicted in Baddeley’s (1996) central executive theory of working memory. He claims that working memory is comprised of two systems: a phonological loop and a spatial-visual scratch pad. We can replay the words over and over but need to create a mental image to tie the concept together. In other words, the ability to create and appreciate metaphors and analogies in language and to generate visual-spatial models that can then be coordinated with that textual input are cognitive traits of those individuals that succeed in occupations that require such spatial abilities.

Importance of Spatial Ability in Various Disciplines

With the proliferation of interactive computer environments in a variety of highly spatial content areas such as mathematics (especially geometry), chemistry, engineering, and physics, the importance of spatial visualization skills is becoming more obvious. Spatial visualization is an important factor in student achievement in a variety of spatial domains such as geometry (Battista, 1990), other higher forms of mathematics, the engineering fields (Battista; Smith, 1964), chemistry (Pribyl & Bodner, 1987), and

physics (Pallrand & Seeber, 1984). Without time pressure, people often resort to entirely nonspatial strategies for solving spatial problems (Smith). Additionally, there is a relationship, long posited by scientists, between acquisition of spatial visualization skill and hands-on interaction. Piaget and Inhelder (1948) suggested that a combination of hands-on touching and integration of different viewpoints is instrumental in children's development of spatial ability and mental models of spatial objects.

To a novice of a new spatial domain that is hidden in the submicroscopic realm (such as electrons moving between atoms within copper wire) who may not be familiar enough with the geometry of that new spatial domain, being able construct the mental imagery necessary for visualizing solutions within this new concept may be a totally impossible task. Once students become more familiar with the geometry of the new domain, they may construct the mental imagery necessary to visualize hypothetical solutions without the scaffolding of hands-on stimuli.

Since the Bologna Declaration was signed in 1999 by 29 European countries establishing the European Higher Education and Research Area: A New Learning Paradigm, changes are being initiated in many engineering courses throughout Europe. As described by Contero, Company, Saorin, and Naya (2005) at the Technical University of Valencia in Valencia, Spain, "…spatial reasoning, understood as a core competence for future engineers, does not only remain but gains relevance in current and future engineers' curricula." Dr. Contero and colleagues further explained, "In particular, we believe teachers of engineering graphics should put the emphasis in spatial reasoning, since we do consider it a core competence for future engineers…" (pp. 25-26).

Spatial reasoning was a well known engineering skill in the pre-Computer Aided Design (CAD) era. Designs were conveyed between engineers and departments via drawings and even simple sketches. Engineers, draftsmen, and fabrication technicians required the mental modeling skill required to convey such information verbally and graphically. Ferguson (1992) defined engineering drawings as a means by which a vision in one person's mind is conveyed by material means—drawings—to another person's mind. Additionally, mental models serve to explain the relation between one's cognitive activity and the world. We all know people, or are guilty ourselves, of speaking with our hands and other gestures. This phenomenon has been explained over the ages by countless philosophers as putting actions to words by which we are really explaining an internally constructed mental image—much as designers do via sketches and drawings.

The subject of spatial reasoning and learning via model-based constructing has only recently been broached by educational psychologists and science education researchers (Gilbert, 1999). As noted by Gilbert, a preferred method of instructing in the task of constructing a mental model of a system is to first simplify it (similar to breaking it down to simpler geometric parts as described earlier) and then selecting those relevant parts that are needed for the particular situation and representation. These simplified models now can describe the behavior and action of the target system and one can mentally refer to the initial structure and mechanism for more in depth details. The initial simplification furthermore will depend on the prior domain knowledge the user has as well as their spatial ability level.

Researchers have studied the development of spatial and visualization skills in

students, many who are capable of working with simplified symbolic and mathematical models, but find that they respond better to concrete, 3-D models. They found that though they have complex imaginations, without sketching and drawing skills, they have difficulty representing the designs they perceive in their mind's eye in a two-dimensional space. Welch, Barlex, and Lim (2000) found that 12- to 13-year-old novice designers approach sketching differently than professional designers when using sketching and drawing to explore ideas. Although the youngsters may be adept at drawing and sketches, they prefer to develop their design ideas in three dimensions. When assessing the mental models of the experts, they found that sketching helps the problem solver store information externally, allowing them to explore more fully the design and to experiment in finding the solution at the conceptual and system level. Additionally, people that have more than one mental model of a concept will choose the simpler model of explaining a concept unless they are asked specifically for a more technically precise explanation.

In the field of study of electronic and electricity, the mental model that one attempts to present is that of current circulation in a circuit. A model of electricity involves several interrelated concepts and many teachers may have little empirical basis on which to decide which concepts are more important and why. For example, when explaining the concept of electricity to a novice listener, the expert may use the simpler model analogy of water flow versus more complex models such as bi-polarity of charges, electron particle movement, or the more accurate model of field phenomenon. As noted in Shepard's (1978) work on scientific theories and inventions as externalized mental images, most breakthroughs occurred via mental imagery. Notable examples he includes

begins with Nikola Tesla who invented the self starting induction motor, fluorescent lighting, and the three-phase electrical distribution system used worldwide. One story Shepard related to Tesla is that he "…before actually constructing a physical machine, would first determine which parts were most likely to wear by 'inspecting' an imaginary model that he had 'run for weeks' purely in his mind" (pp. 141-142). Albert Einstein claimed to achieve his insights into the fundamental nature of space and time by means of experiments on mentally visualized systems of light waves and idealized physical bodies in states of relative motion. Einstein's special theory of relativity actually first came to him as he imagined himself traveling alongside a beam of light, which struck him that the stationary spatial oscillation that he mentally "saw" went beyond anything that could be perceived as light and superseded the equations for the propagation of electromagnetic waves developed by Maxwell, his predecessor in theoretical physics. James Clerk Maxwell is said to have "developed the habit of making mental pictures of every problem" (Shepard, p. 135). He conceived his famous equations governing the properties of electric fields, magnetic fields, and the propagation of magnetic fields (essentially now known as light), as a series of increasingly abstract models of what was then referred to as "ether" underlying the electromagnetic fields and waves. His visualized models went beyond the lines of electrostatic force as tubes in which electricity flowed like a fluid such as water, which was posited by his predecessor, Michael Faraday. Faraday, who had a tremendous aversion to writing, indeed to language itself, envisioned the "invisible lines of force" as narrow tubes curving in the space surrounding magnets and electric currents and extending throughout the universe. He claimed the conceptualized image

"rose up before him like things" (Shepard, p. 137).

Nevertheless, the question arises—how does one teach and convey these ideas of what happens at the atomic and microscopic level without using mental models that are created in the mind's eye and necessarily require spatial reasoning ability? The acquisition of a scientific understanding of a given aspect of the physical world is best conceptualized as a mental model of it. Once the model is perceived, it can then be manipulated in the mind's eye to generate explanations and predictions regarding the behavior of that system.

Spatial Ability in Engineering Education

Colleges of engineering at virtually every university examine the ACT/SAT scores in mathematics and science of the engineering school applicants and consider their GPA—all indicators of success in a rigorous engineering curriculum program. However, these indicators do not guarantee the success of newly entering engineering students. For example, the Semiconductor Industry Association (SIA; Greenagel, 2005) noted that approximately 50% of all students majoring in electrical engineering drop out of their major before completing their studies. They also reported that the US graduation rate for all entering freshmen engineering students is only 40 percent. With the dropout rate for engineering students averaging 60%, the colleges and schools of engineering are looking for other indicators that correlate with achievement in engineering.

One such indicative test was developed by Guay (1977) at Purdue University and is known as the Purdue Spatial Visualization Test: Rotations (PSVT:R). In this test,

subjects must visualize the direction and extent of rotation of the sample figure before mentally rotating the second figure in a similar manner. Sorby and Baartmans (1996) relate that the Kuder-Richardson and split-half reliabilities of the PSVT:R test have been calculated in the range of .70-.85 with samples of undergraduate chemistry students, a reliability of .80 when testing preservice elementary teachers, and (KR-20) of .87, .89, and .92 from studies conducted on university students, machinists, and university students, respectively. Guay reported a KR-20 coefficient of .82 for university students.

Meta-Analysis of Spatial Ability Correlations

An integrated meta-analysis of studies (Table 1) investigating the correlation between spatial ability and student achievement (or other success measure) showed an average Pearson's *r* of .3493. Based on a commonly used rule-of-thumb scale: small = .1; medium = .3; large = .5 (Howell, 2007), the average of .3493 is just over a medium effect size and is considered to be a positive correlation (a rise in spatial ability correlates to a rise in the measured outcome). The goal of this meta-analysis was to investigate prior studies showing correlations between a student's measured spatial ability and their measured achievement in an electronics course. Since prior studies directly focusing on a correlation between spatial ability and electronics courses were not found, a broader search was initiated that included studies using data in other engineering disciplines and disciplines as nearly related to electronics as possible.

Of the 21 data sets, within the 10 studies analyzed, four involved architectural

Table 1

Compilation of Relevant Data Included in the Meta-Analysis

Study (year)	Sample size	Major studied	Outcome measured	Test instrument	Quality of study	*ES*
Battista, Wheatley, & Talsma (1982)	82	Other	Ability:achievement	ROT	Good	.39
Kovac (1989)	29	Other	Ability:achievement	ROT	Fair	.525
	29	Other	Ability:achievement	ROT	Fair	.355
	29	Other	Ability:achievement	ROT	Fair	.329
Bodner & Guay (1997)	1,643	Chemistry	Ability:achievement	ROT	Good	.35
	1,643	Chemistry	Ability:achievement	ROT	Good	.32
	285	Chemistry	Ability:achievement	ROT	Good	.387
Leopold, Gorska, & Sorby (2001)	220	Architecture	Ability:achievement	ROT	Good	.237
	196	Architecture	Ability:achievement	ROT	Good	.363
	55	Architecture	Ability:achievement	ROT	Good	.155
Sorby (2001)	536	Design	Ability:achievement	ROT	Fair	.36
Alias, Black, & Gray (2003)	138	Architecture	Ability	VIS	Good	.48
Tai, Yu, Lai, & Lin (2003)	60	Other	Ability:achievement	ROT	Good	.256
Towle et al. (2005)	213	Other	Ability:rank	ROT	Good	.275
	73	Mechanical	Ability:achievement	ROT	Good	.23
Burton & Dowling (2005)	132	Other	Ability:achievement	ROT	Good	.25
	66	Other	Ability:achievement	VIS	Good	.32
Velez, Silver, & Tremaine (2005)	56	Various	Ability:ability	ROT	Good	.541
	56	Various	Ability:ability	ROT	Good	.491
Hedman et al. (2006)	54	Medical	Ability:achievement	ROT	Good	.278
	54	Medical	Ability:achievement	VIS	Good	.443
Average	269				Good	.349

students, three involved chemistry students, two involved medical students, two involved mechanical design students, and the remainder were various discipline students. The sample sizes within these studies varied from 1,643 students to 29 students. At first, only relatively current studies (within the past 10 years) were reviewed, but then the search was expanded to within the past 25 years and two additional studies were discovered. It appears that most seminal work regarding the correlations between spatial ability and achievement in subject areas deemed requiring spatial intelligence, has indeed been investigated within the last decade. Another requisite for inclusion within this meta-analysis was that the study used a qualified and reliable test instrument when measuring spatial ability.

All the studies included within this meta-analysis used either the PSVT:R, the Purdue Spatial Visualization Test: Visualizations (PSVT:V which is a subset using angle of view, versus rotations), or the Differential Aptitude Test: Space Relations (DAT:SR) which is similar to the PSVT:V visualization test and was developed by Bennett, Seashore, and Wesman (1973). Additionally, the studies were evaluated for quality. All but two of the studies included were of good quality. The Kovac (1989) study was rated of moderate quality since it included only 29 subjects for each data set and only incidentally included correlations between spatial ability scores and academic achievement, which is the core information that was being looked for in this meta-analysis. The Sorby (2001) study was also rated of moderate quality because the experimental group for this quasi-experiment was voluntary. The validity for this study is suspect since these volunteer students could not realistically be considered from the same

population as students who chose to not take the course to improve their spatial skills.

The positive correlation between measured spatial ability and measured achievement, rank, or success was found consistently in all of these studies across a multitude of disciplines and areas of concern. For the meta-analysis, a common measure metric was defined as being the Pearson's product-moment correlation coefficient (*r*).

A study from 1982 was conducted to measure the spatial visualization and cognitive development in pre-service elementary teachers learning geometry (Battista et al., 1982). Since the course, taught at Purdue University, was partially a mathematical study of spatial relations, it seemed logical for the researchers to test the student's ability in spatial ability. The instrument they used was the PSVT:R to both pre-test and post-test the spatial ability of the 82 students involved to determine how it relates to the grade received for the course. There was a positive correlation coefficient *r* of .39 between the spatial ability pretest and the course grade for the 82 students. There was also a slightly higher correlation (*r* of .42) between the post-test score on the spatial ability test and the grade but this increase lacks internal validity due to repeating the same test.

An early study to determine the validity of spatial ability tests was conducted in 1989 by Kovac (1989) at Ball State University due to the increasing focus on development and use of "whole-brain" curricula at the time. In particular, the study attempted to assess the usefulness of the tests as accurate testing instruments for measuring user processing strategy. The 29 subjects were randomly selected from a pool of 58 students in the eighth-grade at Burris Laboratory School. The students were administered the PSVT:R, the PSVT:V, and the DAT:SR tests on consecutive Mondays

and then were interviewed immediately following. For this meta-analysis, only the correlations between the spatial ability test scores and the students' grades were relevant. For the mathematics subject grade, the highest correlation was with the PSVT:R test and had a coefficient *r* of .5248, the correlation with the PSVT:V test had a coefficient *r* of .4767, and the correlation with the DAT:SR test had a coefficient *r* of .3581. For the science subject grade, the highest correlation was with the PSVT:V test and had a coefficient *r* of .4137, the correlation with the PSVT:R test had a coefficient *r* of .3549, and the correlation with the DAT:SR test had a small coefficient *r* of only .1861. For the practical arts subject grade, the highest correlation was with the PSVT:R test and had a coefficient *r* of .3290, the correlation with the PSVT:V test had a coefficient *r* of .2463, and the correlation with the DAT:SR test had a coefficient *r* of .2392. These subject areas showed statistically significant, or highly significant, correlation to spatial ability. The other subject areas did not have such a degree of correlation. In his conclusion however, the researcher deemed the tests not reliable for measuring spatial ability when compared and correlated to the interview questions.

The largest study (Bodner & Guay, 1997) reviewed in this meta-analysis, involving 1,643 students in the Department of Chemistry at Purdue University, examined the relationship between spatial ability and students' performance in introductory chemistry courses. This research is arguably the most inferential to this correlational study of spatial ability to introductory electronics course since both subjects are in a realm not visible to the naked eye. The chemistry subject areas tested for included crystal structures, atomic structures at the molecular level, and 3-D spatial orientation tasks in

general chemistry. The PSVT:R test was used to measure the spatial ability of students enrolled in a general chemistry course for science/engineering majors, a general chemistry course for agriculture/health science majors, and a sophomore organic chemistry course for biology/pre-med majors. The positive correlation coefficients *r*, for spatial ability to achievement in each of these courses were: .35 in the general chemistry course for science/engineering majors, .32 in the general chemistry course for agriculture/health science majors, and .387 in the sophomore organic chemistry course for biology/pre-med majors.

