

PREDICTING STUDENT PERFORMANCE IN SONOGRAPHIC SCANNING USING SPATIAL  
ABILITY AS AN ABILITY DETERMINENT OF SKILL ACQUISITION

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In Partial Fulfillment  
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Doctor of Philosophy

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By  
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The undersigned, appointed by the dean of the Graduate School,  
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PREDICTING STUDENT PERFORMANCE IN SONOGRAPHIC SCANNING USING SPATIAL  
ABILITY AS AN ABILITY DETERMINENT OF SKILL ACQUISITION

Presented by Douglas Wayne Clem

A candidate for the degree of

Doctor of Philosophy

And hereby certify that, in their opinion, it is worthy of acceptance.

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## **Dedication**

Many people have contributed to the success of this project in one way or another. Thank you to my family and friends for standing by me and encouraging me through the entire process.

A huge thank you goes out to my mother, Dorothy, who oversaw much of my writing throughout the coursework. Sharing her expertise in academic writing with me was invaluable for my success in the coursework and beyond. Her never ending support and constant encouragement helped me get through the tough times. I also appreciated the support from the rest of my family - Dad, Sharon, Bryan, Kelly, and Brad - for at least being interested in this huge undertaking. Last, but not least, thanks to Cici, the wonder dog, who spent many nights lying at my feet, bored to death as I read.

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**ABSTRACT**

Spatial ability refers to an individual's capacity to visualize and mentally manipulate three dimensional objects. Since sonographers manually manipulate 2D and 3D sonographic images to generate multi-viewed, logical, sequential renderings of an anatomical structure, it can be assumed that spatial ability is central to the perception and interpretation of these medical images. Using Ackerman's theory of ability determinants of skilled performance as a conceptual framework, this study explored the relationship of spatial ability and learning sonographic scanning.

Beginning first year sonography students from four different educational institutions were administered a spatial abilities test prior to their initial scanning lab coursework. The students' spatial test scores were compared with their scanning competency performance scores. A significant relationship between the students' spatial ability scores and their scanning performance scores was found. This result suggests that the use of spatial ability tests for admission to sonography programs may improve candidate selection, as well as assist programs in adjusting instruction and curriculum for students who demonstrate low spatial ability.

## Chapter 1

### OVERVIEW

#### Introduction

Spatial ability is a neuro-physiological aptitude which allows humans to visualize and mentally manipulate objects in space. Gardner (1983), in his theory of multiple intelligences, views spatial ability as a separate aspect of human intelligence that can be empirically evaluated. John Carroll (1997) views visual-spatial reasoning ability as one of the three most influential intellectual abilities that manipulate and process information operating within "g" or overall general intelligence (as cited in Woolfolk, 2007).

Research on spatial abilities testing in relation to occupational aptitude has been done by a host of researchers since the 1920s (Likert & Quasha, 1995). Spatial ability aptitude tests have been shown to be valuable in predicting individual performance and success in occupations such as dentistry, art, engineering, industrial machine operating, drafting, designing, surgery and many others. Many of these careers require high scores on spatial ability tests prior to hire or for admission to their educational programs.

Sonography is an occupation where the practice of rendering images produced by the ultrasound machine, or "sonographic imaging," is utilized by professionally trained individuals, or "sonographers," to produce sonographic images which are called "sonograms." Sonographers are medical technologists charged with the task of imaging anatomical objects and analyzing pathological conditions of anatomical structures within patients, producing diagnostic medical images for the physician to read and interpret. Scanning patients and producing sonographic images is a skill that requires



manual manipulation of a transducer, or probe, while at the same time operating the ultrasound machine. It is an acquired skill developed through several years of diligent practice assisted by professional instruction. Like many other performance-oriented skills, such as in sports and music, daily practice is required to maintain the acquired scanning skills or they will deteriorate.

The Society of Diagnostic Medical Sonographers (SDMS) has published an official "scope of practice" for the work expectations of sonographers. The scope of practice includes: Perform patient assessments; acquire and analyze data obtained using ultrasound and related technologies; provide a summary of findings to the physician to aid in patient diagnosis and management; use independent judgment and systematic problem-solving methods to produce high quality diagnostic information and optimize patient care (SDMS, 2011).

The sonograms that sonographers create are two-dimensional (2D) representations of three-dimensional (3D) anatomical objects, recorded on either static or real-time digital images displayed by the ultrasound machine. More recent technological developments allow for 3D sonographic imaging, but its clinical use is currently rather limited. In order to produce a diagnostic quality ultrasound image, the sonographer must have a thorough knowledge of anatomical normality, as well as a keen understanding of all the possible pathological possibilities of the object in question. Standard protocols for imaging are pre-established and scripted by industry standards and guidelines. Yet, the pathological question drives the sonographer to create an examination which moves in directions necessary to accurately depict the

existing condition of the anatomical object. Therefore, it can also be assumed that a high degree of flexibility and creativity in the thought process of creating a sonogram is also required.

The images produced are "slices" of the anatomical structure, or cross-sections, which must be presented in a logical order to create a series of images that represents the overall anatomy of the structure. Since sonographers manipulate 2D and/or 3D ultrasound images to generate this series of images, it can be assumed that a sonographer's level of spatial ability is central to the perception, generation, and interpretation of these anatomical medical images. Rochford (1985) found that anatomy students with high spatial ability test scores have greater success in understanding human anatomy (as cited in Luursema, Verway, Kommers, & Annema, 2008).

### Conceptual Framework

The conceptual framework of this paper uses Ackerman's (1988) theory of cognitive ability determinants of individual differences in skill acquisition. Ackerman's theory identifies three phases of skill acquisition in which each phase requires certain underlying abilities.

The first phase, or the cognitive phase, is characterized by high cognitive load on the learner. Task performance is related to general intelligence (g) in verbal, figural, and numerical content areas. Spatial visualization ability is a component of the figural content. The second phase is the associative phase of skill acquisition, with demands placed on perceptual speed abilities, or the rate at which a task can be completed. The autonomous phase is the third phase of skill acquisition and places demands on

psychomotor abilities, utilizing little, or no attention, or cognitive effort. While learning a skill such as sonographic imaging requires successful passage through all three phases of skill acquisition, it is the individual's level of spatial ability, as the ability determinant, which directly relates to the conceptual foundation of this particular study.

Ackerman's theory suggests that a primary cognitive ability determinant is responsible for performing complex, inconsistent information processing tasks.

The ability determinant will be different based upon the task at hand. It is the investigator's theory that a student's individual level of spatial ability is a primary cognitive determinant in learning sonographic imaging.

Beginning sonographers endure a high cognitive load when first attempting to learn sonographic imaging during the first phase of skill acquisition. They must visually comprehend the 2D cross-sectional anatomical images of the 3D object produced through their manual manipulations of the ultrasound probe, and at the same time, operate a complicated technical, scientific machine. In addition, interpretive and analytical thought processes are occurring in the formation of a diagnosis of the anatomical structure(s).

With diligent practice and feedback from the instructor, the student sonographers move out of the cognitive phase and into the associative phase, where the integral components of sonographic scanning become more connected and fluid. Manipulating the probe, operating the ultrasound machine, and analyzing the images become more connected and automated. Finally, in the autonomous phase, little cognitive effort is needed to manipulate the probe and operate the machine. The eyes

are fixed on the monitor, gazing at the anatomical structure while the student operates the machine and probe effortlessly and without error. This study seeks to explore spatial ability as the ability determinant within the framework of Ackerman's theory of skill acquisition.

### Measuring the Spatial Ability Construct

Visual spatial ability refers to the visual system's processing of three-dimensional objects and their imaging properties. Current research of spatial ability contends that there are five general classifications that can be arranged in hierarchical order from low level ability to high level ability: a) edge and surface extraction b) edge orientation encoding c) whole object recognition d) imagery involving the spatial relations of object parts in 2-D, and, e) imagery involving 2D and 3D whole object spatial relations and translations (Anastakis, Hamstra, & Matsumoto, 2000).

#### *Spatial Ability Tests*

Spatial tests have been developed in which each test is uniquely suited for each level of spatial ability. Therefore, one must be careful to choose a testing instrument that appropriately assesses for the level of spatial ability that is of interest to the investigator. Upon examination of the task analysis of what sonographers do in their work (as presented above) a visual spatial ability test that assesses the fifth and highest form of spatial ability--imagery involving 2D and 3D whole object processing is required.

A wide variety of tests exists relating to the assessment of the fifth category of spatial ability. A review of the literature on spatial ability testing in surgery and dentistry shows that many different visual-spatial ability tests have been used for investigating

the role of spatial ability in medicine. The Purdue Spatial Visualization Test (Guay,1977), Vandenberg and Kuse Mental Rotations Test (1978), the Revised Minnesota Paper Form Board Test (Likert & Quasha, 1970,1995), the spatial ability section of the Differential Aptitude Test (Bennet, Seashore, & Westman,1981), and the Perceptual Ability Test (PAT) section (1998) of the Dental Admissions Test (DAT) are among tests most often cited in the literature. Literally hundreds more like them are commercially available.

It is imperative for the investigator to carefully choose a test that is relevant and particular to sonographic imaging. The Vandenberg and Kuse Mental Rotations Test is one of the most widely used in the medical spatial literature due to its having high construct validity in the area of spatial visualization ability. The Revised Minnesota Paper Form Board Test (RMPFBT), likewise, loads well in visual spatial ability, and is also robust in measuring spatial orientation since it requires a high degree of analytical processing (Branoff, 1999). Criterion related validity evidence, according to the test manual authors,

...addresses the inference that individuals who score better on tests will be successful on some criterion of interest. By collecting test scores and criterion scores (e.g., job performance ratings, grades in a training course, supervisor's ratings), one can determine how much confidence may be placed in using test scores to predict job success (Likert & Quasha, 1995, p.37-38).