An international study by Leopold and colleagues (2001) was conducted to compare the spatial visualization skill levels for entering engineering freshman students at the University of Kaiserslautern in Germany, the Cracow University of Technology in Poland, and the Michigan Technological University (MTU) in the United States of America. This study was designed to evaluate the experiences and courses developed to improve spatial ability at the respective universities involved. The researchers also reported the correlation between the DAT:SR pretest and the final exam scores in the engineering graphics courses to determine if spatial tests are predictors of achievement in the courses. At University of Kaiserslautern, there was a positive correlation coefficient *r* of .2366 between the spatial ability test and the course scores for the 220 students examined. At Cracow University of Technology, there was a positive correlation coefficient *r* of .3627 between the spatial ability test and the course scores for the 196 students examined. At MTU, there was a positive correlation coefficient *r* of .1546 (low significance) between spatial ability test and course scores for the 55 students examined.

Another study involving students at the Michigan Technological University (Sorby, 2001) investigated whether improving their spatial ability had an impact on their retention rate as well as their performance in engineering design graphics courses. Since 1993, students that have shown a weakness in their spatial ability level have been encouraged to enroll in a course designed especially to improve their 3-D spatial skills. The PSVT:R test has been given to all entering engineering students during freshman orientation. During a five year time frame, a total of 536 students failed to score above the 50^{th} percentile on the PSVT:R test. This study compared the performance in a subsequent graphics course offered to these students to improve their spatial ability. The experimental group consisted of the 175 students that completed the course to improve their spatial skills. The control group consisted of the 361 students that did not complete the spatial skills improvement course. Sorby's findings led her to conclude that "the difference in overall mean graphics course GPA for the two groups was highly significant with students in the experimental group outperforming the students in the comparison group" (Sorby). The correlation between the improved score in spatial ability to graphics course grade had a coefficient *r* of .36.

A study by Alias and colleagues (2003), examined the correlation between spatial ability and problem solving in structural design. The aim of this study was to test whether spatial visualization activities to improve spatial ability would affect the students' problem solving skills. It was a quasi-experimental design with 77 civil engineering students in an experimental group taught spatial skills prior to learning the subject and a control group of 61 civil engineering students with only normal lectures. The PSVT:R

instrument was used to test the spatial ability while a structural design instrument was developed specifically for the study. It was found that there was a high statistically significant correlation coefficient *r* of .48 between the score on the PSVT:R and the score on the structural design instrument. The researchers concluded that spatial ability aids in the understanding of structural behavior and thus enhances problem solving in structural design.

A study at the National Changhua University in Taiwan (Tai et al., 2003) investigated the effects of spatial ability on the logical thinking and problem solving abilities of 60 students with regard to computer programming. This study actually was comprised of two steps to determine the correlation between spatial ability and achievement in computer programming. The first step was to use the PSVT:R instrument to measure the spatial ability and then to correlate this to the score on logical ability test designed for this study for a correlation coefficient *r* of .277. The second step utilized the score on the logical ability test to correlate against the performance score for computer programming and found a correlation coefficient *r* of .235. The mean correlation coefficient *r* was found to be .256.

A study presented at the Institute of Electrical and Electronic Engineers (IEEE) and American Society for Engineering Education's (ASEE) Frontiers in Education Conference in 2005 (Towle et al., 2005) examined if spatial ability has a correlation to self efficacy, a student's confidence, as well as retention of the student in an engineering program. They measured spatial ability, using the PSVT:R test, and self efficacy, using a test developed specifically for this research, of over 200 students from five different

engineering disciplines. Though their results show a strong correlation between self efficacy and spatial ability, they also included the correlation between spatial ability and the class ranking of the students in their results, which was more relevant for this review. For the 213 students tested, there was a positive correlation coefficient *r* of .275 between the scores on the PSVT:R and their ranking as upperclassmen. Additionally, this study reported the correlation between spatial ability and achievement in a 3-D (3-D) computer aided design (CAD) course as positive and having a coefficient *r* of .230.

A study conducted by Burton and Dowling (2005) to find key factors that influence student success in a university, was described in a paper presented at the Higher Education Research and Development Society of Australasia conference in 2005. The research team used a battery of tests to gather information from students during their first year of study in engineering at the University of Southern Queensland. As part of the cognitive testing, spatial ability tests were administered. The PSVT:R test scores for 132 students and the DAT:SR test scores for 66 students were the only data examined for a relationship to GPA in this meta-analysis. The correlation between the PSVT:R score and GPA had a coefficient *r* of .25 and the correlation between the DAT:SR score and GPA had a coefficient *r* of .32. The university's admissions panel concluded that spatial ability "seems especially relevant to success in first year of engineering studies" (Burton & Dowling).

This study examined why visualizations are difficult for some people but not others. Velez and colleagues (2005) specifically lookws at the spatial ability differences in a diverse population selected for spatial ability variance. Fifty-six students from

different fields of study at Rutgers University were tested to determine the correlation between the spatial ability measured via an instrument adapted from the PSVT:R to alleviate gender and other biases, and the accuracy in their visualization performance and spatial orientation scores as measured with the Kit of Factor-Reference Cognitive Tests (Ekstrom, French, Harman & Dermen, 1976). There was moderately highly statistical significance in the correlation between both the cognitive tests of spatial orientation (a coefficient *r* of .541) and spatial visualization (a coefficient *r* of .491). These researchers concluded "…that high spatially skilled participants can create accurate mental images of objects that are significantly more complex than those of participants with lower spatial skills" (Ekstrom, et al., p. 117). They also found that spatial ability is related to visualization comprehension.

The final study, done by medical researchers in Sweden (Hedman et al., 2006), was conducted to measure spatial ability for novices as it relates to performance in visual-spatial complex surgical simulations. This study looked at two different datasets for the 54 Swedish surgical novices. The first dataset measured the spatial ability score of the novice surgeons utilizing the PSVT:R and correlated this to the performance score for Instrument Navigation in Key Surgical Activities. They reported a statistically significant correlation coefficient *r* of .278 for these data. The second dataset correlated the spatial ability score to the Manipulate and Diathermy in Minimally Invasive Surgical Trainer score. They reported a highly statistically significant correlation coefficient *r* of .443 for these data and concluded overall that spatial ability is important for surgical novices to possess in the early training phase of a complex task in Key Surgical Activities.

How Spatial Ability Is Affected by Age and Gender

According to Piagetian theory, an individual acquires special visualization ability through three distinct stages of development. At the first stage, children learn a simple and topological visualization where they can discern between objects such as proximity, size relationships, grouping, and so forth. At the second stage, we are able to grasp the idea of perspective and can envision how objects might appear from different angles and distances. The third stage is a combination of the first two stages and a person starts to develop a concept of measurement with projection. There are standardized tests, which have roots in development back to World War I, which are available to test a person's spatial ability across the first two stages.

One of the first tests developed to measure spatial ability is the water-level task (WLT). The WLT was developed by Piaget and Inhelder (1948) as part of their investigations into children's spatial intelligence. They proposed that children gradually develop a Euclidean (3-D) conceptual system of depth along with horizontal and vertical axes to represent object's orientation in space. However, in a study by Rebelsky (1964), it was reported that some of her graduate and undergraduate students at Boston University had considerable difficulty with the task and since then numerous other studies have confirmed that many adults do not respond correctly. In addition, Rebelsky reported that females were less accurate than males, a finding that has been replicated in virtually all subsequent findings of this task and many other tests of spatial ability. During this meta-analysis of spatial ability research, these gender differences were found to be significant in virtually all modern tests for spatial ability.

The current standard test for measuring spatial ability, the original PSVT:R, repeatedly yields a significant difference in mean scores between the genders. However, Dr. Ted Branoff (2000) created a revised version of the PSVT:R in 1998 with the coordinate axes labeled as x, y, and z. After several studies using the new labeled version, he concluded (Branoff) that there was no significant score difference between males and females in these studies. Additionally, based on statistical analyses, it was determined that the revised PSVT:R was as good a measure of spatial visualization ability as the original PSVT:R. The reliability of the revised PSVT:R was determined using the Kuder-Richardson 20 (KR-20) coefficients which were calculated for the original PSVT:R and the revised PSVT:R. The value of 0.83 for the revised PSVT:R was consistent with previous research regarding KR-20 reliability.

Spatial Ability Improvement

The good news for those that lack a high level of spatial ability is that it can be improved through various means of training and practice. One such course is offered at Michigan Technological University. Their 10-week course, developed by Sorby and Baartmans (1996), which has been longitudinally studied since 1993, has shown highly significantly positive and consistent results since its introduction. It has been improved since its first inception and today is composed of workbook, lecture, and computer training material for the improvement of spatial visualization skills. A major finding in all of the spatial ability improvement courses that were examined is that the improvement, particularly in model rotations, is seen in both genders. Since spatial ability can be

improved, it should be advocated for in normal education curriculum, and a requirement for the engineering, math, and science education curriculums.

Summary

In summary, it is generally acknowledged that spatial ability is important in many fields. Visual intelligence has been attributed to many renowned scientists and inventors. The physical engineering disciplines require a person to have spatial ability in order to conceive, design, and communicate objects, ideas, and concepts. Spatial ability is also important in simulation exercises and training for medicine and surgery. Studies have also shown a strong correlation between spatial ability and degree of comprehension at the atomic and molecular level in the field of chemistry. However, there had not been a study examining the correlation between spatial ability and the degree of understanding of electronics; hence, the need for this study.

CHAPTER III

METHODS AND PROCEDURES

The purpose of this study was to examine the correlation between the spatial ability test score, used to measure the spatial ability of the pre-engineering student; and the cumulative score for the semester in an electronics fundamentals course, the measure of the student's achievement in learning the curriculum material. Variables such as gender, age, major, and GPA were also included in the analyses and controlled for.

The participants for this study were students enrolled in Electrical Engineering for non-majors, course ETE-2210, in the Department of Engineering and Technology Education (ETE) of the College of Engineering at USU during the spring and fall semesters of 2008. Undergraduate engineering students from the departments of Biological and Irrigation, Civil and Environmental, and Mechanical and Aerospace were required to take this course offered through the ETE department. The students are encouraged to take this course during their sophomore year—which most do. The student demographic make-up at USU does not follow the national norm of a typical sophomore engineering student being 19 years of age due to the predominant religion sending their young men to serve a mission at the age of 19 for a period of 2 years (Peterson, 2009, p. 3). Peterson's report noted also that 85% of USU students are of the predominant religion. Many male students at USU have been out of the academic circle for a minimum of two years and are starting their freshman year at the age of 21. The author was a graduate student teaching assistant for both semesters alongside the course's professor, Dr. Ward Belliston, associate professor in the ETE department. Participation in the study

was voluntary. Each student participant was provided a copy of the introductory letter inviting students to participate and explaining the test and their rights, which was assigned as study #1910 by the Institutional Review Board for the protection of human participants at USU. Most students were curious about the PSVT:R test and readily chose to participate. One hundred fifty-five students participated in the study, representing 91% of the 171 students enrolled in the course.

Data Acquisition

The data for this observational study were the course grades and the scores from the modified PSVT:R test (see Appendix B) for each of the students participating in the study. The demographic data (gender, age, major, and GPA) were obtained from student records. The PSVT:R test was administered during a lecture period within the first week of the semester to all students choosing to participate in the study. A modified subset of the PSVT:R test, with the coordinate axes labeled as described by Branoff (2000), was chosen to minimize the gender effect normally seen with spatial visualization exams. The students were allotted a maximum of 20 minutes to complete the 20-item test. Pilot studies, conducted the previous year, had shown that approximately 75% were able to complete the test within the 20-minute timeframe with time left for a quick review. The pilot studies also showed that just over 10% of the students scored 100% on the test, the class average was 83.5%, and less than 4% of the students scored less than 50%. In addition, the pilot studies made apparent the need to stress diligence from the students while taking the PSVT:R test in order to get a true measure of their spatial ability.

To collect the composite course scores for each student participating in the study, the final score for these students were compiled from the semester coursework. The final composite score for the course was computed from the following:

1. The average score from six separate exams (30%)
2. Total of scores from completed homework (10%)
3. Total of scores from laboratory assignments (30%)
4. Impromptu quizzes throughout the semester (5%)
5. Comprehensive final exam (25%)

After the data had been collected at the end of the semester, the demographic data (gender, age, major, and GPA) and the final semester scores were matched to the PSVT:R tests. The resultant packet for each of the participants was then assigned a unique number starting from 101 with each new packet having its assigned number incremented by one. The number was then used exclusively as the identifier for each participant and the names were removed from the data packet in order to preserve the anonymity of the participants as was specified in the application to the Institutional Review Board at USU.

Data Analysis

Prior to statistically analyzing the data using SPSS statistics software (versions 12 and 14 on different computers), the PSVT:R tests were first reviewed for completeness. The tests were then checked for legibility and given a score based on number of questions answered correctly. Nine tests had one-two skipped or nonanswered questions, which

were marked as incorrect since this was a timed test and the students were advised to answer the easy problems first. One test had an entire page of four questions unanswered and was eliminated from the study. The assumption for variable independence was met inasmuch as the data for each variable is not inherently related to each other.

The coefficient of reliability was also analyzed using the Kuder-Richardson formula in an Excel® spreadsheet. As noted earlier, the Kuder-Richardson (KR-20) and split-half reliabilities of the PSVT:R test have ranged from .70 to .92 in the studies examined in the literature review. However, it was deemed prudent to analyze the reliability of the test instrument for this study's cohort.

The data were then analyzed using SPSS statistics software to obtain descriptive statistics (Howell, 2007). The descriptive statistics were analyzed to determine the measures of central tendency, variability and dispersion, and outliers that might have been present while also looking for odd, or not normal, distribution. Histogram and bar chart plots for each of the variables were generated by the computer software in order to visually examine the data distribution. The distribution curves—for GPA, spatial ability test, and course score—were all skewed negatively to the right showing prevalence for high GPA, high spatial test score, and high achievement in the course. Box plots were also generated for each of the variables in order to visually examine the data dispersion and further define the few occurring extreme outliers.

The possibility that there was no relationship between any two variables was also tested with a *t* test by the SPSS statistics software. This test was used to determine whether the slope of the regression line differed significantly from 0 (no relationship, or

correlation). From the *t*-test value, using the degrees of freedom (n-2), a *p* value of .05 was used to indicate the probability of no degree of relationship. All *t*-test probability values indicating a strong probability of no relationship (e.g., gender and major) were noted in the results section.

The SPSS statistics software was used to test for normalcy of distribution using the Shapiro-Wilk test, as well as testing for the homogeneity of variances using the Levene's test. The Shapiro-Wilk test reported no violations due to a sample size of noninteger values being greater than 30. The Levene's test results reported no violations were discovered.

The correlation between spatial ability and a student's achievement in a fundamental electronics course was examined. Additionally, the correlations between gender, age, major, and GPA; to the student's achievement in a fundamental electronics course were examined. To test for statistically significant correlations, SPSS statistics software was again used. Initially, checking for correlation between spatial ability and a student's achievement was chosen over a regression analysis since the predictor, as well as the criterion, are variable—not fixed (Howell, 2007). Ultimately however, the research looked for the degree of relationship of all the variable predictors (gender, age, major, GPA, and spatial ability) to the student's achievement in a fundamental electronics course to determine which variables had a statistically significant correlation to be controlled for in the partial correlation analysis.

The Pearson's product-moment correlation coefficient (typically denoted by *r*) was the statistical measure used in this portion of the study. The Pearson's *r* is the

standard used to indicate the correlation between two variables and is defined as the sum of all the products of each variable's standard scores and dividing this by the degrees of freedom (n-1), which is also the covariance of the two variables divided by the product of their respective standard deviations. The correlation between two variables is the measure, or degree, of linear relationship between the two variables. A maximum of +1.0 indicates a perfect positive 1:1 correlation, a -1.0 indicates a perfect negative 1:1 correlation, and zero indicates no correlation. A conventional "rule of thumb" scale for the Pearson's *r*, in educational and social science studies, is: ±.1 = small, ±.3 = medium, and ±.5 = large correlation (Howell, 2007).

Because the Pearson's *r* correlation coefficient cannot replace the individual examination of the data, scatter plots of the correlations were also produced by the SPSS statistics software in order to see a visual representation of the correlations. The data for the scatter plots were the points corresponding to each student's semester score (found on the horizontal axis) and the predictor variables (found on the vertical axis). The scatter plots also showed the linear distribution, which indicated a good fit between the criterion and predictor meeting this assumption needed for a Pearson's correlation. The line of best fit was calculated as a linear regression equation and indicates the degree of slope between the two variables.

Finally, a controlled partial correlation analysis was ran with the SPSS statistics software to determine the amount of variance, and the predictability of, spatial ability, as measured by the PSVT:R test, to a student's achievement in a fundamental electronics course. There were significant correlations between spatial ability score, GPA, and

semester score. The purpose of calculating a partial correlation is to find the unique variance between two variables while eliminating the variance from a third variable. This study was designed to examine the correlation between spatial ability and achievement in the electronics fundamental course, so a partial correlation (controlling for the GPA variable) was calculated to determine the amount of variance in the semester score due to the spatial ability score.

Summary

To reiterate, this study examined the correlation between spatial ability and a student's achievement in an electronics fundamentals course at USU. The PSVT:R test was used to measure the spatial ability—the primary predictor. The cumulative score for the semester was used to measure the achievement in the course—the criterion. Examination of the data was performed to discover anomalies, followed by analyzing the data for normalcy. In addition to the primary predictor (spatial ability) demographic data (gender, age, major, and GPA) were also examined for degree of correlation to the student's achievement in a fundamental electronics course. The data were initially analyzed in SPSS to determine the Pearson's *r* correlation coefficient. The data were then subjected to a partial correlation analysis using the SPSS statistics software to determine the amount of variance, and suggestion of predictability, of spatial ability. Scatter plots were produced with a linear regression line of slope to visually represent the data. These procedures produced the results that were analyzed in the following chapter.

CHAPTER IV

ANALYSIS OF DATA

Introduction

Though there is ample evidence showing a positive relationship between a student's spatial ability and achievement in many fields of science, technology, and engineering; this study was seeking evidence that a relationship exists between a pre-engineering student's spatial ability and achievement in an electronics fundamentals course.

The analysis of data chapter reports the findings in five separate categories. These five categories include:

1. The reliability of the spatial ability test instrument.
2. The descriptive statistics which present the demographics, academic standings, and scores of the students.
3. The correlations between all the variables, looking for patterns and significant relationships.
4. The correlation between spatial ability and the semester composite score for the entire cohort and subgroups within each demographic variable (e.g., gender – male vs. female).
5. The partial correlation analyses to find the unique variance between two variables while eliminating the variance from a third variable.

To establish the ranking methodology used when reviewing the statistical

significance, a scale was determined based on maximum alpha levels of .05, .01, and .001. Statistical significance was considered met when the alpha level was equal to or less than.05, more significant when equal to or less than the .01 alpha level, and highly significant with an alpha level equal to or less than .001.

Reliability of Test Instrument

The data analysis for this study began with an overall assessment of the PSVT:R tests to determine completeness, score distribution, and reliability. As noted earlier, of the 171 students enrolled in the two semesters of the Electrical Engineering for Non-majors, course ETE-2210, in the ETE Department of the College of Engineering at USU, 155 chose to participate in the study. The scores on the PSVT:R test ranged from a low of 8 correct to a high of all 20 correct. Thirty-one students scored a perfect 20. One test was removed due to incompleteness, leaving a dataset of 154.

The internal consistency reliability of the PSVT:R test for this study was calculated using two different methods (electronic spreadsheet and SPSS software) for corroborative support of the results. Commonly acknowledged (Branoff, 2000; Guay, 1977; Sorby & Bartmans, 1996), the coefficient of reliability, as measured using the Kuder-Richardson (KR-20) formula for dichotomous responses, should exceed a value of .70 in order to be deemed valid. The KR-20 is a special case of Cronbach's alpha, commonly referred to as "the reliability coefficient" (Howell, 2007), and is reported in SPSS in the reliability analysis. The KR-20 formula is:

$KR_{20} = (k/k\text{-}1) * (1- ((\Sigma p*q)/\sigma^2))$; where,

k = number of items in the test

p = the proportion of correct answers

q = the proportion of incorrect answers

σ^2 = the test score variance

The formula takes into account the number of items on the test (the higher the better) as well as the variability between subjects and consistency within subjects. The Excel® spreadsheet calculation of the PSVT:R scores, for this study's cohort, reported a reliability coefficient of .782, which is commonly accepted as a good measurement instrument. As shown in Table 2, the SPSS software reported a Cronbach's alpha of .784, corroborating the results of the spreadsheet calculation. The SPSS results also revealed that the most difficult test item was number 13, which only 68% of the students marked correctly. The easiest test item was number four, which was marked correctly by 100% of the students. (Note: the SPSS software reported only 19 items on the test as question number four was removed due to zero variance.)

Descriptive Statistics

The descriptive statistics were analyzed in order to understand the demographics, academic standing, and scores of the students. This was accomplished by using the SPSS

Table 2

Reliability Statistics Reported by SPSS Software

Cronbach's apha	Cronbach's alpha based on standardized items	Number of items
.784	.767	19

software to report the frequencies and summary statistics for each numerical variable (as shown in Table 3), as well as graphs and charts to illustrate the distributions.

Age

The age demographic was a range between 18 and 32 years old with the average age of 22.64 years old and the median age of 22 years old. The average age of the female students was 21.19 years while the average age of the males students was 22.81 years. The frequency curve (Figure 2) was slightlyly skewed to the left with 89.7% of the students from 19 to 25 years old. The box-plot graph (Figure 3) indicated the four students older than 28 years of age were outliers.

As noted in Chapter III, the demographic make-up of the typical USU student may be unlike that for students in other areas of the country. Because of the propensity for males of the predominant religion to serve 2-year missions upon attaining the age of

Table 3

Summary Statistics Reported by SPSS Software

Variable		Age	GPA	Spatial score	Semester score
N	Valid	154	153	154	153
	Missing	0	1	0	1
Mean		22.64	3.4064	17.53	85.5592
Median		22.00	3.4600	18.00	87.4500
S*D*		2.408	.4120	2.539	7.40105
Minimum		18	2.29	8	48.55
Maximum		32	4.00	20	96.22

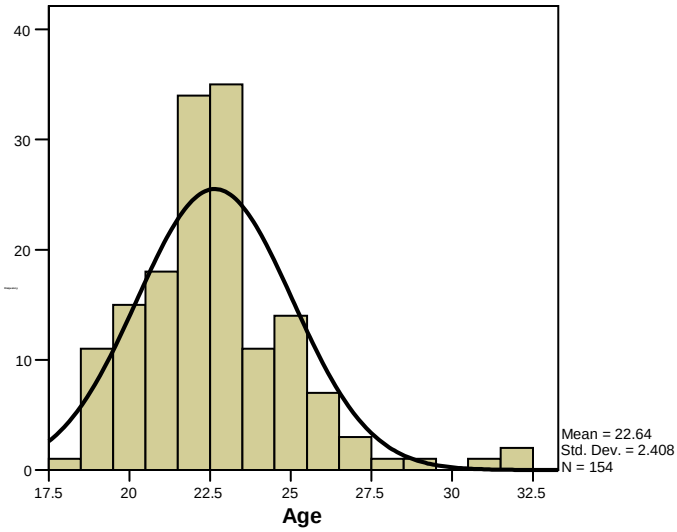

Figure 1. Frequency curve for age demographic.

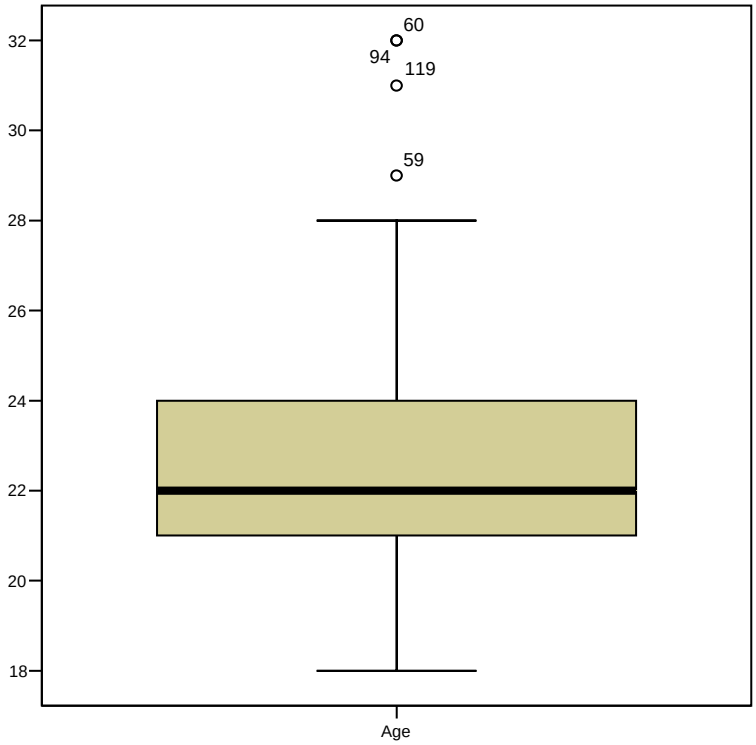

Figure 2. Box-plot graph for age demographic.

19 years old, their age when beginning, or resuming, higher education will be 2 to three 3 older than the national norm (Peterson, 2009).

Gender

The gender demographic was 138 males (89.6%) and 16 females (10.4%). An interesting factor showed that the females' age range was only between 19 and 23 years of age with an average of 21.19 years versus the males' average age of 22.81 years. The difference in age, based on gender, was statistically significant, as shown in the one-way ANOVA in Table 4. The females were significantly clustered into the Biological Engineering major, while the males preferred Mechanical Engineering. A chi-square cross tabulation comparison, shown in Table 5, indicates that 62.5% of the females were Biological Engineering majors and 64.5% of the males were Mechanical Engineering majors.

Table 4

One-Way ANOVA Reported by SPSS Software for Gender Demographic

Variable		Sum of squares	*df*	Mean Square	*F*	Sig.
Age	Between groups	37.818	1	37.818	6.766	.010
	Within groups	849.539	152	5.589		
	Total	887.357	153			
GPA	Between groups	.316	1	.316	1.872	.173
	Within groups	25.485	151	.169		
	Total	25.801	152			
Spatial score	Between groups	17.166	1	17.166	2.387	.124
	Within groups	1093.275	152	7.193		
	Total	1110.442	153			

Table 5

Chi-Square Crosstab Results Reported by SPSS for Gender/Major Demographic

Variable		Major				
		Aerospace	Biological	Civil	Mechanical	Total
Sex	Male	2.2%	13.8%	19.6%	64.5%	100.0%
	Female	6.3%	62.5%	18.8%	12.5%	100.0%
Total		2.6%	18.8%	19.5%	59.1%	100.0%

Major

The demographic for the student's engineering major of study, as declared by the student, included four categories. As shown in Table 5, the four categories included the Aerospace emphasis with four students (2.6%), Biological Engineering with 29 students (18.8%), Civil Engineering with 30 students (19.5%), and Mechanical Engineering with 91 students (59.1%). The curve shown in Figure 4 was heavily skewed to the Mechanical Engineering side. The box-plot graph, shown in Figure 5, was extremely weighted at the Mechanical Engineering end and indicated the four students emphasizing in Aerospace were outliers.

GPA

The GPA demographic ranged from a cumulative low of 2.29 to a high of 4.00, with the average of 3.41. The GPA was based on a 4.0 scale and only 4-year college or university credits were used as a baseline measurement for comparison. Credits awarded through testing, high school AP classes, and transfers from 2-year colleges were not included. One of the participant students declined to have their GPA examined for the

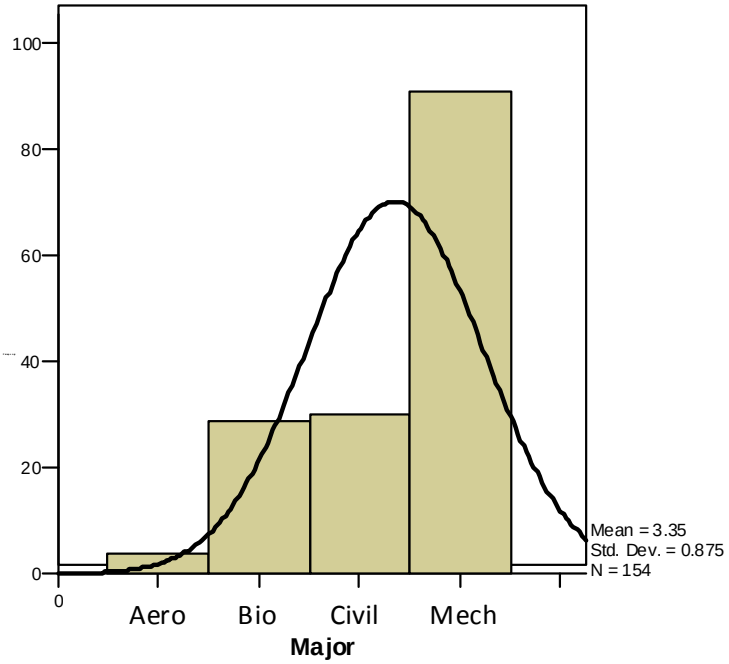

Figure 3. Frequency curve for declared major demographic.

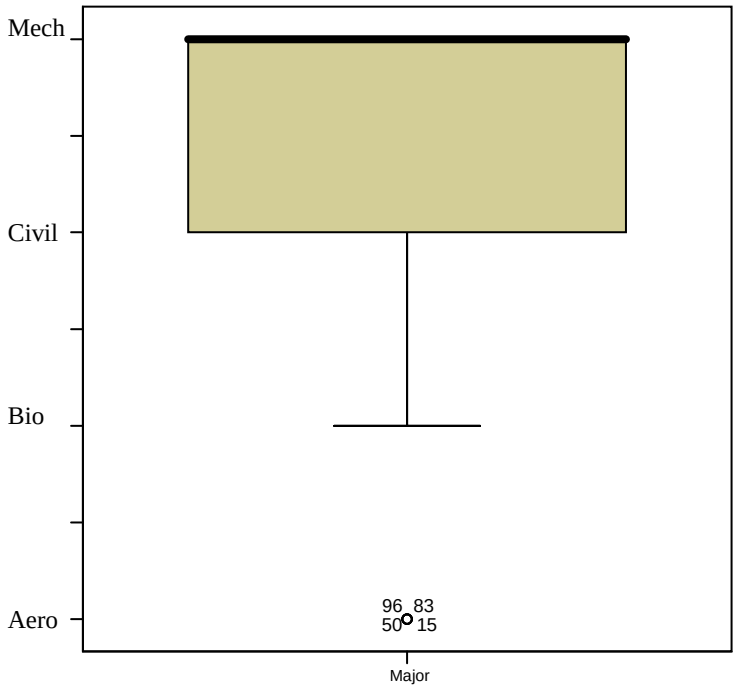

Figure 4. Box-plot graph for major demographic.

study so this population consisted of 153 data. The curve, as shown in Figure 6, for the GPA data was skewed slightly to the right indicating a high proportion clustered around the 3.41 average. The box-plot graph, as shown in Figure 7, indicted the single student with a GPA of 2.29 was an outlier.