Sonographers constantly manipulate 2D images of 3D anatomical structures whereby accurate spatial orientation is required to render appropriate representations of the anatomical object. The RMPFBT was chosen for this study since it is a spatial ability test. No previous studies could be found in the literature that investigated the

relationship of spatial ability and sonographic scanning. Therefore, no precedent has been set as to which spatial ability test is most appropriate.

The original Minnesota Paper Form Board Test (RMPFBT) was developed in the late 1920s and early 30s by Likert and Quasha. It was one of the first psychometric tests assessing visual-spatial ability (Likert & Quasha, 1934). The test has been reviewed and revised many times since then, most recently in 1995. According to the test manual authors, "the test measures the ability that predicts performance in jobs requiring the capacity to visualize and mentally manipulate objects in space," which correlates to assessing the fifth and highest category of visual-spatial ability of mental rotation and transformation of objects (Likert & Quasha, 1995, p.8).

It has been well documented in the literature that an individual's spatial ability can be improved through diligent practice and other methods to be discussed later. However, the test's authors maintain that an individual's score on the RMPFBT can only be marginally improved through specified training. Research regarding sex differences in scores on other spatial ability tests has also shown that, in general, males perform better than females (p.29). However, eight studies have found that the difference in scores between males and females on the RMPFBT is only a one-point advantage in favor of the males. It is also important to note here that the test manual authors maintain that a dramatic improvement due to "practicing for the test" cannot be achieved which would affect interpretation of test results on the RMPFBT (Likert & Quasha, 1995).

Studies on age and educational level differences of scores on the RMPFBT have found that, in general, younger participants tend to score higher than older test takers and that the scores also tend to increase slightly as the level of education increases (p. 30). Three different studies have shown that high school graduates scored higher on the RMPFBT than high school dropouts. Although research evidence suggests age and educational level can affect scores on the RMPFBT, the relationship is only moderate.

Some individuals with little formal education may score higher than those who are highly educated. Sharma (1973) found in a study of 1,660 students from four different grade levels that, in general, the ability level of the examinee, not the educational level, is responsible for performance on the RMPFBT. In light of these findings, it seems that the RMPFBT is an acceptable spatial ability test for all participants, regardless of age, gender, or educational level in sonography instruction programs. A detailed description of the RMPFBT appears in chapter three.

#### Spatial Ability Research in Medicine

Numerous recent studies have linked the role of spatial ability and its importance in learning certain skills in medical occupations, especially in general surgery (Risucci, 2002; Wanzel, Hamstra, Anastakis, Matsumoto, & Cusimano, 2002), colonoscopy (Luursema, Buzink, Verway, & Jakimowicz, 2010), laparoscopic surgery (Hassan et al 2007; Keehner et al, 2004; Wanzel, Hamstra, Caminiti, Anastakis, & Resnick, 2003), and dentistry (Evans & Dirks, 2003; Hegarty, Keehner, Khooshabeh, & Montello, 2008).

Wanzel et al (2003) examined the influence of individual spatial abilities and manual dexterity on performance among dental students, surgical residents and staff surgeons. Each group was administered the Vandenberg Mental Rotations Test (Vandenberg & Kuse, 1978) to assess high-level spatial abilities, and the Surface Development Test (Ekstrom, French, Harmon, & Dermen, 1976) for low-level spatial abilities. The results confirmed that high-level visual-spatial ability is related to and could potentially predict initial student performance and product quality on spatially complex procedures, especially in laparoscopy procedures. The high-level spatial ability tests were more predictive of performance than the low-level spatial ability tests, or the manual dexterity tests. Interestingly, those general surgery students who were identified with low spatial ability achieved results equal to the surgical residents and staff surgeons after supplementary instruction on the specific technical tasks.

While a novice with low spatial ability may initially exhibit low performance scores, additional instruction and deliberate practice can overcome and eventually increase the level of performance on the assigned tasks equal to the level of those with high spatial ability (Ekstrom et al, 1976). In light of this finding, the authors do not support the use of high-level spatial ability testing for the selection of candidates for admission purposes into surgical or dental schools. Rather, they contend that the tests would be most beneficial in identifying those novice trainees who might benefit from supplementary instruction during their course of study.

As mentioned above, Wanzel and colleagues did not support using the tests for admissions selections. By contrast, other researchers noted above, such as Keehner and



Risucci, supported using spatial ability tests for selection of candidates, stating that the extra time and instruction necessary to overcome initial poor student achievement due to having low level spatial ability may not be practical with limited time and resources. It seems to be an issue best decided upon by the admission committees of the respective schools.

Several studies confirmed Wanzel's findings that spatial ability strongly correlated with initial success in acquiring skills in laparoscopic surgery (Keehner et al, 2003), general surgery, Hedman, L., Strom, P., Kjellin, A., Wredmark, T., & Fellander-tsai, L. (2006) and dentistry, (Risucci, 2002). All found that high-level spatial ability testing can predict initial performance in these fields, and that the correlation with spatial ability diminished with extended practice and instruction. Each of the aforementioned researchers used a different spatial relations test, but all agreed that the high-level spatial tests correlated most strongly with high initial student achievement.

Other studies, which focused on repeated measures of spatial ability throughout the learning period, found that spatial ability not only correlated highly with initial success in skill acquisition, the correlation remained high in the latter stages of learning. Studies on laparoscopic virtual reality simulators (Hassan et al, 2007), and traditional laparoscopic training (Keehner, Lippa, Montello, Tendrick, & Hegarty (2006), reported that correlations with spatial ability remained strong throughout the end stages of training. This issue will be discussed at length in Chapter Two.

Some researchers assume that spatial cognition is central to understanding medical images, including those produced by CT, MRI, X-Ray, and ultrasound (Hegarty,

Montello, & Lippa, 2007). However, as of this writing, the only empirical evidence that has been identified in the literature that supports this assumption for the occupation of sonography has been performed by this investigator (Clem, Anderson, Donaldson & Hdeib, 2010). The exploratory study needed to be replicated to validate the findings of the exploratory study, and expanded to include more variables and additional research questions.

#### Purpose of the Study

The purpose of this study is to determine if the RMPFBT, a spatial abilities test, is valuable in predicting student achievement in learning sonographic imaging by replicating and expanding the work of the exploratory study. If so, the test may be used as an additional tool for admissions committees in assessing potential candidates. Also, it could be used as an assessment tool to identify students with low spatial ability who may need extra practice time and instruction, or even curricular alterations to help them be successful.

#### Research Questions

Traditional admissions criteria for most sonography education programs take into account a student's academic record (GPA) and the usual aptitude tests, such as the ACT, SAT or GRE. Other tests specific to allied health care, such as the Health Occupations Basic Entrance Test (HOBET) are sometimes included. What is not measured is the candidate's aptitude for sonographic imaging. Upon observation from 9 years of teaching first-year sonography students during their initial lab experience at the University of Missouri-Columbia, I have noticed that some students master the

technique of ultrasound scanning faster than others and therefore achieve higher competency scores.

Another observation is that while on one hand, although some students do well in didactic coursework, they may struggle with learning the techniques to scan. On the other hand, some students may struggle with coursework, but learn to scan very easily. Therefore, it is difficult to know whether or not a student being interviewed and assessed for admission to a sonography program will be successful as a sonographer based solely on traditional measures such as incoming GPA, ACT, or GRE scores, health care experience or interviews.

Reflecting upon the assumption that spatial cognition is central to understanding medical imaging and the results of the exploratory study, the following questions are investigated in the expanded study: a) what is the range of spatial ability of beginning sonography students; b) is there a relationship between spatial ability and learning to scan sonographic images; c) does spatial ability improve throughout the learning period in the sonography program; and d) is the student's level of spatial ability related to student retention in the sonography program?

#### Research Design and Procedures

The current study's design was built upon the same design as the exploratory study performed during my research internship (see Appendix A). A summary of the exploratory study is offered here. The initial pilot project was a correlation study conducted at a large Midwestern research university within the diagnostic medical

ultrasound program. After IRB approval, 17 first-year students in the program volunteered to participate.

### *Exploratory Study*

Two groups of ultrasound students were studied, which consisted of 6 first-year students enrolled in cardiac ultrasound and 11 first-year students in beginning abdominal ultrasound. Fifteen participants were female and two were male. The eleven abdominal students were undergraduates of traditional age in their junior year of college and all had just begun their first year of the ultrasound program. The cardiac students were older graduate students. Both groups were studied for two semesters and were taught by different instructors. The RMPFBT was administered to each of the participants in both groups at the beginning of the semester, prior to lab instruction, by a test administrator who was not associated with instructing or evaluating the participants.

The tests were hand-scored by the primary investigator at the end of the two semester learning period to alleviate any unintended teacher coercion, grading, or scoring bias for the competency exams of the students. None of the instructors of the participants in the study had any knowledge of their students' individual spatial test scores at any time throughout the instructional period, nor during competency scanning testing. All spatial ability scores were kept confidential, except to the primary investigator.

The study investigated two measures of the student's competency scores. First, the students were given scanning competency tests at the end of the first 30 hours of

instruction. For the group of 11 beginning abdominal students, the first competency test was that of a scan of the aorta. The students used each other as models and the instructor evaluated each student as they scanned in the laboratory setting, according to the performance objectives outlined in the Sonographer Clinical Assessment Book (SCAN), which is a commercially available assessment tool developed by the Society of Diagnostic Medical Sonographers (2000, IFSCR). See Appendix B.