Spatial Score

The spatial test scores ranged from a low of 8 to a high of a perfect 20, with the average being 17.53. As shown in Figure 8, the curve for the spatial test scores was skewed to the right supporting the median score of 18 with a large majority (64.9%) scoring 18 or above. As shown in Figure 9, the box-plot graph indicted the four students scoring less than 12 on the spatial test were outliers.

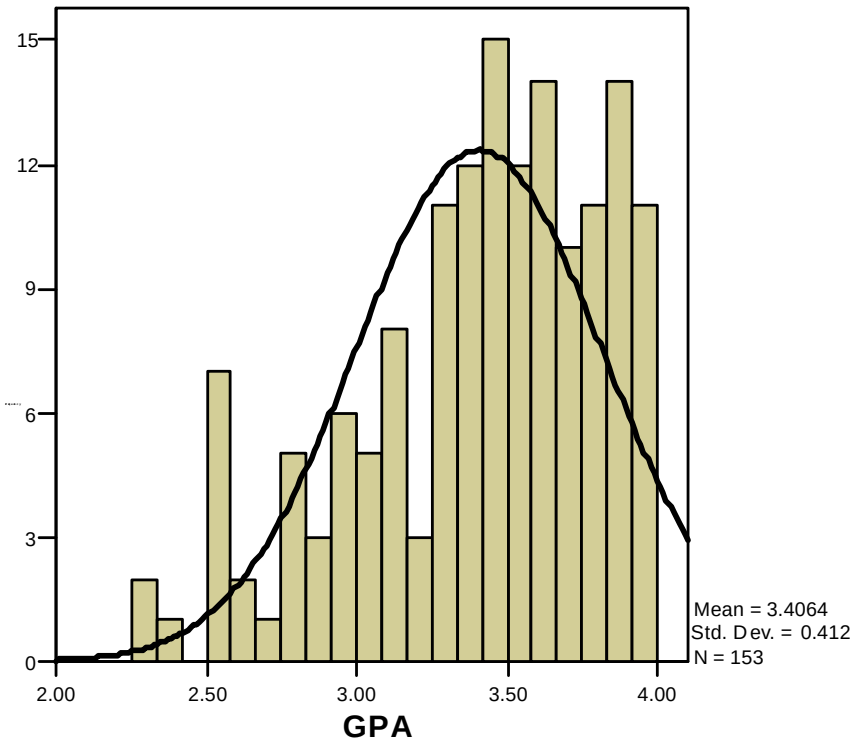

Figure 5. Frequency curve for GPA demographic.

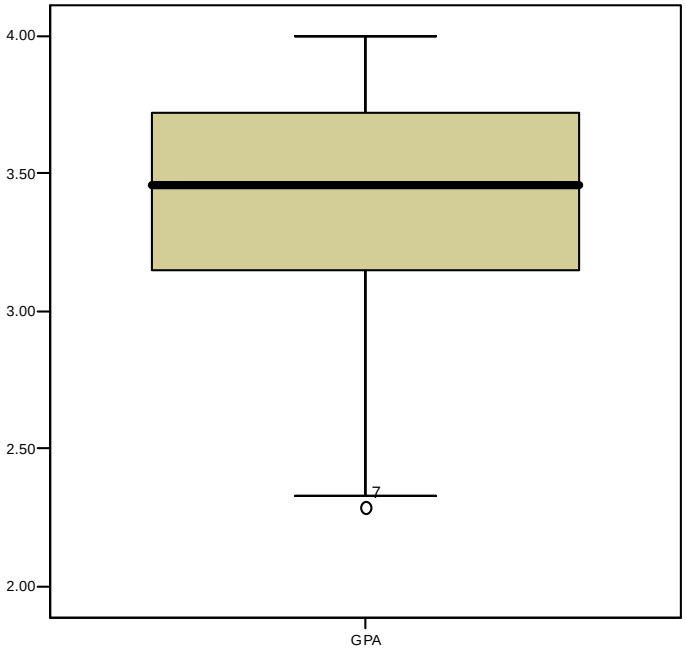

Figure 6. Box-plot graph for GPA demographic.

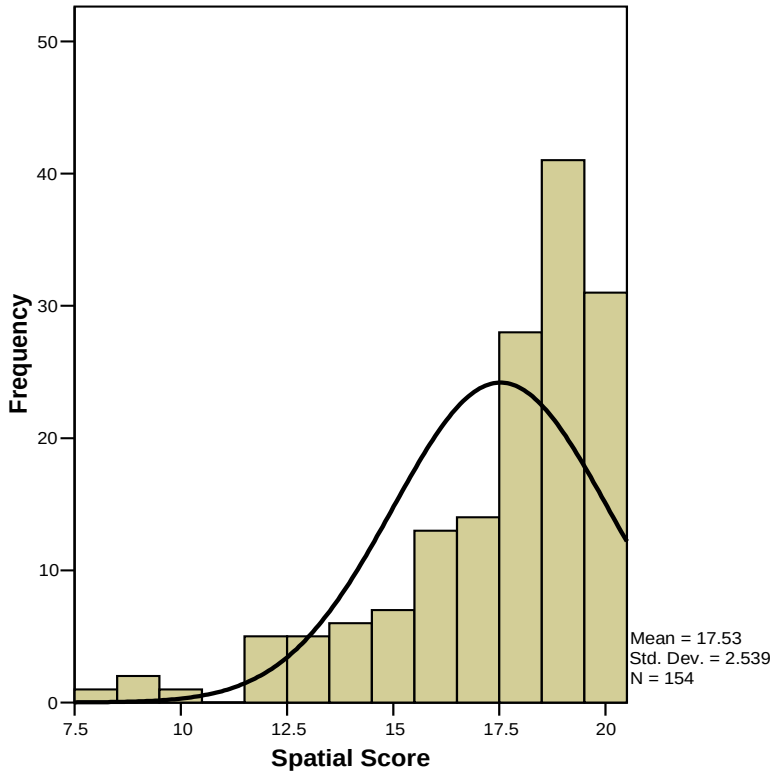

Figure 7. Frequency curve for spatial scores.

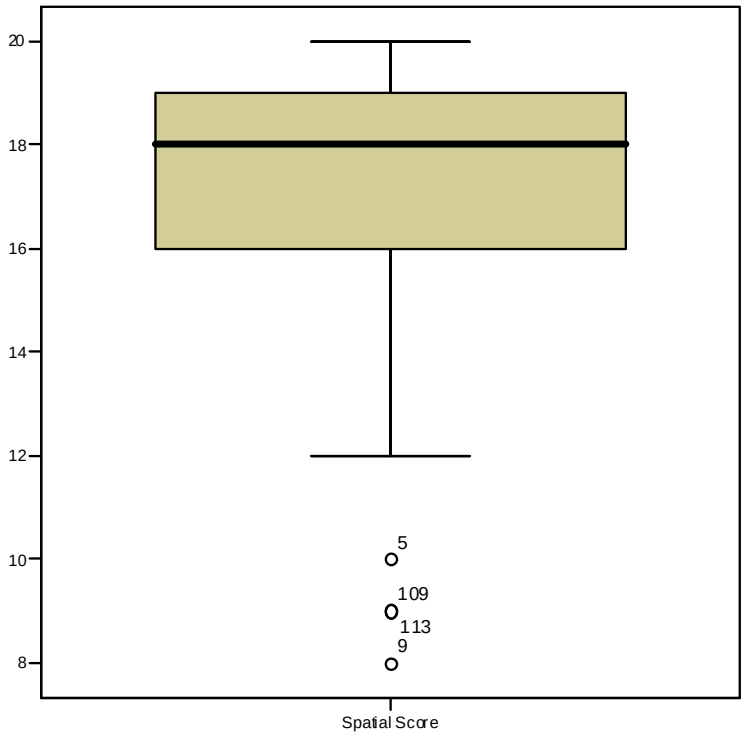

Figure 8. Box-plot graph for spatial scores.

Semester Composite Score

The semester composite scores from the course showed a range from a low of 48.55 to a high of 96.22. One of the participant students dropped the course during the semester leaving a data set for course composite scores numbering 153. The average semester composite score was 85.56—an average B+ grade. The curve for the semester composite score data, as shown in Figure 10, was skewed to the right indicating a high proportion clustered around the 85.56 average. The box-plot graph, as shown in Figure 11, indicated the eight students scoring less than 68 on the semester composite score were outliers with the bottom two students flagged as extreme outliers.

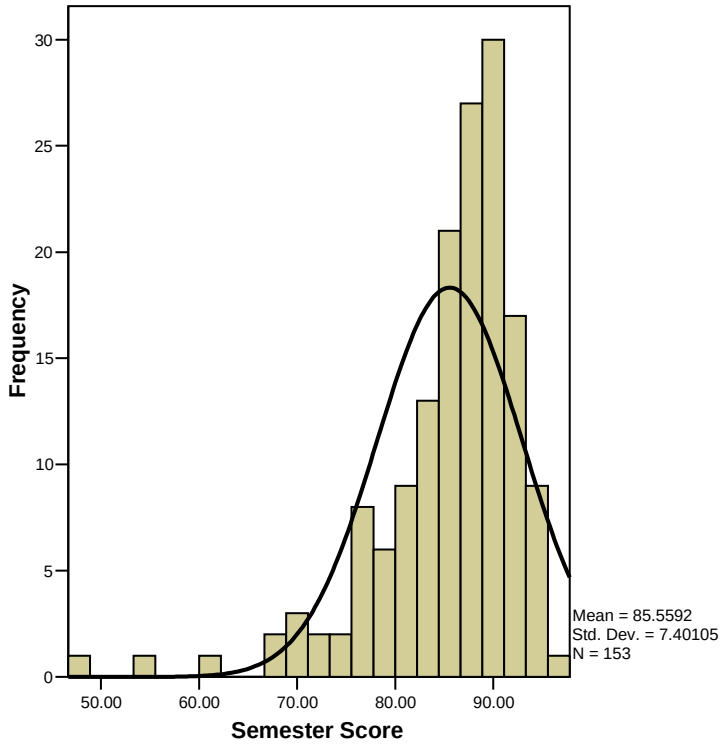

Figure 9. Frequency curve for semester composite scores.

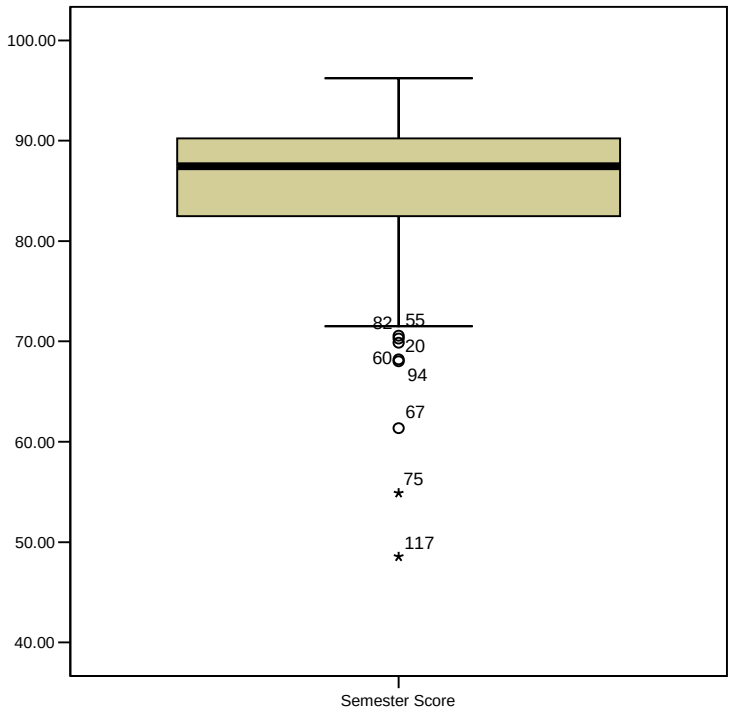

Figure 10. Box-plot graph for semester composite scores.

Demographic Variables Correlations

The individual variable correlations were analyzed next with several statistically significant relationship patterns noted. Of particular note, the correlation between gender and spatial ability as measured with the modified PSVT:R test, one of the critical relationships, had a small Pearson's *r* of -.11, as shown in Table 6, with a nonstatistical significance (at the .05 alpha 2-tailed level) toward the males.

Age

The age demographic had a few correlations that did show statistical significance (at the .05 alpha 2-tailed level). The correlation between the age and gender variables had a small Pearson's *r* of -.21, as shown in Table 7, which coincides with the frequencies indicating the females being younger than the males (gender was coded as male=1 and female=2). Also of statistical significance (at the .01 alpha 2-tailed level) was the correlation between the age and GPA variables which had a small Pearson's *r* of -.27, as shown in Table 7, indicating the younger students had higher GPAs than did the older students. The correlation between the age and semester composite scores variables had a medium Pearson's *r* of -.32, as shown in Table 7, indicating that the younger students

Table 6

Correlation Between Gender and Spatial Score

Spatial Score	Sex
Pearson correlation	-.113
R^2	.013
Sig. (2-tailed)	.164
N	154

Table 7

Correlations Between Age for Gender, GPA, and Semester Composite Scores

Variable		Gender	GPA	Semester scores
Age	Pearson correlation	-.206*	-.271**	-.316**
	R^2	.042	.073	.100
	Sig. (2-tailed)	.010	.001	.000
	N	154	153	153

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

also did better throughout the course than the older students at a highly statistical significance (.000 alpha 2-tailed level). These negative correlations are better illustrated in the scatter plot correlation between the age and composite score shown in Figure 12.

Gender

Though the female students were typically younger than the male students, there was no statistically significant correlation between gender and GPA, as appeared in the previous section examining age. As noted in the frequencies earlier, the female students were clustered in the Biological Engineering major, which also had a Pearson's *r* of -.38, as shown in Table 8, indicating the correlation between gender and the major was of medium statistical significance (at the .01 alpha 2-tailed level).