The six beginning cardiac students' first competency scan consisted of obtaining the four basic 2D views of the heart, which included the parasternal long axis views, parasternal short axis views, apical, and subcostal view. Similarly, evaluations of student scanning were made according to the performance objectives stipulated in the SCAN. The students used each other as scanning models and the instructor evaluated them in a laboratory setting during normal testing times as prescribed in the laboratory course syllabus.

The students' scanning scores were correlated with their spatial test scores at two times of measure: after the first thirty hours of instruction, and then averaged over the 2 semester period. The scores were averaged to mediate the myriad of potential factors that can affect a student's scanning competency score. Some of these factors may include a student not feeling well the day of competency testing, test anxiety, motivational influences, teacher-student relationships, and a host of other unforeseen factors that can affect college students. The scores for both groups were combined and were then correlated with their respective scores on the RMPFBT. The independent

variable (X) was the spatial aptitude score and the dependent variable (Y) was the achievement, or scanning score.

### *Results of the Exploratory Study*

The study examined the spatial ability of each student to assess how those scores vary amongst the students. The minimum aptitude score for spatial ability was 34 and the maximum score was 55. Normative data have not been established for the occupation of sonography for the RMPFBT. As an example for comparison, normative data for grade 12 females indicate that a score of 34 would be in the 15th percentile and a score of 55 would be in the 90th percentile (Likert & Quasha, 1995). Therefore, the beginning ultrasound students had a very wide range of spatial ability with normal distribution.

The relationship between the students' spatial test scores and their scanning test scores was acquired after the first 30 hours of instruction, which was the time from their first lab to their first competency test, and then after 2 semesters of instruction. The combined scanning performance scores of the two groups after the first 30 hours ranged from 52% to 98%. Regression analysis was done for student performance after 30 hours and resulted in a Pearson Product correlation coefficient ( $r$ ) of .26,  $p > .05$ . The coefficient of determination, or  $r^2$ , which is the proportion of the total variance in the scanning scores (Y) that can be associated with the spatial ability scores (X), was .07. The adjusted R square for having a sample  $N < 30$  was .008. The standard error of the estimate was 10.91.

For the first part of the study, regression analysis was done to correlate the students' spatial scores with their initial scanning scores after 30 hours of lab instruction for all participants in the study. A one-way ANOVA was done to test if a statistically significant proportion of the variance of the dependent variable, the scanning scores, was associated with the independent variable, the spatial ability scores. The results were not statistically significant.

For the second part of the study, regression analysis was done for the combined student performance after 2 semesters of instruction. In contrast to results after 30 hours of instruction, the Pearson Product Moment correlation coefficient ( $r$ ) was .60,  $p < .01$ . The coefficient of determination,  $R$  squared, was .36. The 2 semester averaged result is quite significant and also shows a strong relationship between spatial ability and the scanning competency scores. The adjusted  $r^2$  for having a sample less than 30 was .35, and the standard error of the estimate was 3.89, since we have a small sample size. A statistically significant association for the variables after 2 semesters of instruction was found. This suggests a much stronger relationship between the spatial scores and student performance when looking at the 2 semester averaged time of measure. Repeated measures of ANOVA could not be done because the two groups had a different number of tests throughout the two semesters. See Figure 1 for regression scatter plot of the students' 2 – semester averaged SCAN scores and the spatial test scores.

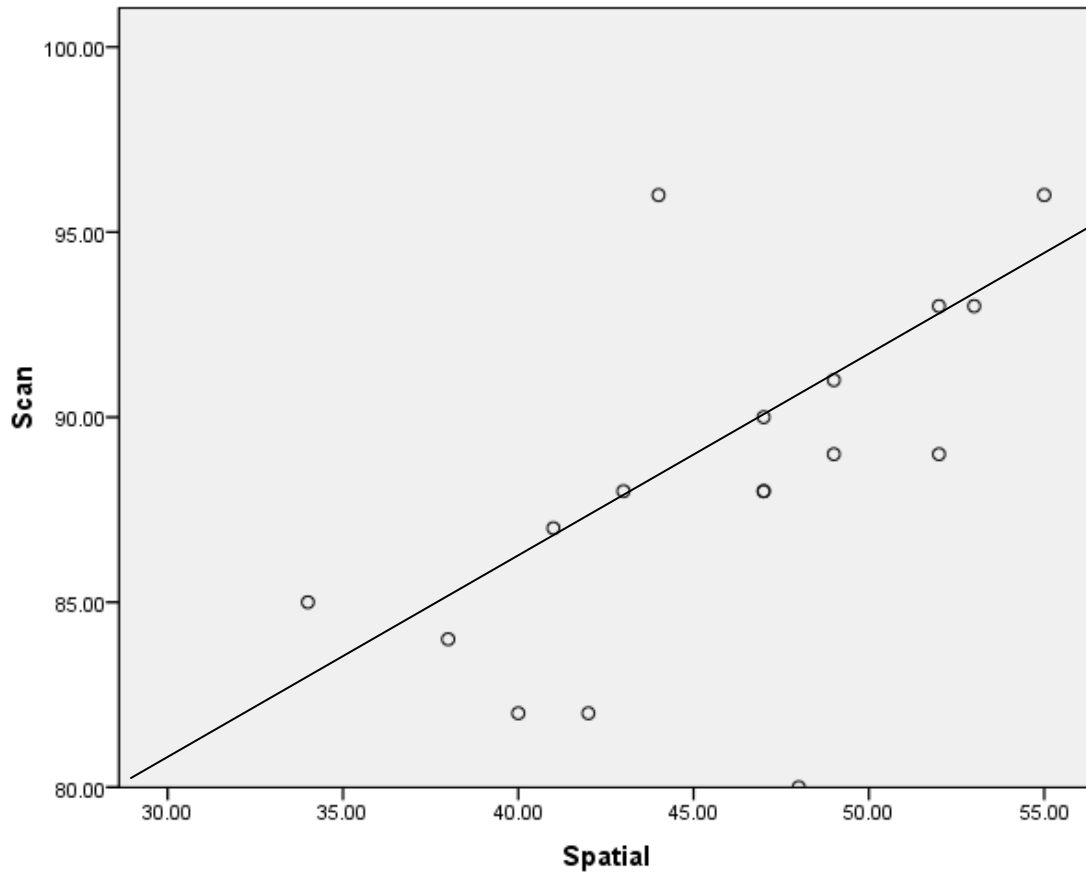


Figure 1. Regression scatter plot for the students' two-semester averaged scanning scores compared to their spatial ability test scores. The graph shows a strong linear relationship between the two variables.

*Discussion and Conclusions of the Exploratory Study*

The first research question asked was: What are the levels and variations of spatial abilities amongst the sonography students? As mentioned in the results section, the students had a very wide range of spatial ability, ranging from the 15<sup>th</sup> to 90<sup>th</sup> percentiles and the scores were distributed consistently throughout the range. This indicates that traditional pre-admission screening *does not* “weed out” low spatial ability candidates from high spatial ability candidates.



The second research question explored the relationship between the RMPFBT spatial ability scores and the performance scores recorded after 30 hours of instruction, and then after averaging all the competency scores for the two semesters. Unexpectedly, a weak correlation of .26 was found after the first 30 hours of instruction, whereas a strong correlation of .60 was found with the average of the two-semester performance scores.

It was anticipated that initially, a strong correlation would be seen. In the literature as described above, some investigators reported strong correlations with spatial ability and task performance after initial instruction, then weaker relationships due to mediating aspects of extended instruction and practice. Other studies have found that the correlation of spatial ability remained strong throughout the learning period.

One potential explanation of the findings may be the different experiences of the two groups of students who participated in the study. Performance scores of the 11 students in the abdominal group were clustered together after the first 30 hours of instruction and then diverged throughout the 2 semesters as the scanning competencies became more difficult. By contrast, the performance scores of the 6 students in the cardiac class varied widely after the first 30 hours, and then converged throughout the 2 semesters as the weaker students caught up with the competency levels of the stronger scanners. This variation in student experiences and associated performance scores may have skewed the scores for the first 30 hours. The expanded study controlled for the varied student experiences during the initial instructional period by sampling students from one specialty, such as abdominal students only.

It was necessary to combine abdominal and cardiac classes in the exploratory study in order to increase the number of participants to achieve a sufficient sample size where  $N = 17$  for the number of independent variables in the study, which is one. For simple regression using one independent variable, in this case student achievement on scanning scores, the sample size must equal about 15 to 20 participants (Field, 2009). Between group and within group analyses would be inappropriate for two small groups of twelve and five participants. Of central importance to this study was the question regarding the relationship between innate spatial ability test scores and student achievement in ultrasound scanning, for which positive results were demonstrated.

#### Limitations of the Exploratory Study

There were several significant limitations of the exploratory study. One limitation was the small sample size in which only 17 students participated. The participants were all from one program at one university, and of the 17 participants, 15 were female and only two were male, adding to the limited scope and diversity of the sample population. A more balanced representation would be more advantageous. However, as stated above, recent findings in the literature have failed to find a statistically significant difference between male and female scores on the Revised Minnesota Paper Form Board Test.

Another limitation to the study was that the spatial ability test cannot account for the individual's level of psychomotor skills. Sonographic scanning is an acquired skill through many hours of diligent individual practice with a high cognitive load pressing on the learner. An individual's level of eye-hand coordination is certainly a factor in learning

how to scan, so even if a person has a high level of spatial ability within the visual system, the level of psychomotor skills could affect an individual's scanning score. The use of a spatial ability test that combines testing for psychomotor skills would be most appropriate for future study. These types of tests usually require a trained professional to administer and was cost prohibitive for this study. Nevertheless, the positive results of the exploratory study cannot be ignored and provide foundational empirical evidence on which to build for future research.

### Conclusions

The results from the exploratory study offered some initial insights regarding the relationship between spatial ability and student achievement in learning to scan. It was expected that those students with high spatial ability would have significantly higher scanning scores than the low spatial ability students, and that this would be most apparent after the first scanning test. Instead, a weak relationship was seen between spatial ability and scanning scores after the first scanning test. Interestingly, as shown above, when averaging the student's scanning grades over 2 semesters, a strong relationship resulted, indicating that spatial ability was indeed important in learning to scan.

It is unclear why this result happened. The proposed study's intent is to replicate the exploratory study, yet in an expanded format, in order to explore validation of the exploratory study's findings. The results may have important implications for improving the admission process and curriculum in sonography programs. If a high correlation exists between high scores on spatial tests and high scores on scanning competencies,

the test may be used for admission purposes for candidate selection into diagnostic medical ultrasound programs. It may also be useful in identifying a weakness in student aptitude for scanning after being admitted to a program. Proper counseling and instruction could be offered to help the student overcome low spatial abilities in learning how to scan.

#### Definitions

Revised Minnesota Paper Form Board Test (RMPFBT) - Measures aspects of mechanical ability requiring the capacity to visualize and manipulate objects in space. Individuals with high scores in spatial ability tend to perform well on tasks requiring the mental transformation, manipulation, and analysis of dimensional objects. The test uses geometric shapes to assess the candidate's mechanical-spatial abilities. The 64 two-dimensional shapes are drawn in separate pieces, requiring the examinee to visualize the pieces as a complete geometric shape to choose the correct answers. The RMPFBT can determine which applicants have the aptitude for jobs requiring creativity and visualization skills, such as: Designer, draftsman, electrician, engineer, and HVAC technician.

SCAN - The SCAN (Sonography Clinical Assessment Notebook), was developed by the International Foundation of Sonography Education and Research (IFSER) in 1994, and is the current gold standard for clinical assessment tools in sonography. The SCAN is an educational evaluation instrument in which student sonographers, educators and clinical instructors use for clinical competency evaluation.

Sonography – Sonography is a diagnostic medical procedure that uses high frequency sound waves (ultrasound) to produce dynamic visual images of organs, tissues, or blood flow inside the body. Sonography can be used to examine many parts of the body, such as the abdomen, breasts, female reproductive system, prostate, heart, and blood vessels. Sonography is increasingly being used in the detection and treatment of heart disease, heart attack, and vascular disease that can lead to stroke. It is also used to guide fine needle, tissue biopsy to assist in taking a sample of cells from an organ for lab testing (for example, a test for cancer in breast tissue). Unlike X-rays, sonography is a radiation-free imaging modality.

Sonographers - A diagnostic medical sonographer is a highly-skilled professional who uses specialized equipment to create images of structures inside the human body that are used by physicians to make a medical diagnosis. The process involves placing a small device called a transducer against the patient's skin near the body area to be imaged.

Sonographic Imaging - The process involves placing a small device called a transducer against the patient's skin near the body area to be imaged.

Sonogram - A dynamic visual image(s) of organs, tissues, or blood flow inside the body.

This type of procedure is often referred to as an ultrasound scan.

Spatial ability - Ability to perceive or solve problems associated with relationships between objects or figures, including position, direction, size, form, and distance.

Student Achievement - Student achievement in sonographic imaging for this study is assessed by the student's instructor/preceptor at each site using a 1-5 Likert scale on

the SCAN competency form, with the following description for each level of competency:

- 5 = Optimal execution of the specific competency - competent
- 4 = Executed well but some improvements can be made – competent
- 3 = Satisfactory execution of the competency but several improvements can be made – competent.
- 2 = Unsatisfactory execution of the competency with several errors adversely affecting the diagnostic quality of the competency – not competent.
- 1 = Non-diagnostic quality of the competency – not competent.

Transducer - A small electro - mechanical device (probe) that is placed against the patient's skin near the body area to be imaged. The transducer works like a loudspeaker and microphone because it can transmit sound and receive sound. The transducer sends a stream of high frequency sound waves into the body that bounce off the structures inside. The transducer detects sound waves as they bounce off the internal structures. Different structures in the body reflect these sound waves differently. These sounds are analyzed by a computer to make an image of the structure(s) on a television screen or that can be recorded on videotape or digitally recorded.

## Summary

The expanded study builds on the design of the previous work. It addresses some of its limitations, and seeks to answer the research questions examined in the exploratory study, and to expand into other areas with additional research questions. To address the difference of classroom instructional experiences and having two competency evaluators from classes learning different ultrasound specialties, participants are from homogenous classes with one instructor as the scanning competency evaluator. The Revised Minnesota Paper Form Board Test is utilized again and administered at the start of the students' initial ultrasound lab work. In the expanded study, the participants are tested again at the end of the study to see if their spatial ability scores change after a time of instruction and practice to see if the students' spatial ability improves.

Additionally, several more schools with sonography educational programs are added to the database in order to broaden and diversify the sample in an attempt to more closely reflect the demographics of the population of sonography students in the U.S. In order to do this, the sample includes participants from one proprietary school, two community colleges, and a large research university. This sample covers a wider array of learning experiences, producing a more accurate reflection of the current types of sonographer education programs.

The results of the research project may give insight as to how spatial ability relates to learning ultrasound scanning. The data gleaned from the study may be instrumental in offering admission committees of sonography programs an additional

assessment tool, that of a spatial ability test like the RMPFBT, which can be used to more clearly define a candidate's aptitude for ultrasound scanning. Understanding the relationship between spatial ability and student achievement in scanning may also provide educators greater insight into the capabilities of their students, so that curriculum adjustments and pedagogical techniques can be made to enhance teaching effectiveness and student learning.



## Chapter 2

### LITERATURE REVIEW

#### Introduction

This literature review will focus on three general areas of interest regarding the exploration of the relationship between spatial ability and learning sonographic imaging: a) the conceptual and theoretical framework upon which the study is based and how it relates to spatial ability research, b) contextual considerations of the role and importance of spatial ability in everyday life, and c) a review of the recent research in the medical field that explores the prospect of spatial ability as an ability determinant of skill acquisition in various medical domains such as surgery, dentistry and diagnostic imaging.

#### Conceptual Framework – Skill Acquisition Theory

The conceptual framework for the proposed study is developed from well-established theories derived from scholarly work done regarding human skill acquisition. A voluminous body of scholarly work on skill acquisition exists, traversing a hundred years of research. Therefore, a review of the literature of skill acquisition theory lies beyond the scope of this chapter. Yet, a brief introduction is offered. Fundamental characteristics of skill acquisition have been well - established through the integrations of scholarly work dating from the late 1800s. Works by James (1890), Bryan and Harter (1899), and Book (1910) established the first ideas of the fundamental characteristics of skill acquisition (as cited in Ackerman, 1988).

Later, influenced by cognitive psychological learning theory and information processing perspectives, Fitts (1964), and later Fitts and Posner (1967) established the now universally accepted three phases of skill acquisition: The cognitive phase, the associative phase, and the autonomous phase. The important contributions of ideas relating to controlled and automatic processing, along with delineation of consistent and inconsistent processing of information, led to further refinement of the three-phase model (Shiffrin & Schneider, 1977).

Ackerman's theory of ability determinants integrates the prior work of Fitts, Fitts and Posner, and Shiffrin and Schneider, and extends these ideas to suggest that a primary cognitive ability determinant is responsible for performance in complex, inconsistent information processing tasks. This ability is domain specific in the sense that it is based upon the type of task performed. To understand Ackerman's theory, one must first sort out certain components within the model. Ackerman integrates the three - phase skill acquisition model with an associated three level ability structure. Within his three level ability structure, he draws upon the concepts of controlled and automatic information processing, which in turn, are predicated on a distinction between consistent and inconsistent information processing demands.

Consistent information processing is defined as a situation in which stimuli and responses are mapped in a manner that allows for complete certainty once the relationships have been learned. Once these relationships have been learned, task accomplishment can be performed in an effortless manner. Examples of consistent, automatic processing tasks include tying one's shoe, riding a bicycle, typing, and the

playing of memorized scales on musical instruments. Each task requires a limited amount of initial inconsistent processing and progression to the autonomous phase is relatively quick.

Inconsistent information processing is defined as situations that demand a high level of uncertainty between stimuli and responses, occurring in "on the spot" decision-making. Examples include monitoring jobs such as air traffic controller and sonar operator, accomplished musician, and engineer. While there is often an underlying task of consistency actually existing, it is not obvious to the learner in the initial phase of skill acquisition. When no consistency exists, or when the learner does not realize consistency, task accomplishment of greater complexity requires a great deal of additional cognitive resources.

Ackerman's (1988) theory of ability determinants concerns changes in ability - performance relations as a function of three task characteristics: a) consistency of information processing demands, b) task complexity, and c) degree of task practice. The theory integrates a hierarchical model of cognitive intellectual abilities that correspond to the three phases of skill acquisition. A representative radix model is presented below in Figure 2.