GPA

The GPA demographics also had statistically significant relationships with both the spatial scores and the semester composite scores. The Pearson's *r* of .274 for the correlation between the GPA and spatial score, as shown in Table 9, indicates a moderate

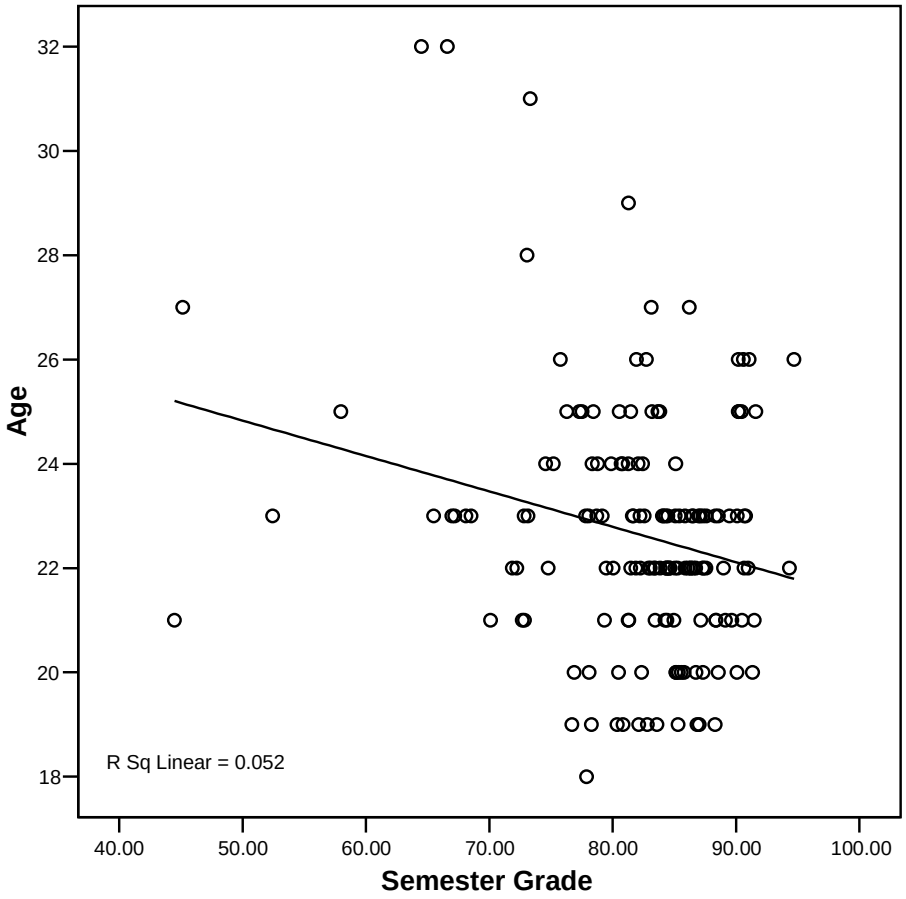

Figure 11. Correlation between age and semester composite score.

Table 8

Correlation Between Gender and Major of Study

Variable		Major
Sex	Pearson Correlation	-.381**
	R^2	.145
	Sig. (2-tailed)	.000
	N	154

** Correlation is significant at the 0.01 level (2-tailed).

Table 9

Correlations Between GPA and Spatial Scores, and Semester Composite Scores

Variable		Spatial score	Semester score
GPA	Pearson Correlation	.274**	.680**
	R^2	.075	.462
	Sig. (2-tailed)	.001	.000
	N	153	152

** Correlation is significant at the 0.01 level (2-tailed).

strength, while the Pearson's *r* of .680 for the correlation between the GPA and semester composite score, as shown in Table 9, indicates a strong and highly statistically significant (.000 alpha 2-tailed level) relationship.

These positive correlations are better illustrated in the scatter plots of the correlations between the GPA and spatial score, and between the GPA and semester composite score, as shown in Figures 13 and 14, respectively.

Spatial Ability Score with Semester Composite Score Correlations

The correlation between the spatial ability score and the semester composite score for the entire cohort of students revealed the overall relationship. However, because of the student demographics, range of standings and scores, each variable was divided into subgroups that were revealed in the earlier sections of the data analysis. Each variable's subgroup was then analyzed for the correlation between the spatial ability score and the semester composite score—unique to only that subgroup.

The Pearson's *r* correlation of .290 between spatial ability score and semester

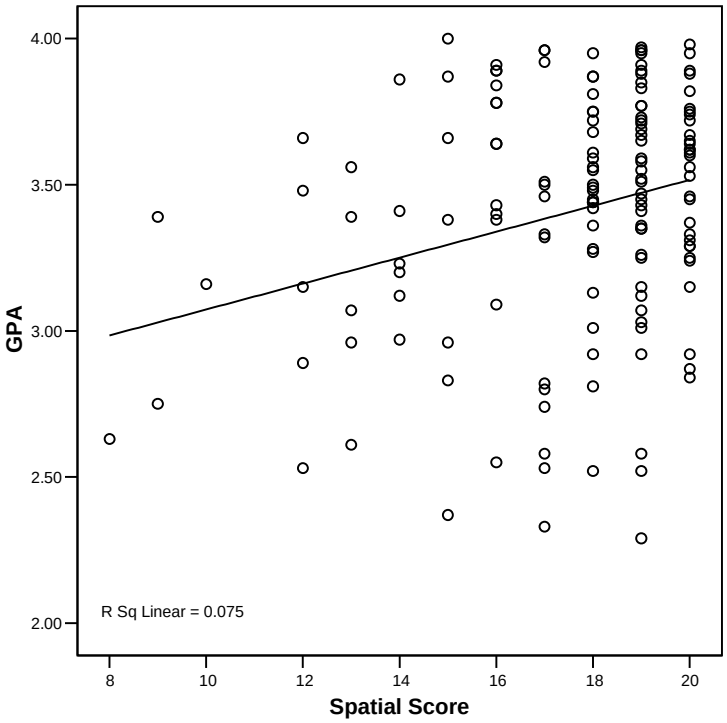

Figure 12. Scatter plot of GPA and spatial score.

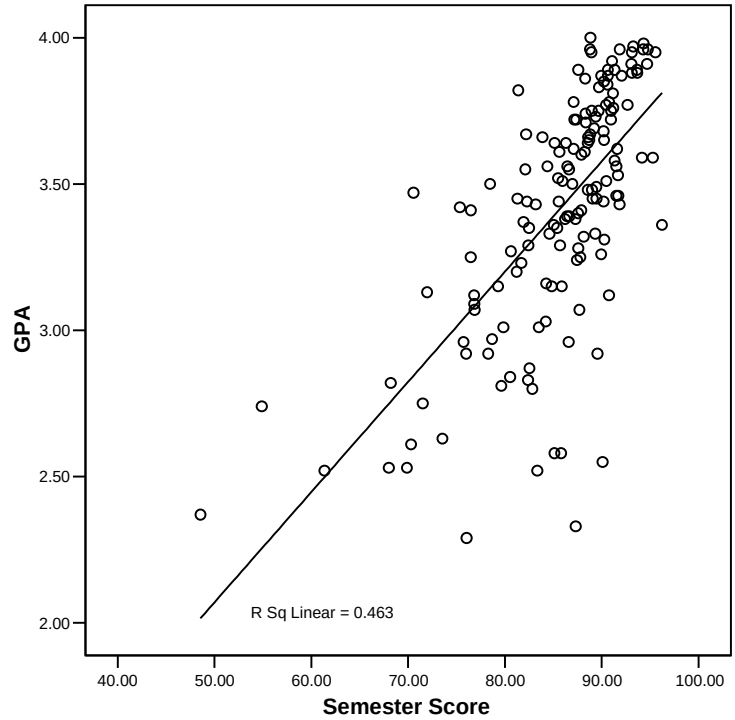

Figure 13. Scatter plot of GPA and semester composite score.

composite score for the entire cohort of students, as shown in Table 10, indicated a near-medium positive relationship that was highly statistically significant (.000 alpha 1-tailed level). This .290 correlation coefficient, illustrated in the Figure 15 scatter plot, was stronger than the relationships between the major and semester composite score

Table 10

Correlation Between Spatial Ability Scores and Semester Composite Scores

Variable		Semester score
Spatial score	Pearson correlation	.290**
	R^2	.084
	Sig. (1-tailed)	.000
	N	153

** Correlation is significant at the 0.01 level (1-tailed).

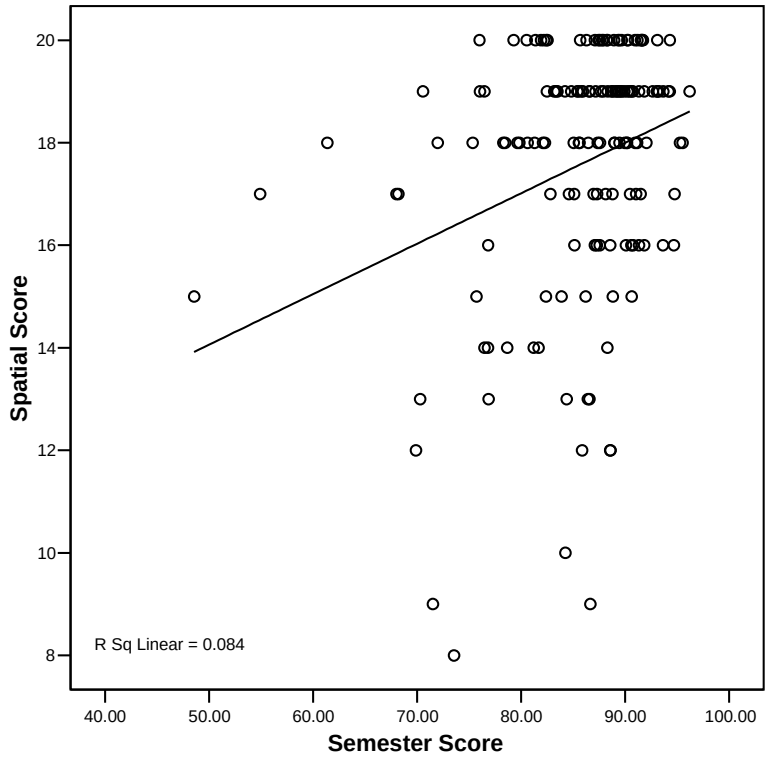

Figure 14. Scatter plot of spatial scores to semester composite scores.

(*r* of -.021) as well as that between the gender and semester composite score (*r* of -.019). As was noted and illustrated in the preceding section, it was not as strong as the relationships between the age and semester composite score (*r* of -.316 and statistically significant at the .01 alpha 2-tailed level) nor as that between the GPA and semester composite score (r of .680 and statistically significant at the .01 alpha 2-tailed level).

Gender Subgroup

When isolating the students by gender subgroups, the correlations between spatial ability score and semester composite score were statistically significant for each. The correlation for the female students was statistically significant (at the .05 alpha 1-tailed level) with a medium strength Pearson's *r* of .444, as shown in Table 11. The correlation for the male students was more statistically significant (at the .01 alpha 1-tailed level) with a Pearson's *r* of .272, also shown in Table 11. These correlations indicate moderately good relationships between spatial ability and semester composite score for both genders. These positive correlations for each gender are better illustrated in the scatter plots seen in Figures 16 and 17, respectively. Though the slope of the fitted

Table 11

Correlations Between Spatial Scores and Composite Scores for Both Genders

Variable		Males spatial scores	Female spatial scores
Semester scores	Pearson correlation	.272**	.444*
	R^2	.074	.197
	Sig. (1-tailed)	.001	.043
	N	137	16

* Correlation is significant at the 0.05 level (1-tailed).

** Correlation is significant at the 0.01 level (1-tailed).

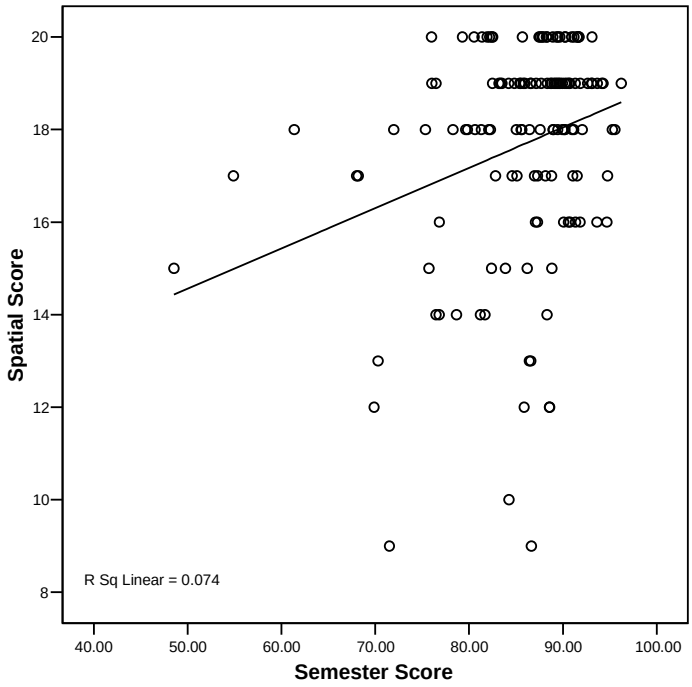

Figure 15. Scatter plot of correlation between spatial score and composite score for males.

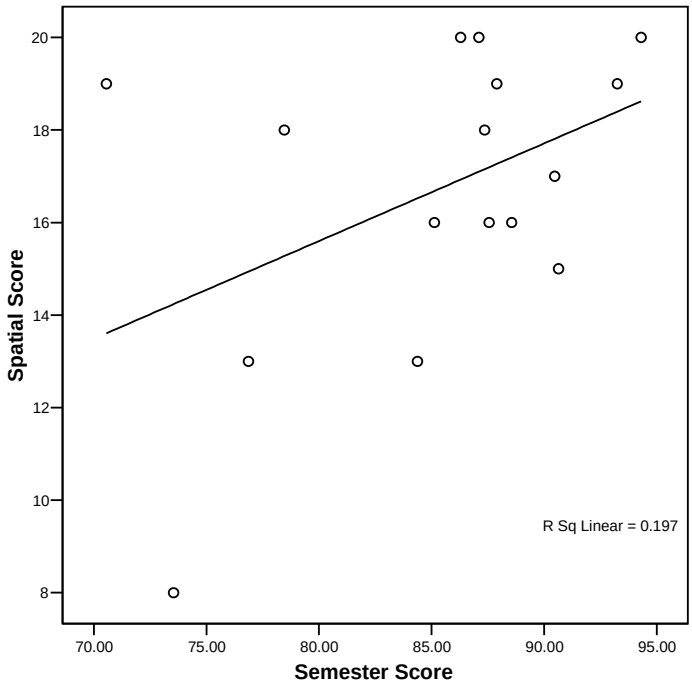

Figure 16. Scatter plot of correlation between spatial score and composite score for females.

regression line is nearly identical, the variance dispersion is greater for males and this was seen in Pearson's *r* difference, .444 for females and .272 for males, between genders.

Declared Major Subgroup

When isolating the students by declared major subgroups, the correlations between spatial score and semester composite score, as shown in Table 12, were:

1. a Pearson's *r* of -.336 for the four Aerospace emphasis students;
2. a Pearson's *r* of .445 for the 29 Biological Engineering students (which was statistically significant at the .01 alpha 1-tailed level);
3. a Pearson's *r* of .271 for the 30 Civil Engineering students; and
4. a Pearson's *r* of .288 for the 91 Mechanical Engineering students (which was statistically significant at the .01 alpha 1-tailed level).

The positive correlations for the statistically significant correlations between the semester composite scores and spatial scores for the Biological Engineering students and the Mechanical Engineering students are better illustrated in the scatter plots seen in Figures 18 and 19, respectively.