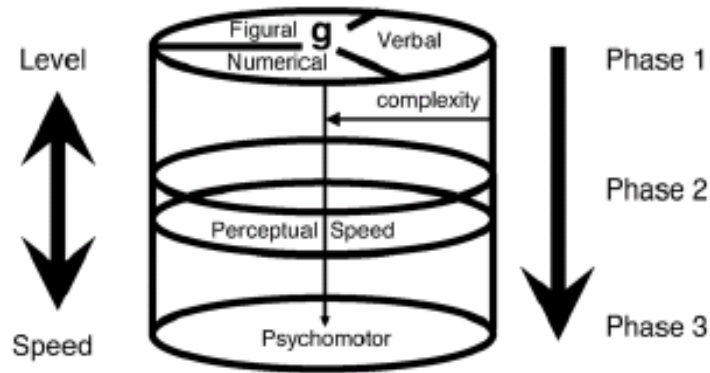


Figure 2. Ackerman's radix model of human abilities and skill acquisition.

All first time learning experiences require some level of inconsistent learning processes. The complexity and amount of practice time it takes to accomplish the task at hand determines the amount of cognitive load on the learner. During the cognitive phase, task performance places high demands on general intellectual abilities (g) in verbal, figural, and numerical areas. In the associative phase, skill acquisition places demands on perceptual speed abilities, or the rate at which a task can be accomplished. In the autonomous phase of skill acquisition, demands are placed on psychomotor skills (muscular movements resulting from mental processes) to the point whereby performance of the skill becomes automatic, and proceeds with little or no concentrated effort.

### *Skill Acquisition in Sonography*

Ackerman's theory on ability determinants can be applied to learning the skill of sonographic scanning. The cognitive phase of learning sonographic scanning is quite demanding. Sonography students must manually manipulate the probe of the ultrasound machine to generate the best image possible viewed on the machine's

screen. While one hand is manipulating the probe, the other is operating the machine to optimize the images produced. At the same time, they must visually understand what they see and make the appropriate corrections with the probe. Additionally, they must interpret the images of the anatomical object to determine normality versus pathology and adjust the direction of interrogation for the study accordingly.

The associative phase of skill acquisition involves strengthening the associations that the learner has made during the cognitive phase and places demands on perceptual speed abilities. This is where "practice makes perfect." Repetition and deliberate practice hone the skills necessary for task accomplishment in a timely fashion. It is not unusual for a beginning sonographer to take many times the amount of time to complete a task that it would take an accomplished sonographer to perform.

Finally, the autonomous phase places demands upon psychomotor abilities. After a certain amount of diligent practice, performing the task becomes automatic and requires little cognitive effort. While cognitive processes may be ongoing to fine tune appropriate adjustments, the task is largely accomplished quickly and accurately. Inconsistent processing has now become consistent processing. In this phase, the sonography student scans effortlessly with one hand, operates the machine with the other, and mentally interprets the images throughout the varying protocol of the study.

It is generally accepted in the field that sonography schools help to advance students past the cognitive phase and push them well into the associative phase. After several years of continuous work experience, the novice eventually advances through the autonomous phase and become professional sonographers. As with all other tasks that

demand the development of expertise, sonographers must continuously practice the acquired skills on a daily basis, or they will gradually diminish with time (Ericsson, 2006).

It is therefore hypothesized that spatial ability, as a component of the figural realm of general intellectual abilities as shown in Ackerman's radix model in figure 2.1, is an ability determinant that predicts individual differences in initial skill acquisition during the cognitive phase of skill acquisition. It remains to be seen whether or not spatial ability is important in all phases of sonographic scanning skill acquisition. As reported in Chapter One, mixed results have been seen in this regard. Utilization of the Revised Minnesota Paper Form Board Test to assess an individual's spatial ability in this study may be an important evaluation tool that predicts an individual's success in learning sonographic scanning.

Ackerman's theory has been cited in over 800 articles outside of the medical field. Utilization of Ackerman's theory in prior research on spatial ability as a cognitive determinant for skill acquisition in medical domains is not unprecedented. As well, it has been called upon to support conceptual frameworks in the shallow, but significant spatial ability literature in medicine. Several recent studies in medicine have either based their conceptual frameworks on the theory, or have cited the theory in some way in support of their research (Gray & Deem, 2002; Hegarty, Keehner, Kooshabeh & Montello, 2008; Keehner, Lippa, Montello, Tendick, & Hegarty, 2006; Keehner, et al, 2004), as noted in Chapter One.

Ackerman's theory of ability determinants of skill acquisition is an appropriate theoretical basis with which to support the premise that spatial ability is a figural ability

determinant for learning in the cognitive phase of sonographic image skill acquisition. Based on previous usage of the RMPFBT in similar medical research relating spatial ability and skill acquisition as shown above (Evans & Dirks, 2001), I have concluded that the 3D and spatial relations problem-solving requirements of the Revised Minnesota Paper Form Board Test render it a suitable assessment tool for the exploration of whether or not the level of individual spatial ability is a primary cognitive ability determinate for pre-clinical sonographic imaging task performance.

### Spatial Ability

In simplest terms, spatial ability can be defined as the neuro-psychological (or neuro-physiological, depending upon one's point of view) capacity to perceive form in objects as they are encountered in the environment (Gardner, 1983). Spatial images can be thought of as "pictures in the mind" which are the products of a mental process that constitutes a concrete mental image constructed identically to the object viewed in reality (Hauptman, 2010). As an extrapolation of the mental process perspective, others expand the construct's definition as the ability to "generate, retain, retrieve, and transform well-structured images" (Lohman, 1996, p.3).

Most researchers agree that spatial ability is not a unitary construct, but they do not agree on the number of units that make up the construct. It consists of a collection of skills, and some authors believe that the collection may be infinite in number (Gardner, 1983; Lohman, 1996; Voyer, Voyer, & Bryden, 1995). Though many distinct components of spatial skills can be identified, researchers since the early part of the 20th century have generally divided spatial ability into two or three main categories.

As early as 1938, Thurstone divided spatial ability into three main visual/mental capacities: The ability to recognize the identity of an object when it is seen from different angles, the ability to imagine movement and displacement among the parts of an object; and the ability to think about spatial orientation of an object in reference to the observer, placing oneself as part of the problem (as cited in Gardner, 1983). Contemporary researchers have identified as many as five general classifications of visual spatial abilities arranged in hierarchical order from low level ability to high level ability: a) edge and surface extraction; b) edge orientation encoding; c) whole object recognition; d) imagery involving the spatial relations of object parts in 2-D; and e) imagery involving 2D and 3D whole object spatial relations and translations (Anastakis, Hamstra & Matsumoto, 2000).

Gardner (1983) lists several capacities, or operations of spatial ability which are all loosely connected: The ability to recognize instances of the same element; to recognize a transformation of the object or elements therein; to generate mental imagery and to mentally transform that imagery; and to produce a graphic likeness of that imagery. These capacities come together to aid the observer in many different facets of everyday life. They are important for locating oneself in different locales, be it standing in a room or floating on a boat on the ocean. They are important for the recognition of objects and scenery and their alterations as encountered in reality.

While 2D and 3D graphic depictions of real-world scenes through symbols, maps, diagrams, and geometric forms would not be possible without visual-spatial skills, spatial ability is not limited to concreteness. It is essential to abstract thought in



domains such as science, math, art, music and architecture. For example, it provides sensitivity to line and form, use of tension, and balance in painting. It also enhances the capacity to metaphorically discern and connect diverse domains, such as the analogy of micro-organisms and human organization in society, i.e., conjuring up the mental picture of an amoeba and relating its systems of survival to that of leadership in a complex human organization.

Current research recognizes several broad categories of spatial abilities, each connected to different aspects of the process of image generation, storage, retrieval, and transformation (Lohman, 1996). Contemporary thought represented in the literature on the construct of spatial ability maintains that it consists of mental rotation, which involves rapidly and accurately rotating two and three dimensional objects; spatial perception, which involves the ability to perceive spatial relationships with respect to the orientation to the observer's body; and spatial visualization, which involves complicated, multi-step mental manipulations of objects in space (Linn & Peterson, 1985).

Lohman (1988) proposed the three categories noted above to be named spatial orientation, spatial relations, and spatial visualization. Unanimous agreement does not exist for the existence of these three categories. Some researchers have limited them to two: spatial relations and visualization (Clements & Battista, 1992; Elliott & Smith, 1983; and Pellegrino & Kail, 1982). Indeed, most spatial testing can be separated by those which assess spatial relations or those who assess spatial visualization, but there are as many forms of spatial testing as there are components of spatial ability (Olkun, 2003).

As one can see, there is no real consensus on the definition of "spatial visualization skills" (Sorby, Leopold, & Gorska, 1999). Everyone seems to be in agreement, though, that it is a collection of skills, and there is broad support that it consists of mental rotation, spatial perception, and spatial visualization (Linn & Peterson, 1985).

Beaumont and Davidoff (1992) stated that "the assessment of basic visual processes is probably the most technically difficult of all areas of neuropsychological assessment, and it is rarely performed adequately by clinical neuropsychologists." The two main reasons for this are 1) the inherent complexity of visual-spatial abilities, and 2) the neuropsychologists who normally develop clinical tests of visual performance generally lack the training and resources to conduct this kind of investigation (as cited in Anastakis, Hamstra, & Matsumoto, 2000). Literally hundreds of spatial ability tests are commercially available and each has certain construct validity strengths and weaknesses, and each targets certain aspects of spatial ability.

#### *Anatomy and Neurophysiology of Spatial Ability*

Within the realm of neurophysiology, spatial ability's presence and functionality in the brain, with the possible exception of language, has had more established research published than most other abilities (Gardner, 1983). The left hemisphere of the brain is the location for linguistic processing. The right hemisphere in the parietal lobe is predominately the prime location of visual-spatial processing, yet not exclusively. Some spatial capacity can be limited in the event of left brain damage. For the most part, traumatic damage to the right brain has shown to produce deficits in recognizing objects, faces, scenes, and noticing fine details.

Cognitive psychologists' research has yielded important contributions in understanding how individuals encode, remember, and transform visual images. Scholarly work on hemispheric specialization suggests a well-defined difference between "verbal-sequential processing" and "spatial-analog processing" as a "fundamental dichotomy in human cognition" (Lohman, 1996, p. 3). Authors such as Pavio (1971) contend that verbal and spatial information are stored in different codes. In contrast, other authors, such as Anderson (1983), support a multi-code theory of memory, with separate codes for storage of information. The process of how information is encoded into specific brain locations continues to be debated among contemporary researchers in which currently, inconclusive evidence seems to be predominating current thought.

In sum, as has been previously discussed, there is no real consensus on a singular, unified definition of "spatial visualization skills" (Sorby, Leopold, & Gorska, 1999). It is a collection of skills, however, and there is broad support that in general, it consists of mental rotation, spatial perception, and spatial visualization (Linn & Peterson, 1985).

### *Spatial Ability and Human Intelligence*

Since the beginning of the 20th century, spatial ability has been included in all theories of intelligence, no matter which perspective of human intelligence is espoused. General intelligence, or "g," was first proposed by Charles Spearman (1927) in the early days of the 20th century as the main component or mental attribute used to perform any mental test, and called it the g-factor. Along with the g-factor, other specific

cognitive skills exist such as spatial ability, in which he called s-factors, complimenting "g".

Thurstone (1938) proposed that primary mental abilities fall into seven categories and included spatial relations as one of the seven categories. He concluded that the sum of these categories composes human intelligence. Cattell (1963) and later Horn (1998) developed concepts of fluid and crystallized intelligence in which spatial ability tasks would draw on both. Other notable theorists within the general intelligence (g) camp are Phillip Vernon's (1950) hierarchical model, J.B Carroll's (1997) three stratum theory, and Robert Sternberg's (1985, 2004) triarchic theory. All include spatial ability as an important aspect of human intelligence (as cited in Woolfolk, 2007).

By contrast, other psychologists such as Gardner (1983) and Guilford (1988) eschew the concept of "g" and insist that there are at least eight, perhaps more, multiple intelligences which comprise human intelligence. In this model, spatial ability is considered a unique, separate intelligence altogether, rather than an ability operating and controlled under the auspices of "g." No matter which perspective of human intelligence one adheres to, spatial ability is an important aspect in any regard.

Developmental psychologist Jean Piaget (Piaget & Inhelder, 1956) characterized spatial thinking as a developmental sequence in children. He believed that a child's spatial system is organized around topological properties such as convergence, connectedness and continuity at first. Then, as they the child matures, progresses to thinking geometrically. Finally, the child becomes able to work with abstract objects.

### *Improving Spatial Ability*

It is well documented in the spatial testing literature that an individual's spatial ability can be improved. Several studies have found that merely manipulating the testing environment will improve test scores amongst women (Sharps, Welton & Price, 1993; Sharps, Price & Williams, 1994). They found that highly spatial instructions decreased scores for women, but not for men. Furthermore, emphasis on the tested abilities as useful for male-stereotyped occupations produced a larger gender gap in scores. In contrast, if emphasis on the tested abilities were placed on female-stereotyped occupations, an insignificant difference of scores was obtained.

Many studies have explored the question as to exactly which experiences and activities promote enhancement of spatial abilities. Activities found to improve spatial abilities include musical experiences (Robichaux, 2002); creating artwork (Caldera, Culp, O'brian, Truglio, Alvarez, & Huston, 1999); playing with certain toys such as Legos, Lincoln Logs, and Erector sets (Sorby & Baartmans, 2000); previous geometry instruction, vocational training, work experience, and participation in certain sports (Sorby, Leopold, & Gorska, 1999). Deno (1995) created the Spatial Experience Inventory (SEI) which collected information for 480 spatial activities in three categories: academic subjects, nonacademic activities, and sports. The study found many activities in all three categories which enhanced the development of an individual's spatial ability.

Most recently, strong empirical evidence for the improvement of spatial abilities has come from research on practice, training, and education (Melancon, 2001). Practice and training research has centered largely on the use of virtual reality computer

programs to improve spatial ability. The results are mixed, however. Shavaliar (2004) investigated whether CADD-like software called *Virtus Walkthrough Pro* (CADD - computer aided design and drafting), could be used to enhance the spatial abilities of middle school students. No difference between the control group and the experimental group was found.

By contrast, a very recent virtual reality program specifically designed to enhance spatial abilities called *Virtual Spaces 1.0* has shown promising results (Hauptman, 2009). The research showed that a passive experience using virtual reality computer programs does not yield enhanced spatial skills. The learner must be actively engaged in the experience through self- regulation and manipulation of the program in order to improve higher order spatial skills. In further support of these findings, participants in another study learned human bone anatomy using hand held controllers to rotate an on-screen 3D bone model (Stull, Hegarty, & Mayer, 2009). They concluded that self- regulation of orientation references elevated learning in low spatial ability learners to a level near that of high spatial ability learners.

New educational courses have been developed which focus solely on improving a student's spatial ability. Several studies have suggested that seventh grade is the optimal time for the teaching of spatial visualization tasks (McGee, 1979). Hands-on manipulation of objects along with the utilization of 3D graphics helped the seventh grade students to improve their spatial ability test scores. Sorby and Baartmans (2000) conducted a 6 year longitudinal assessment of a college level course specifically designed to help struggling engineering students improve their spatial scores. The

students' spatial test scores did improve, resulting in increased retention rates for both men and women, but especially for women within the engineering school.

Researchers involved with developing spatial ability in educational settings have studied which factors make educational efforts most effective: allowing for practice and providing feedback (Law, Peligrino & Hunt, 1993), allowing for self- discovery (Vasta, Knott & Gaze, 1996), and concentrating three or four sessions directly to a single spatial measure (Baenninger & Newcome, 1989). These studies indicate that increasing the number of strategies for effective problem- solving helps learners to score higher on spatial ability tests. It is debatable, however, whether or not true spatial ability is actually improved, or if the learner is merely applying strategic skills of analyses with which to "figure out" the correct spatial test answer.

### *Spatial Ability and Sex*

A large body of research evidence in the spatial testing literature has shown that in general, males perform better on tests of spatial perception and mental rotation, while men and women perform equally well on spatial visualization tests (Linn & Peterson, 1985). This holds true for international studies as well, comparing the sex differences in which men outperformed women on spatial abilities tests in comparing adults from the United States and China (Geary & Desoto, 2001). The question arises then, is this discrepancy due to nature or to nurture? Do males have an innate ability for spatial ability that women do not, or is it a matter of socialization and exposure to activities that encourage the development of skills which require spatial abilities?

Several studies exploring the nature versus nurture scenario have gleaned some interesting results. Voyer, Voyer, & Bryden (1995), over the span of 50 years of research, did not find any difference in gender scores of the mental rotations test below the age of seven. After age seven, though, males performed better than their female counterparts. Caldera, Culp, O'Brian, Truglio and Huston (1999) also found no differences of scores between genders on the mental rotations test in 51 pre-school children. The present literature has not found any support that X and Y chromosomal genetic expressions account for the differences in spatial ability between men and women, whereas empirical support does exist for environmental and socialization factors (Linn & Peterson, 1985).

There is evidence that the gap between males and females in spatial ability may be narrowing. In an earlier study that explored the role of playing action video games and its relationship to spatial development in the areas of spatial attention and mental rotation, Feng, et al, (2007) found that after only 10 hours of training of males and females with an action video game, both sexes realized substantial gains in both spatial attention and mental rotation, with females benefitting more than males.

In recent years several studies have shown that spatial ability can be improved by playing certain types of video games, such as action video games (Feng, Spence & Pratt, 2007; Hong, Cheng, Hwang, Lee, & Chang, 2009). In fact, the disparity of spatial scores between men and women on the spatial mental rotations test seems to be narrowing due to prolific gaming of both male and female children and adolescents. Feng, Spence and Pratt's study (2007) concluded that training with appropriately



designed video games could play a significant role as part of a larger strategy to pique the interest of more women to pursue career choices in science and engineering.

Since the early 1990s, video games have assumed an important place in the lives of all children, both male and female, with both sexes participating in playing them (Hong, Cheng, Hwang & Chang, 2009). They also found that other types of video games, other than action games, have been identified in improving spatial ability for both sexes, such as word search games and first – person shooter action games. With more females being exposed to video game play, the gender gap in spatial ability continues to narrow.

#### *Spatial Ability and Psychomotor Skills*

Bloom's (1956) taxonomy of education stipulates that there are three domains relevant to educational outcomes: the cognitive, affective, and psychomotor skills domains (as cited in Woolfolk, 2007). Psychomotor skills are defined as the ability to do acts relevant to the field of study. A skill can be defined as the level of performance of a specific task (Fleishman, 1972). Psychomotor learning is a function of the relationship between cognitive functions and physical movement. The learning process progresses through three stages of development, as previously described above by Ackerman (1988): the cognitive phase, the associative phase, and the autonomic phase.

The autonomic phase is associated with demands on psychomotor abilities (p. 600). In skill acquisition, this is the phase whereby effort of thought is minimal and performance of the skill becomes speedy and automatic. Ackerman's (1988) theory suggests that a specific cognitive ability determinant is responsible for performance in complex, inconsistent tasks. Spatial ability is one part of the figural domain of general

abilities, and has been linked as an ability determinant in affecting psychomotor learning in acquiring certain skills in dentistry (Evans & Dirks, 2001; Gray & Deem, 2002).