Table 12

Correlations Between Spatial Scores and Composite Scores for Major of Study

Variable		Aerospace spatial scores	Biological spatial scores	Civil spatial scores	Mechanical spatial scores
Semester scores	Pearson correlation	-.336	.445**	.271	.288**
	R^2	.113	.198	.073	.083
	Sig. (1-tailed)	.332	.008	.078	.003
	N	4	29	30	91

** Correlation is significant at the 0.01 level (1-tailed).

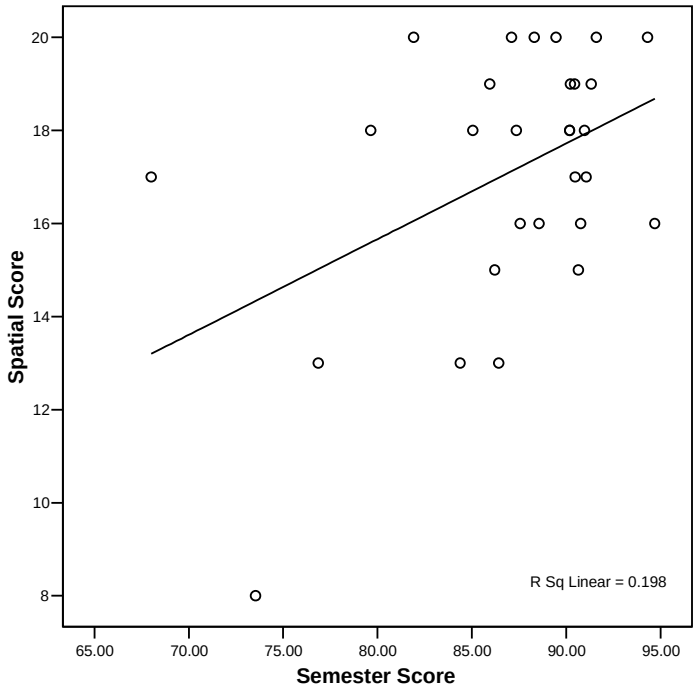

Figure 17. Scatter plot of correlation between spatial score and semester composite score for biological engineering students.

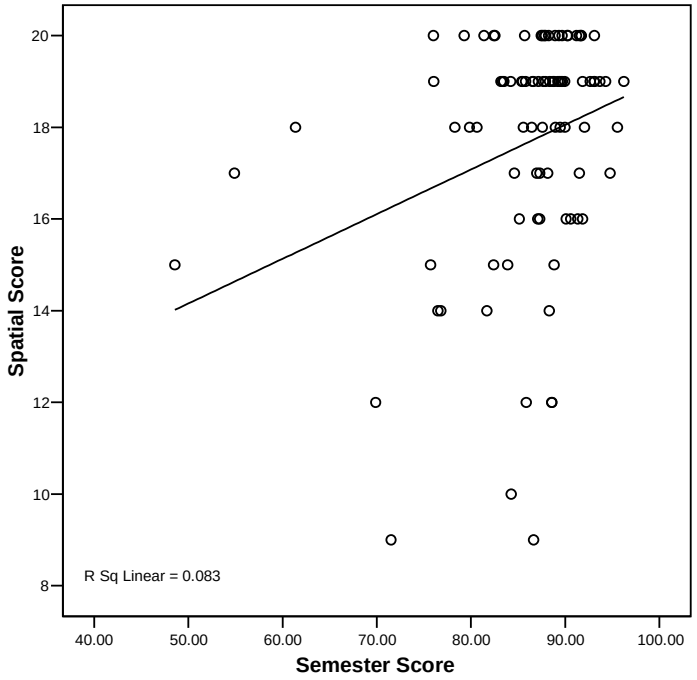

Figure 18. Scatter plot of correlation between spatial score and semester composite score for mechanical engineering students.

GPA Subgroup

When isolating the students into subgroups based on their GPA, as shown in Table 13, the correlations between spatial ability score and semester composite score were:

1. a Pearson's *r* of .248 for the 27 students with a GPA below 3.0;
2. a Pearson's *r* of .117 for the 56 students with a GPA between 3.0 and 3.5; and
3. a Pearson's *r* of .078 for the 70 students with a GPA above 3.5.

None of these correlations were statistically significant at the .05 alpha 1-tailed level, so will only be evaluated as a whole group. Noteworthy is the pattern of negative relationship between GPA level and the strength of correlation between spatial ability score and semester composite score– indicating that spatial ability becomes more of a factor influencing a student's achievement in an electronics fundamentals course as their GPA becomes less of a factor.

Age Subgroup

When isolating the students by age subgroups, the correlations between spatial

Table 13

Correlations Between Spatial Scores and Composite Scores for GPA Range

Variable		<3.0 GPA spatial score	3.0-3.5 GPA spatial score	>3.5 GPA spatial score
Semester score	Pearson correlation	.248	.117	.078
	R^2	.062	.014	.006
	Sig. (1-tailed)	.106	.195	.260
	N	27	56	70

ability score and semester composite score, as shown in Table 14, were:

1. a Pearson's *r* of .496 for the 44 students under-22 years old (highly statistically significant with an .000 alpha at the 1-tailed level);

2. a Pearson's *r* of .218 for the 80 students 22-24 years old (statistically significant at the .05 alpha 1-tailed level); and

3. a Pearson's *r* of .352 for the 29 students over 25 years old (statistically significant at the .05 alpha 1-tailed level)

These correlations are better illustrated in the scatter plots seen in Figures 20, 21, and 22, respectively.

There were no significant changes to the correlations when removing the outliers when performing the calculations. For example, the Pearson's *r* for the entire population was increased slightly to .297 when removing the single outlier from the GPA data set. Similar results were observed among the other variables with slight increases or decreases without significant changes in the Pearson's *r* coefficients.

Table 14

Correlations Between Spatial Scores and Composite Scores for Age Range

Variable		<22 years spatial score	22-24 years spatial score	>24 years spatial score
Semester score	Pearson correlation	.496**	.218(*)	.352*
	R^2	.246	.048	.124
	Sig. (1-tailed)	.000	.026	.031
	N	44	80	29

** Correlation is significant at the 0.01 level (1-tailed).

* Correlation is significant at the 0.05 level (1-tailed).

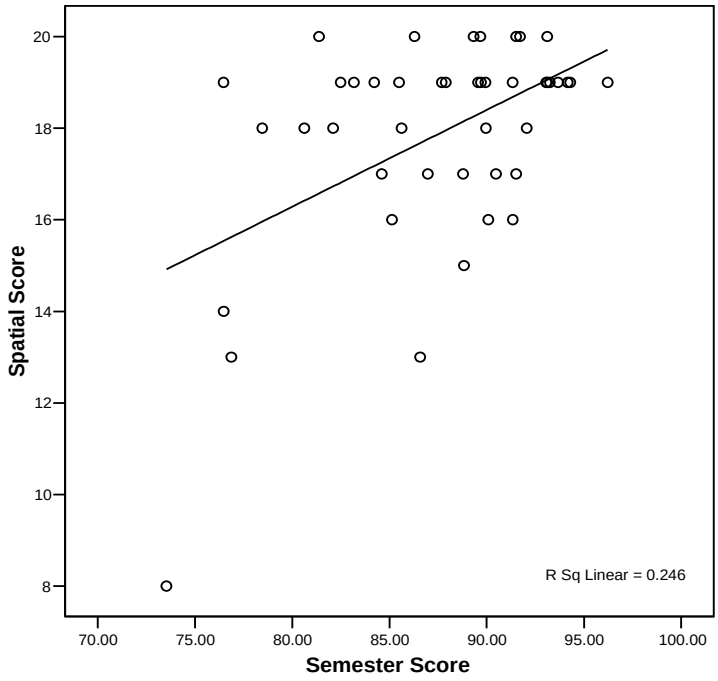

Figure 19. Scatter plot of correlation between spatial score and semester composite score for students 21 years and under.

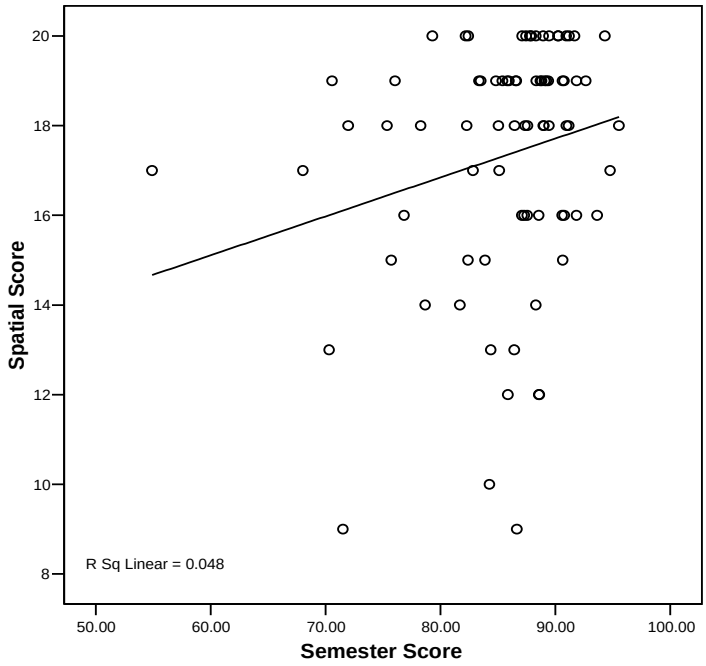

Figure 20. Scatter plot of correlation between spatial score and semester composite score for students 22 through 24 years old.

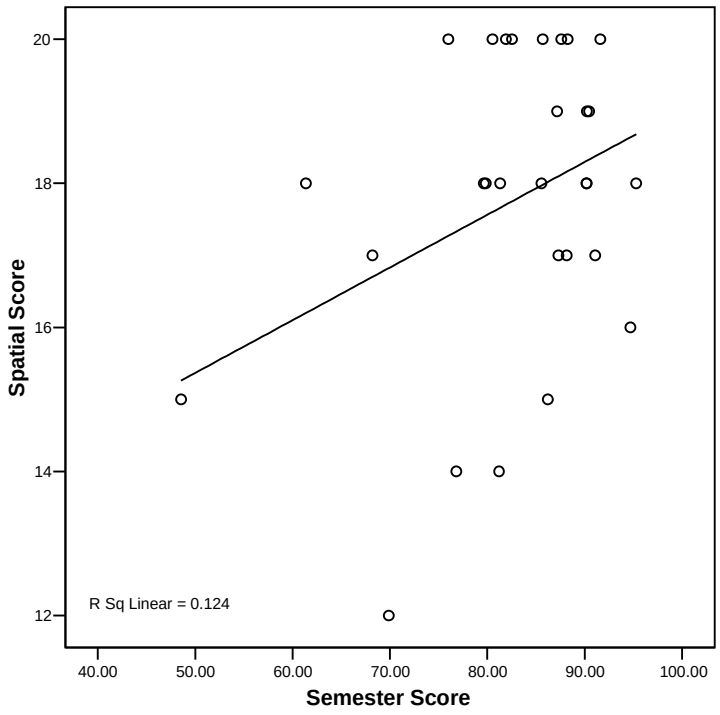

Figure 21. Scatter plot of correlation between spatial score and semester composite score for students 25 years and over.

Partial Correlations

The controlled partial correlation results, as shown in Table 15, indeed do confirm that spatial ability does account for a significant amount of variance after controlling for GPA with statistical significance at the 0.05 (1-tailed) alpha level. Additionally, the R^2 value of 0.026 is a good value and suggests that spatial score provides some good predictability of semester score above and beyond what GPA predicts.

Summary

The analysis of the data revealed both expected and unexpected results. To begin with, the high measure of reliability for the PSVT:R spatial ability test instrument proved

Table 15

Zero and First Order Partial Correlation Controlling for GPA

Control variables		Age	Sex	Major	GPA	Spatial score	Semester score
None	Semester score	-.316**	-.019	-.022	.680**	.290**	1.000
GPA	Semester score	-.176*	-.127	.087		.159*	1.000

*Correlation is significant at 0.05 level

**Correlation is significant at 0.01 level

it to be a good measurement device. The demographics and standings of the students showed they tended to be male and older than the national norm for sophomores, had good GPAs and spatial ability, and did well in the course when viewed as a group.

A few patterns did emerge when viewing the relationships between all variables, as shown in Table 16 with the summary of all correlations. There was prevalence for females to be Biological Engineering majors and were 1.6 years younger, on average. There was no significant difference on spatial scores, which confirms the reduced gender bias (favoring males) when the modified PSVT:R test is used. The younger students, on average, had higher GPAs and higher semester composite scores. There were significant positive relationships between GPA and spatial ability score as well as GPA and semester composite score.

There also was a correlation between spatial ability and semester composite score for the entire cohort as well as for subgroups of each demographic. For example, a significant correlation between spatial ability score and semester composite score were observed within both male and female subgroups, biological engineering and mechanical engineering student subgroups, and for each of the three age subgroups.

Table 16

Summary of All Correlations

Variable	Age	Sex	Major	GPA	Spatial score	Semester score
Age	1.000	-.210**	-.075	-.282**	-.090	-.316**
Sex	-.210**	1.000	-.381**	.108	-.118	-.019
Major	-.075	-.381**	1.000	-.125	.056	-.022
GPA	-.282**	.108	-.125	1.000	.261**	.680**
Spatial score	-.090	-.118	.056	.261**	1.000	.290**
Semester score	-.316**	-.019	-.022	.680**	.290**	1.000

*Correlation is significant at 0.05 level

**Correlation is significant at 0.01 level

Only the strength of the Pearson's *r* coefficient differed among the subgroups.

The controlled partial correlation, with the GPA variable controlled for, showed that spatial ability and age are both significant contributors to the amount of variance, as well as predictors of scoring well, on the semester composite score.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Introduction

Though there is ample evidence showing a positive relationship between a student's spatial ability and achievement in many fields of science, technology, and engineering, this study was seeking evidence that a relationship exists between a pre-engineering student's spatial ability and achievement in an electronics fundamentals course.

This conclusions and recommendations chapter will review the results of the data analysis of this study in order to give a broad synthesis of the key findings and to lay foundations for further research. The review of the results of the data analysis examines the following key topics.

1. The reliability of the spatial ability test instrument for this cohort.
2. Correlations of variables that were statistically nonsignificant.
3. Correlations of variables that were statistically significant.
4. Noteworthy observations and patterns that appeared in the data analysis that, although not sought after in this study, deserve discussion and further consideration.

This study included 154 students enrolled in two sections of a fundamentals electronics course. The average age of the students enrolled in this fundamentals electronics course was 22.64 years old (*SD* of 2.4 years). The majority of the students were male (89.6%) and 59.1% of the students majored in mechanical engineering. The

average GPA of the students enrolled in this fundamentals electronics course was 3.4 (*SD* of .4). Students enrolled in this fundamentals electronics course scored well on the spatial ability test (avg. 17.5, $_{SD}$ of 2.5, out of a possible 20), and the average grade received in the course was a B (avg. 85.6, $_{SD}$ of 7.4, out of a possible 100).

Conclusions

Test Instrument Reliability

The first item to be analyzed in this study was the reliability of the spatial ability test instrument. The results of this study showed the modified PSVT:R spatial ability test instrument to be a reliable indicator of spatial ability across gender, age, and declared major; with a reliability coefficient of .78 (KR-20 for dichotomous responses). Due to the prevalence of males to score higher on most spatial ability tests, this study searched for a test of spatial ability that was reliable yet nongender biased. The choice of the modified PSVT:R spatial ability test instrument fit this requirement. As noted in the data analysis in Chapter IV, one key relationship was the nonsignificant correlation between spatial ability and gender, providing corroboration to the non-gender bias for the Branoff (2000) modified PSVT:R spatial ability test instrument. Additionally, it was found that the test included questions that ranged from extremely easy to appropriately difficult. Question number 4 was answered correctly by all students while question number 13 was correctly answered by just two thirds of the students.

Nonsignificant Variables

Not only were there variables that were nonsignificant, there were items that had

no effect as factors on the conclusions. For example, though the descriptive statistics analyzing the make-up of the typical and average student showed outliers within each variable, when the outliers were removed during data analysis, the results were not significantly altered; therefore, all data were included.