In the task analysis of sonographers as presented in Chapter One, manipulating the transducer, or probe, in acquiring the sonographic images requires highly developed hand-eye coordination psychomotor skills over an extended amount of time of diligent practice. Direct assessment of an individual's psychomotor ability would require administration of very specific psychometric tests. Tests of psychomotor abilities have had a long period of development over the past 80 years, and they have proven to be valid predictors of complex task performance (Ackerman & Cianciolo, 1999).

Most psychomotor tests require specialized equipment and tools. Use of psychomotor tests for this study was prohibitive due to high costs in acquiring these types of tests, calibration requirements, examiner training, and a low examiner – examinee ratio of one examiner to every four examinees. Therefore, individual assessment of psychomotor abilities on those types of tests is beyond the scope of this study.

In one study, (Francis, Hanna, Cresswell, Crter, & Cuschieri, 2001), The Gibson Spiral Maze Test and the Crawford Small Parts Dexterity Test were utilized to assess the hand-eye coordination performance of master surgeons. Administration of the Gibson Spiral Maze Test requires a trained professional who must “stress” the subject during the test to reveal any psychomotor deficiencies. The Crawford Small Parts Dexterity Test measures both eye-hand coordination and manual dexterity. Tests such as these must

be administered by a trained professional, and are costly. For these reasons, test of psychomotor skills were not included in this study.

### Research on Spatial Skills in Medical Occupations

After an exhaustive review of published research pertaining to spatial ability and medical occupations, there does not appear to be any scholarly work done which is focused on exploring the relationship of spatial ability and learning sonographic scanning. Therefore, the apparent knowledge gap was addressed by my previously published exploratory study (Clem, Anderson, Donaldson, & Hdeib, 2010), and is being reinvestigated in the current expanded study. For reference and support of this study, one has to turn to existing empirical research on spatial ability and its relationship to learning certain skills in other branches of medicine, such as dentistry and surgery, to gain insight on the subject at hand. Though a paucity of research exists on this topic in the medical literature, a few significant studies have been published in recent years.

#### *Dentistry*

Dentistry has utilized spatial ability testing as one of the four testing components of the Dental Admissions Test (DAT) since the 1940s (American Dental Association, 1999). The Perceptual Abilities Test (PAT) is a spatial visualization sub test that has been the subject of several recent papers as to its effectiveness in predicting student achievement in dental schools. A recently published study found that scores on the PAT have been shown to account for approximately 25% of the variance of the final grades in dental preclinical technique courses (Gray & Deem, 2002). The authors centered the conceptual framework of their study on Ackerman's (1988) theory of ability

determinants of skilled performance, using spatial ability as the determinant in this contextual setting.

In support of this finding, (Hegarty, Keehner, Khooshabeh & Montello, 2008) found that spatial ability skills were at least "moderately predictive" of student achievement in dentistry practical laboratory courses. Interestingly, the authors also studied whether or not dental education actually improved the spatial abilities of the students. They found no evidence to support that premise.

One other recent study of dental technology students, rather than of dental students, further supports the above previous findings. Evans and Dirks (2001) compared all of the admission criteria to student success in achievement of learning psychomotor skills inherent to dental technologists. They found that each admission criterion utilized, including assessment of visual-spatial skills, adequately predicted individual differentiation in learning ability and achievement.

### *Surgery*

Surgical procedures have increasingly become more automated through the use of various medical devices and scientific instruments. Medical students learning surgical procedures such as laparoscopy (Hasan et al, 2007; Keehner et al, 2004), colonoscopy (Luursema, Buzink, Verway & Jaimowics, 2010) and general surgical competence (Risucci, 2002; Wanzel et al., 2003) were studied to explore the role that spatial ability has in acquiring those surgical skills. The results of these studies indicated that a learner having high or low spatial ability affects both speed of learning and overall initial competency of the students' performance of the skill.

Returning to Ackerman's (1988) theory of skill acquisition, the learner passes through three phases – the cognitive phase, the associative phase, and the autonomous phase. Since a diminishing role for cognitive processes is realized as skills become increasingly automatic, it would be expected that correlations for general abilities would be strong initially, and then weaken as the learning process continues into automaticity.

Several studies confirmed Ackerman's theory in finding that spatial ability strongly correlated with initial success in acquiring skills in laparoscopic surgery (Keehner et al, 2003), general surgery, (Hedman et al, 2006) and dentistry, (Risucci, 2002). All found that high-level spatial ability correlate strongly with initial performance in these fields, and that the correlation with spatial ability diminished with extended practice and instruction.

Other studies, which focused on repeated measures of spatial ability throughout the learning period, found that spatial ability not only correlated highly with initial success in skill acquisition, the correlation remained high in the latter stages of learning. Studies on laparoscopic virtual reality simulators (Hassan et al, 2007), and traditional laparoscopic training (Keehner, Lippa, Montello, Tendrick, and Hegarty (2006), reported that correlations with spatial ability remained strong throughout the end stages of training.

Ackerman found this to be true about spatial ability in his own study on the training of air traffic controllers (1992). He also found that the correlation of spatial ability remained strong throughout all three phases of learning. Returning to the studies on surgical training, the mixed results as to whether or not the relationship between

spatial ability and surgical is transient (associated with only the early stages of learning), or enduring (associated with all stages of learning) remains unclear. But the results that Ackerman (1998) and Keehner et al (2006), amongst a host of others in other disciplines suggest that when the content of a task is highly spatial in nature, the correlation with spatial ability will remain high even after practice and instruction.

By contrast, in the exploratory study Clem, Anderson, Donaldson and Hdeib (2010) found that after the initial phase of learning sonographic scanning (after 30 hours of scanning), a low correlation of spatial ability resulted (.20), while after averaging all the scanning competency grades over two semesters and strong correlation (.60) emerged. The low initial correlation does not match the expectations predicted by Ackerman's theory. The expanded study seeks to find similar or dissimilar results.

In sum, within the past decade, the above mentioned studies from various fields of medicine explored the role of spatial ability and student achievement in their respective fields. Three general conclusions can be made from these studies: a) spatial ability plays a significant role in learning certain medically related skills, especially in the initial stages of learning, but may or may not be important through all phases of learning, b) additional practice and instruction mediates the learning curve of low spatial ability students, and c) while dental schools continue to assess a candidate's spatial - visual skills for admission into their educational programs, there are mixed opinions as to whether or not surgical medical students should be screened for spatial ability skills for training programs in general surgery, laparoscopy, and colonoscopy.

## Summary and Conclusions

Spatial ability is a multi-faceted neuro-physiological construct that can be empirically evaluated through psychometric testing and assessment. It is an important aspect of human intelligence that can be improved with diligent practice through a variety of means (Melancon, 2001). Males have generally performed better than females on mental rotations tests, but that gap is narrowing due to changing environmental and socialization factors (Feng, Spence & Pratt, 2007; Hong, Cheng, Hwang, Lee, & Chang, 2009).

It has been shown that having high or low spatial ability directly affects skill acquisition performance in learning various medical technical procedures (Hasan et al, 2007; Hegarty, Keehner, Khooshabeh & Montello, 2008; Keehner et al, 2004; Luursema, Buzink, Verway & Jaimowics, 2010; Risucci, 2002; and Wanzel et al., 2003). Some studies have utilized Ackerman's (1988) theory of ability determinants of skilled performance theory in developing the conceptual framework of their research (Evans and Dirks, 2001; Gray & Deem, 2002), others noted above.

The study of spatial ability and its importance of skill acquisition in medical procedures have generated a small, but significant body of work in the literature. Studies mentioned in this chapter have explored the relationship of spatial ability and skill acquisition in dental and surgical education, as well as specialized skills such as laparoscopy and colonoscopy.

The gap in the literature for studying the relationship between spatial ability and learning sonographic scanning was addressed in my exploratory study, and remains the

sole published article on the subject. This study seeks to validate the exploratory study's findings and expand the exploration of spatial ability in learning sonographic scanning. The next chapter will describe the manner of collection of the data and how it will be analyzed in the expanded study.



## Chapter 3

### RESEARCH METHOD

#### Introduction

In Chapter Two, the literature review revealed that many occupations requiring high levels of spatial ability for success in their respective fields use spatial ability tests for entrance into their educational training programs. However, little is known about the use of spatial ability tests for the occupation of sonography. For my research internship, an exploratory study was devised to examine the role that spatial ability plays for beginning ultrasound students at the University of Missouri - Columbia. While previously described in chapter one, a brief review of the study's results follows.

#### *The Exploratory Study*

A quantitative exploratory study based on simple regression was performed to better understand the relationship between spatial ability and learning ultrasound scanning in order to determine if a spatial ability test, the Revised Minnesota Paper Form Board Test, might be used as a predictor of student success in ultrasound scanning (Clem, Anderson, Donaldson & Hdeib, 2010). In the study, one independent variable, spatial ability, was correlated with one dependent variable, the students' scanning scores. Simple regression analysis was utilized. The study focused on two research questions: a) what is the range of spatial ability of the beginning ultrasound students who participated in the study, and b) what is the relationship between the students' spatial test scores and their ultrasound scanning performance test scores?

The first question explored whether the beginning sonography students were being unintentionally "homogenized" into similar classes of abilities, aptitudes and achievement through rigorous college admission screening procedures and subsequent screening for admission into the diagnostic medical ultrasound program. The results found that the students' spatial test scores ranged from the 15th to the 90th percentiles. This indicated that pre admission utilization of admissions criteria, such as GPA, ACT scores, and interviews, did not "weed out" low spatial ability candidates.