The least significant variable examined in the data analysis was the gender variable. Gender had no significant influence on the student's achievement in the fundamentals electronics course. One critical factor relating to gender that was analyzed was the correlation between gender and spatial ability. For this study, that correlation was small and non-significant. There also was no significant correlation between gender and GPA. However, there was a significant correlation between gender and age (female students tended to be 1.6 years younger) and between gender and declared major (female students showed prevalence for biological engineering).

The second least significant variable examined in the data analysis was the declared major variable. Declared major had no significant influence on the student's achievement in the fundamentals electronics course, their GPA, or scoring on the spatial ability test. Other than the preference for the Biological Engineering major by the females, there were no significant results attributable solely to the declared major variable. Only when divided into subgroups of the declared major, for the spatial ability score to the semester composite score correlation, did the Biological Engineering and Mechanical Engineering majors show significant correlations.

Significant Variables

The three variables that were significant included the age of the students, their

GPA, and their score on their spatial ability test. There were several key items that were shown to be significant and have a factor of influence. These items, for each of the three significant variables, are reviewed below.

When the age variable was examined in the data analysis, several interesting results were observed. The semester composite scores were significantly higher for the younger students, indicating the younger students did better in this fundamentals electronics course. The female students tend to be younger than the male students by 1.62 years. The average male student's age for this sophomore class was 22.81 years—somewhat older than from peer institutions (Peterson, 2009). This most likely is indicative of the predominant religion's practice of sending 19-year-old male members to serve a 2-year mission. This lapse in academic endeavor may hinder the momentum of study habits and learning. For example, this study showed significantly higher GPAs for the younger students, indicating a stronger relationship between the younger students and their achievement overall at the university versus that of the older students, which coincides with the correlation between age and semester composite score. The younger students also had a much higher correlation between spatial ability score and semester composite score than both the average and older student subgroups. An interesting note is though the female students tended to be younger in age than the males, the younger age did not appear to be a correlating factor when the students were put into subgroups via gender, as was mentioned above in the gender review.

The GPA as a variable also produced interesting results when examined in the data analysis. As expected, the highest correlation, with a Pearson's *r* of .62, was the

relationship between a student's GPA and the semester composite score. This confirms that pre-engineering students that typically do well in the majority of courses taken at the university will predictably do well in other courses, including fundamental electronics. The student's GPA is an actual measure of academic achievement and therefore is a highly significant prognosticator for further academic achievement. There also was a highly significant correlation between a student's GPA and their spatial ability score, indicating students that score well on the spatial ability test do well academically in other courses, as was revealed in previous studies reviewed in Chapter II.

The purpose for this study (e.g., determining if there might be a correlation between a student's spatial ability and their achievement in an introductory electronics course) was shown to be true at a highly statistically significant level (alpha *p* value .000, 1-tailed) with an almost medium strength for Pearson's *r* of .29. The correlation value increased further, to a high strength of relationship (a Pearson's *r* of .50) for the subgroup age range of 19-21 years old—the target demographic for testing. The other two age subgroups showed good positive correlations as well. In addition, both genders, and the four declared major subgroups, had resulting good correlations between spatial ability and achievement in the fundamentals electronics course.

Predictability

The prediction value of the spatial ability test to a student's achievement in a fundamentals electronics course, from the partial correlation equation, suggested that the spatial ability score provided some good prediction of semester score above and beyond what GPA predicted. When controlling for the extremely high strength correlate of GPA,

there was still a good amount of variance due to the spatial ability score. The student's age also accounted for a good amount of variance after controlling for GPA, and suggested it also provided some good prediction of semester score above and beyond what GPA predicted. Because of the inherent nature of the GPA as a measure of achievement at the university, and the positive relationship to spatial ability, the partial correlation analysis was subsequently done with the GPA controlled for in the equation. Gender and declared major continued to be non-significant. Therefore, it was concluded that spatial ability is a good predictor of a student's achievement in a fundamentals electronics course.

Recommendations

Spatial ability is important not only in engineering, but in everyday life, for abstract concepts and metaphors, perception and visualization. As the National Academy of Sciences (NAS) Committee on Support for Thinking Spatially (2006) so succinctly quoted, "Effective learning depends on having sufficient levels of general and particular spatial thinking skills. Thus, it is important to assess the strengths and limitations of individual learners" (p. 21).

Therefore, it is recommended that colleges of engineering administer a spatial ability exam to the incoming students as an additional indicator of potential success within the engineering curriculum, including the typically non-3-D electronics course(s). Though the overwhelming predictor of achievement in a fundamentals electronics course, with the highest correlation, is the student's GPA, this study indicated an almost medium

Pearson's *r* strength of correlation for the spatial ability score as measured with the modified PSVT:R test instrument. The PSVT:R spatial ability test is currently administered at universities including Purdue University and MTU. MTU has also adopted the policy of encouraging students that score below 60% on the test to take a remedial course to improve their rotational spatial ability. Additional studies are needed to determine, on a designed experiment basis, if improving a student's spatial ability correlates to improvement in engineering curriculum.

It is also recommended that additional research, using different test instruments of spatial ability, be conducted to determine the most appropriate test instrument. This study used the commonly administered PSVT:R test instrument to measure 3-D rotations. There are many other important spatial thinking abilities including visualization, perception, topography, measuring, and scaling. This study used a modified subset to neutralize gender bias (males outperforming females), but the review of literature showed a gender biased scoring difference, which is acknowledged for many spatial ability tests. There are conflicting reports, however, regarding gender scoring differences when spatial display and visualizations are used for test instruments. The visualization type of spatial ability (e.g., pattern recognition and matching) has been shown in the review of literature to be more suitable to the female gender than for the male gender. Matching the best students, male or female, to the best spatial ability measurement instrument, will ensure that those students needing subsequent training can receive it. The Committee on Support for Thinking Spatially (2006) noted in their report that "the committee sees spatial thinking as a basic and essential skill that can be learned and…it should be taught at all

levels in the education system" (p. 108).

To determine the most predictive spatial abilities test instrument for learning electronics, it is recommended that a student cohort from a fundamental electronics course be administered different spatial ability tests. By administering different types of spatial ability tests to the top third of the cohort of students, or a cohort of senior students in the particular field, the recommended study could possibly determine the best spatial ability test instrument to administer to incoming students as a measure of positive achievement in such courses. Perhaps the PSVT:R test instrument is not the most favorable test to measure the correlation between spatial ability and achievement in a fundamental electronics course. This same method of study could be used to determine the best spatial ability test in other fields of engineering.

Finally, it is recommended that spatial ability be compared to other intelligence tests. This study showed a positive correlation between spatial ability, as measured by the PSVT:R test, and a student's GPA (the strongest correlate and predictor). Such correlations to other admission considerations and tests should be researched.

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APPENDICES

Appendix A

IRB Letter of Information

Utah State University

Date Created: October 18, 2007
USU IRB Approved 10/18/2007
Approval terminates 10/17/2008
Amend #1 Approved 10/10/2008; Protocol Number 1910
IRB Password Protected per IRB Administrator

Department of Engineering & Technology Education
6000 Old Main Hill
Logan UT 84322-6000
Telephone: (435) 797-1795
Fax: (435) 797-2567

LETTER OF INFORMATION
Correlation Between Spatial Ability and a Pre-engineering Student's Success in an Electronics Fundamental Course

Introduction/ Purpose Professor Gary Stewardson in the Department of Engineering and Technology Education at Utah State University (USU) is conducting a research study to find out more about how spatial ability relates to understanding electronic fundamentals. You have been asked to take part because of your enrollment in ETE 2210 – Electrical Engineering for non-majors. There will be approximately 100 participants each in the Fall 2007, Spring 2008, and Fall 2008 semesters.

Procedures If you agree to be in this research study, you will be asked to complete a one-time 20 question quiz intended to measure spatial ability. Your score on this quiz will be correlated to your final grade. We will also be examining correlations with gender, age, major and GPA; which will be obtained from student records that USU faculty have access to. The resulting data will be assigned a non-identifiable number which will be used solely as a database marker and will not be linked to any individual. We are asking for your permission to access your GPA information.

Risks There are no anticipated risks involved in participating in this study.

Benefits There may or may not be any direct benefit to you from this study. The investigator, however, may learn more about the relationship between spatial ability and the learning of electronics fundamentals that will be useful in future classes.

Voluntary nature of participation and right to withdraw without consequence Participation in research is entirely voluntary. You may refuse to participate or withdraw at any time without consequence or loss of benefits.

Confidentiality Research records will be kept confidential, consistent with federal and state regulations. Only the investigator and the student researcher will have access to the data which will be kept in a locked file cabinet in a locked room. Your name will be kept with the quiz for the duration of the semester only, after which the cover page with your name will be removed from the quiz and destroyed and a non-identifiable number will be assigned. No personal identifiable information will be kept.

IRB Approval Statement The Institutional Review Board for the protection of human participants at USU has reviewed and approved this research study. If you have any questions or concerns about your rights, you may contact the IRB at (435) 797-1821

Gary Stewardson, PhD Principle Investigator (435-797-1802)	Mark Smith Student Researcher (435-797-1796)

☐ I do not give my permission to have my GPA records accessed for this research. I understand that this decision will not affect my class standing at USU now or in the future.

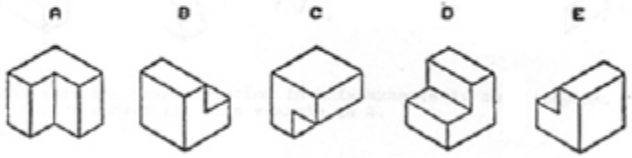
Signature of Student:_____ Date:_____

Appendix B

Modified Purdue Spatial Visualization Test: Rotations Test

Directions

This test consists of 30 questions designed to see how well you can visualize the rotation of three-dimensional objects. Shown below is an example of the type of question included in the second section.



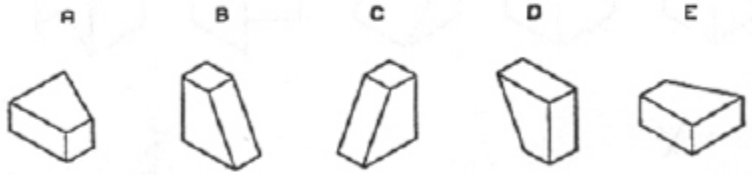
You are to:

1. study how the object in the top line of the question is rotated;
2. picture in your mind what the object shown in the middle line of the question looks like when rotated in exactly the same manner;
3. select from among the five drawings (A, B, C, D, or E) given in the bottom line of the question the one that looks like the object rotated in the correct position.

What is the correct answer to the example shown above?

Answers A, B, C, and E are wrong. Only drawing D looks like the object rotated according to the given rotation. Remember that each question has only one correct answer.

Now look at the next example shown below and try to select the drawing that looks like the object in the correct position when the given rotation is applied.



Notice that the given rotation in this example is more complex. The correct answer for this example is B.

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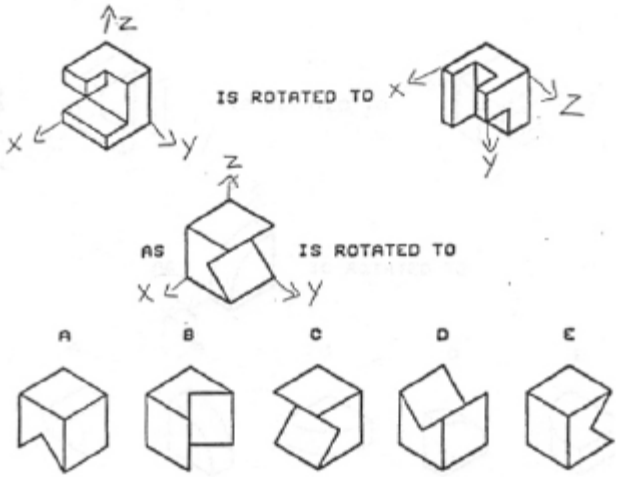
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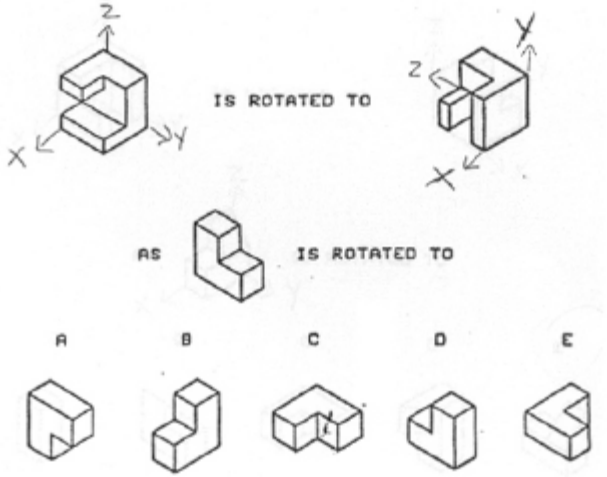
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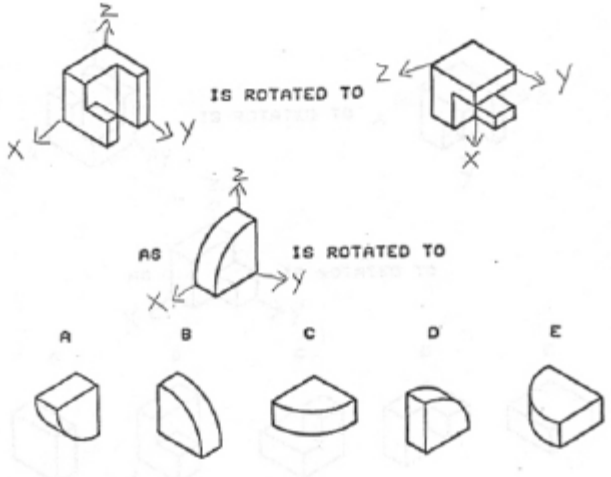
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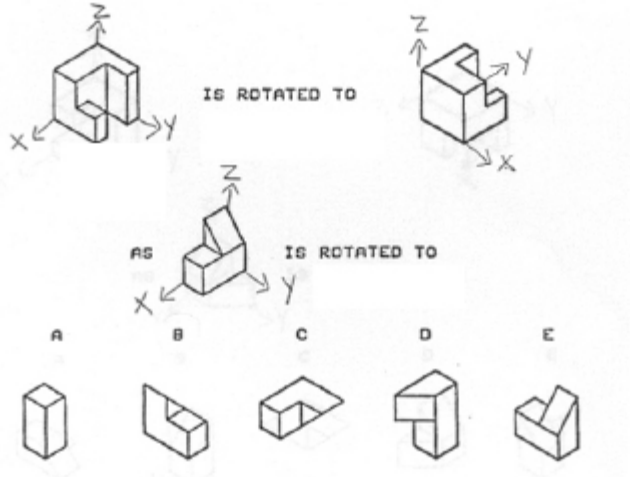
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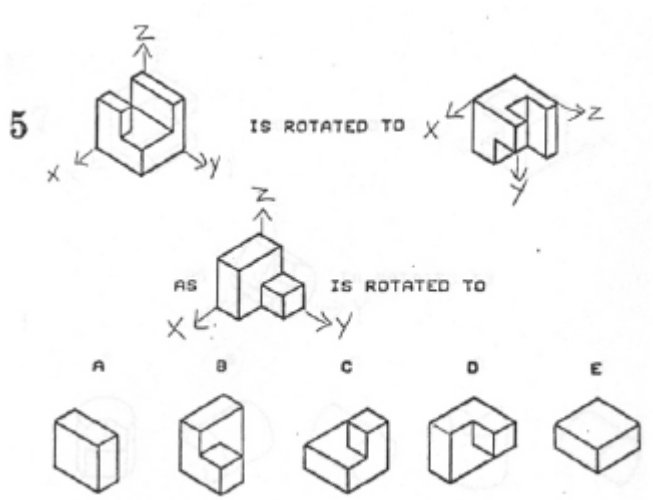
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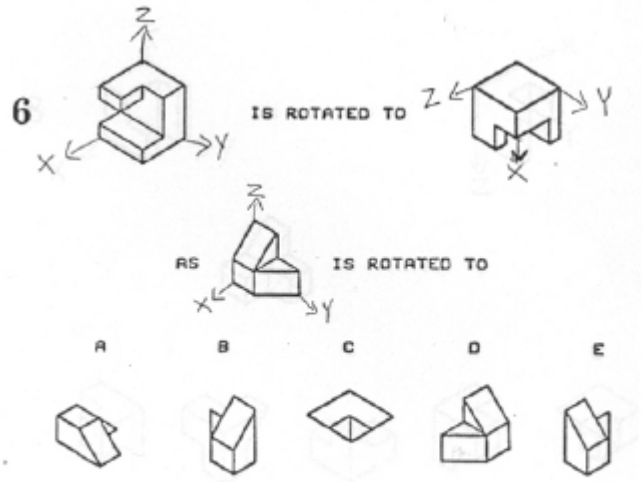
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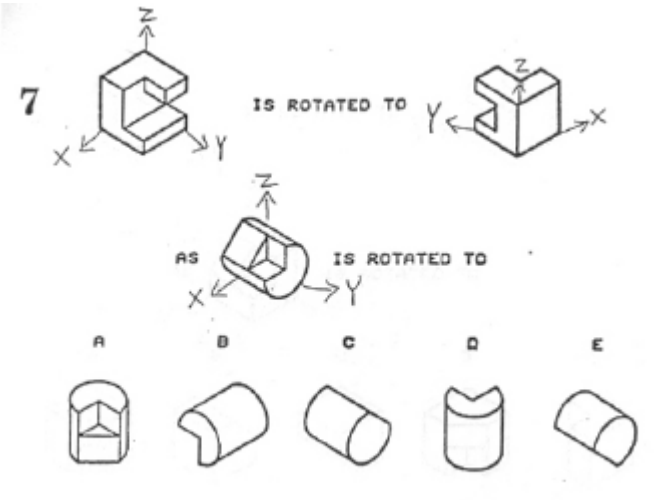
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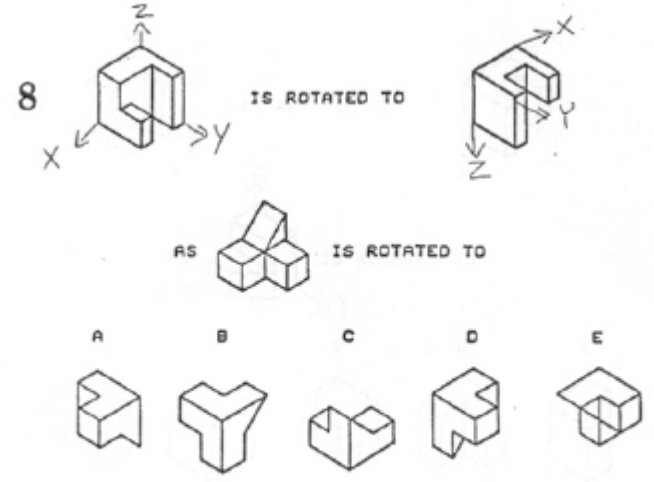
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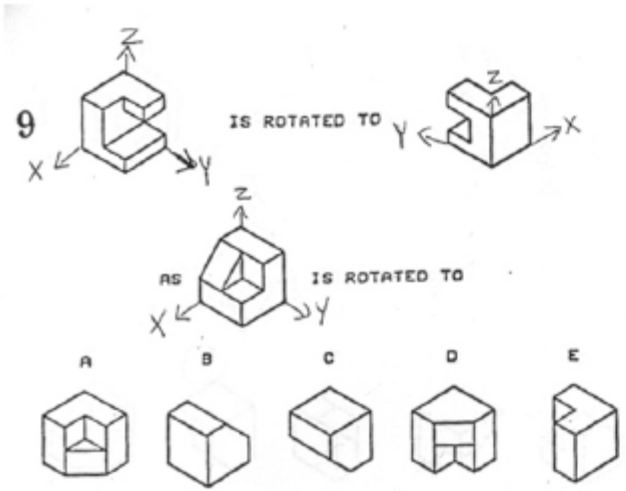
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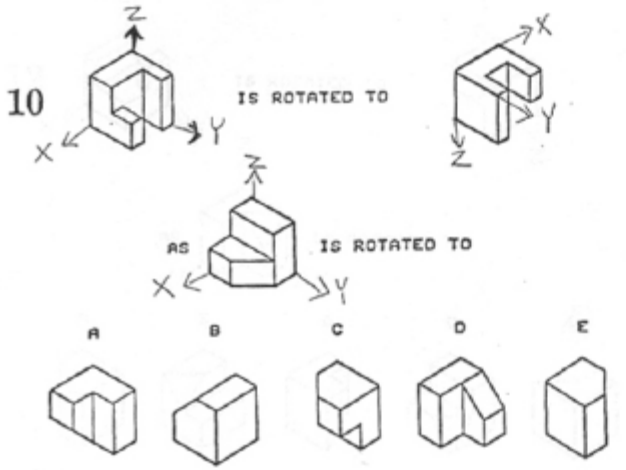
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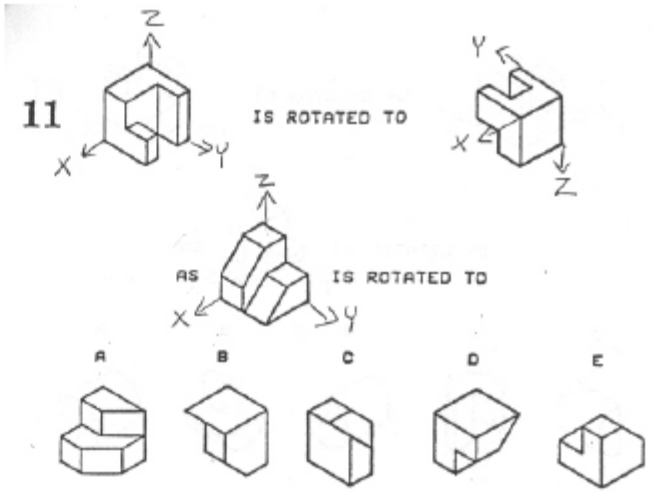
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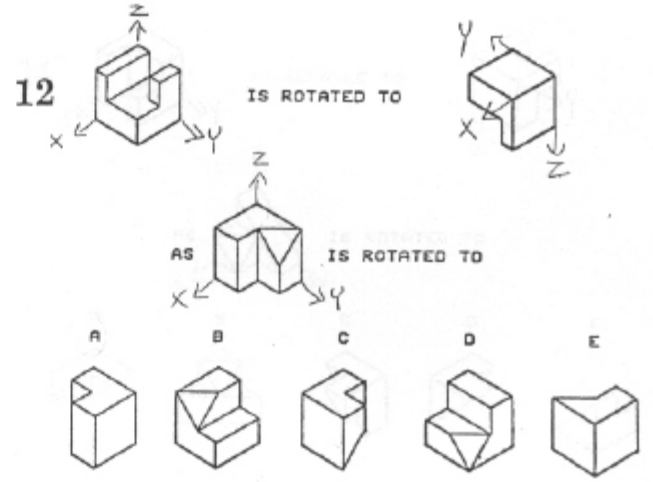
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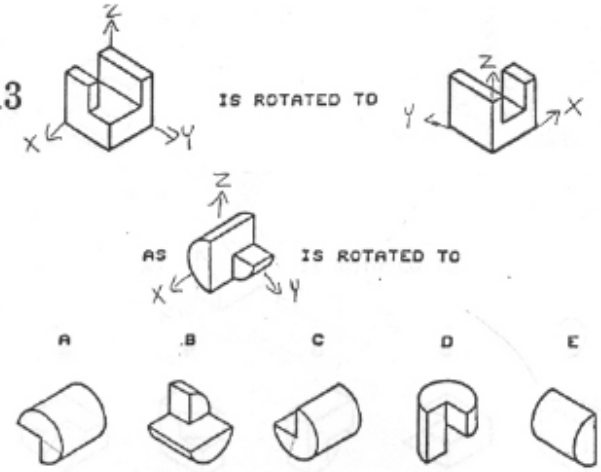
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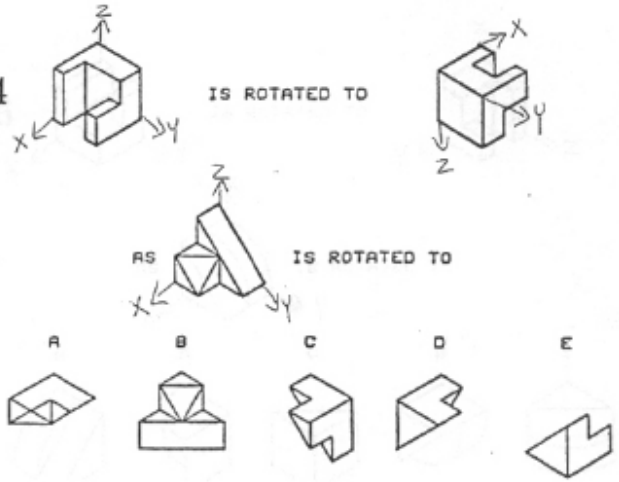
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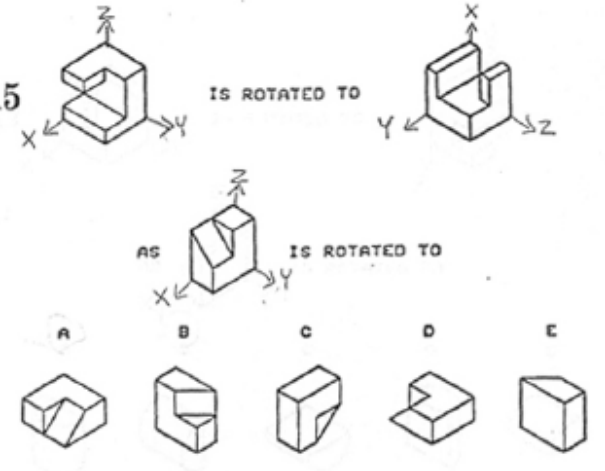
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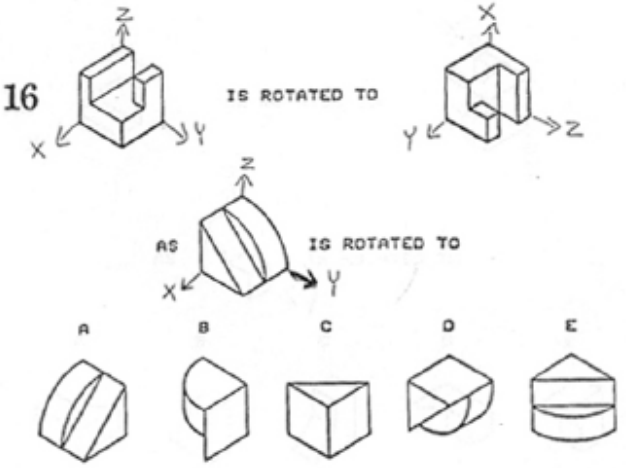
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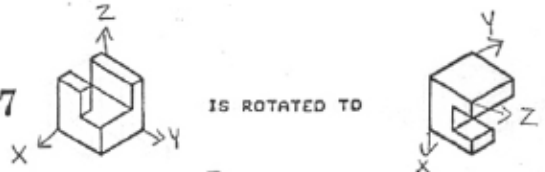

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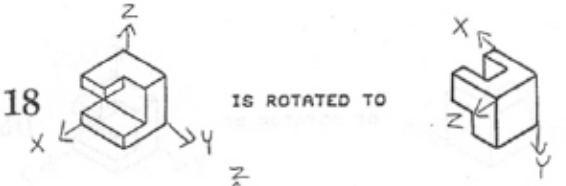

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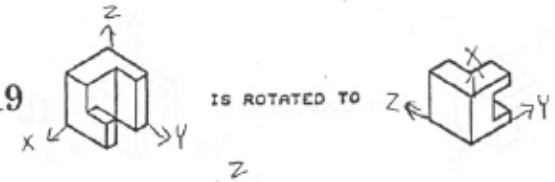

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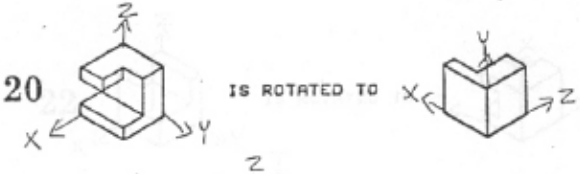

A B C D E

CURRICULUM VITAE

MARK E SMITH

Education:

PhD, Utah State University, May 2009 (Feb. 24, 2009 – defended date)
MS, Utah State University, August 2006
BSEET, Weber State University March 1984

Professional Experience:

- Semi-retired. Professional Ski Patroller, certified EMT and OEC. 2002-2005
- Independent Consultant. Included electro/mechanical software and hardware as well as networking and different operating systems integration. Provided input in sales, engineering, marketing, technical support, and training. 2000-2002
- CSM-USA, Inc. As president, oversaw the software development, marketing, training, sales and support teams, and trade show seminars and exhibitions to develop and market globally our WWW, connectivity and security software for public and private internet businesses. 1997-2000
- Integrated Systems. Responsible for the development of marketing, sales and technical support for CAE/CAD software and networking services. Included extensive use of, and customer training on, DOS, UNIX, IBM MainFrame, and MS windows. 1987-1997
- Dynatech, Englewood, CO. UT/ID Sales Engineer responsible for pre and post sales support and marketing with an emphasis on design-in of electronic and mechanical products Dynatech represented. 1985-1987
- US Steel, Geneva, UT. Engineer/Computer Analyst, responsible for maintaining and upgrading the computer controlled hot roll milling process. This included integrating sensor output and microprocessors with PLCs, minicomputer systems and a legacy GE mainframe. US Steel closed the plant in 1985. 1984-1985

Technical Expertise (As Graduate Student):

Electronics; Information systems; Networking; Spatial ability and learning in Science, Technology, and Engineering.

Courses Taught (As Graduate Assistant):

- ENGR 2930, Electrical Engineering for non electrical engineering students (4 credits)
- ETE 2300, Electronics Fundamentals (4 credits)

- ETE 3050 Computer Systems and Networking (3 Credits)
- ETE 3440: Science, Technology, and Modern Society (3 credits)

Publications (As Graduate Student):

- Smith, M. (2008) Meta-analysis of studies correlating spatial ability to academic achievement in STEM. *26th NRMERA Conference, Rocky Mountain Educational Research Association*, Lake Tahoe, NV., October 9-11, 2008.
- Smith, M., et. al. (To be submitted). The correlation between a pre-engineering student's spatial ability and achievement in an electronics fundamentals course. *Journal of Engineering Education*

Scientific and Professional Societies:

- Member, Institute of Electrical and Electronics Engineers
- Member, American Society for Engineering Education
- Member, International Technology Education Association