The second question explored the relationship between the students' spatial test scores and their scanning competency test scores. It was expected that those students with high spatial ability would perform better on their scanning tests than those students with low spatial ability, especially at the beginning of their laboratory course work. Correlations were made after the student's first scanning competency, or after the first 30 hours of instruction. Then, the scanning scores were averaged after two semesters of instruction. Both measures were correlated to their spatial test scores. Interestingly, instead of a strong relationship, a weak relationship ( $r=.20$ ) was seen after the first 30 hours. When the students' spatial scores were then averaged over a period of two semesters and correlated with their spatial test scores, a strong relationship ( $R=.60$ ) was seen between the two variables.

The results of the exploratory study were published in the July/August 2010 issue of the *Journal of Diagnostic Medical Sonography* (see Appendix A). As original research, the study was the first of its kind to provide foundational understanding about the role that spatial ability may assume in learning ultrasound scanning. The study

needed to be replicated in order to validate its findings, which fuels the rationale for the expanded study.

#### *Rationale for the Expanded Study*

Several limitations were evident in the exploratory study that could be addressed in the expanded study. The sample of participants for the study was drawn from only one ultrasound program located in a large research university setting. The 11 abdominal class participants in the exploratory study were largely traditionally aged juniors in their course of study. Ten females and one male were seeking bachelor degrees. The six cardiac students were graduate students, of whom five were females and one was male.

Bachelor degree seeking students only represent about 12% of the total student population in ultrasound schools in the U.S. The majority of students, about 45%, matriculate through community college programs and 37% through proprietary schools (CAHEP, 2010). In order to obtain a more representative sample, the expanded study sought to include students from other sites - community colleges and proprietary schools, in addition to MU students. Since most ultrasound programs are found in technical schools, small colleges, community colleges, and proprietary schools, the expanded study's results may be more applicable to generalize to the entire population of sonography students than the results from the exploratory study.

Using an N of 17 elicits an *ad hoc* statistical power of .76, using the calculating package in SPSS. Ideally, a statistical power of .80 is desirable. Statistical power is the probability that the test will reject the null hypothesis when it is false, or will not make a

type II error, which would be a false negative. Three factors that influence statistical power are the statistical significance criterion used in the test, or alpha level; the magnitude of the effect size in the population, either small (.2), medium (.5) or large (.8); and the sample size used to detect the effect (Field, 2009).

As the power increases, the chance of making a type II error decreases. A statistical power of .76 is marginally acceptable for the statistical power of a study. Using Cohen's d table for *a priori* statistical power, an N of at least 64 would be ideal for use in a two tailed non directional hypothesis with an alpha level set at .05, a moderate effect size of .5, and desiring a statistical power of .80. The expanded study's N of 73 surpasses that of 64. An N of 73 will result in an *a priori* statistical power of .99, reducing the chances of making a type II error and increasing the sensitivity of the study.

It was expected that the relationship between the spatial and scanning test scores would be more robust when correlating them after about 30 hours of instruction, as opposed to the 2 semester averaged period of instruction. It is unclear why a weak relationship was seen at the beginning stages of learning to scan in the exploratory study.

The expanded study therefore sought to validate the first study's results, increase the sensitivity of the study, and to broaden the student demographics of the sample by creating a more diverse representation of the general population of sonography. By adding participants from community colleges and the proprietary school, a greater diversity of participants which more closely represents the true sonography student population can be studied.

A third research question emerged from a review of the literature regarding whether or not spatial ability improved after the learning period (Evans & Dirks, 2001; Hegarty, Keehner, Khooshabeth & Montello, 2007). These studies found no improvement of spatial ability at the end of the instructional period for dentistry students. By contrast, another study found marked improvement in the spatial test scores at the end of the learning period of students learning technical drawing compared to the pre-learning period test scores (Prieto & Velasco, 2009). It would be interesting to see if the student's spatial ability actually improves through practice and instruction as they progress in acquiring their sonographic scanning skills. Whether or not studying sonographic scanning enhances spatial ability may be important in giving insight for changing curriculum and/or pedagogical teaching techniques to improve spatial ability is needed in helping low spatial ability students learn to scan.

Finally, a fourth research question was asked for the expanded study: Does the student's level of spatial ability affect retention/attrition levels in the sonographic program? Student retention rates are an important factor in the success of any sonography program. Correlating student spatial test scores and scanning with those who stay or leave the program before term may give insight as to how spatial ability plays a role in student retention.

In sum, the expanded study sought to replicate and verify the exploratory study's results of the relationship between spatial ability and sonographic scanning, to broaden the sample population's demographics by adding more diverse students from other sonography school programs in order to enhance the ability to generalize the results for

the entire population of sonography students, to assess whether or not sonography students' spatial ability improved after two semesters of practice and instruction, and to explore the relationship between the spatial ability and student retention.

#### Research Questions

The following research questions are addressed in this study: 1) what is the range of spatial ability of beginning sonography students, 2) is there a relationship between spatial ability and learning sonographic imaging, 3) does spatial ability improve throughout the learning period in the sonography program, and 4) is the student's level of spatial ability related to student retention in the sonography program?

#### Research Design

In exploring the relationship of the two variables, the students' spatial test scores and their scanning competency scores, the overall research design is a quantitative study centered largely on the utilization of descriptive statistics, histograms, correlations, and various forms of regression analysis – simple, multiple, and logistical - to answer the four research questions. The sample of student sonographers was drawn from four separate sonography programs from different parts of the country.

For the expanded study, the participants were beginning sonography students drawn from a large research university program, two community colleges, and one proprietary school. All students were complete beginners; they had no experience scanning any sonographic images prior to this time. The size of the sample population students was increased from 17 to 79, and was drawn from four different types of

educational institutions. The directors of these programs volunteered to participate in the expanded study after having read the published results of the exploratory study, which at the end of the article placed a call for volunteer programs for the expanded study (Clem, Anderson, Donaldson & Hdeib, 2010, p .8).

Each site's preceptor administered the informed consent and then the spatial tests were administered at two times: before lab instruction, and after the two semester learning period. After signing the informed consent, the students wrote their names on the first page of the test booklet, which is numbered. The preceptor kept the front page with the student's name and test booklet number. After the student completed the spatial test, the preceptor gathered the test booklets and consent forms and mailed them to me, the primary investigator.

I had only the student's test booklet number for identification purposes, with no other identifying information. All records were kept confidential and I had no knowledge of the student's name. After I received the completed pre and post spatial tests, I scored the tests after the two semester learning period was over, and recording the spatial test score as student #1, student #2, and so on. The preceptor did not have any knowledge of any student's spatial test scores throughout the two semester learning period. A copy of the informed consent, and the pre and post spatial scores were returned to the preceptors in sealed envelopes to disseminate to the study participants at the completion of the study.

During the two semester learning period, the students' scanning scores from their sonography lab courses were recorded on the appropriate SCAN form for each

particular competency for two consecutive semesters. The proprietary school operates on a modular system, rather than a semester system, but covered the same amount of instructional time as the schools on the semester system – 16 weeks. The SCAN forms had only the student spatial test booklet number as an identifier. When the two semester learning period was completed, the completed SCAN forms were mailed back to me for analysis.

### Data Sources

For the expanded study, student participants in sonography programs from the following types of institutions volunteered to participate: a large Midwestern University (MWU), a Midwestern community college (MWCC), a community college from the Atlantic coastal region (ACCC), and a proprietary school (PS). True names of the educational institutions are not provided in order to protect the identities of the participating schools. Instead, regions of origin and the abbreviations shown above will be used to identify the programs. The expanded study of 73 participants included the 11 abdominal students' scores from the first study (exploratory study). The six cardiac students were dropped, because all of the other sites were abdominal students.

#### *Midwestern University (MWU)*

The Midwestern university (MWU) offers a Bachelor of Health Science (BHS) and a Master of Health Science (MHS) degree in four ultrasound specialties. About 18% of accredited sonography programs offer bachelor degrees in the U.S. by the Commission on Accreditation of Allied Health Education Programs (CAAHEP), (CAAHEP, 2011). Abdominal, OB/GYN, and vascular ultrasound specialties are covered in the bachelor's



degree program, with cardiac offered for the master's degree for continuing students from the bachelor's degree. Only the beginning abdominal students participated in the expanded study. The bachelor's degree program accepts students in their junior year of study after two years completion of pre-requisite general studies. The sonography program is a year round program starting in the summer before the students' junior year, and continues on to the end of their senior year, including the summer session between the junior and senior years of study. The students are then able to sit for abdominal, OB/GYN and vascular national registry examinations upon graduation.

The master's degree student body is composed of two tracks of students: a) continuing students from the bachelor's degree studying cardiac ultrasound, and b) beginning sonography students from other health or science related disciplines. The latter class of students starts in abdominal courses which are cross-referenced with the undergraduate courses. Therefore, each beginning abdominal class contains both undergraduate and graduate students, but all are complete beginners learning to scan. Continuing students can complete the MHS degree in a year and a half, while the other master's degree students with no prior ultrasound background need two years to complete their course of study.

In the fall semester, the students are in lab eight hours each week for 16 weeks. They do not have any clinical experience during this time. For the spring semester, they are again in lab eight hours each week. They also have 64 hours of clinical time which is largely for observation, but some scanning is done too, depending in the site and the student. On Friday afternoons, open lab is available for extra scanning time. In total, the

students have 256 hours of lab time and 64 hours of clinical time for the two semester learning period.

*Midwestern Community College (MWCC)*

This community college offers a certificate in diagnostic medical sonography. MWCC offers “advanced certificates” in either cardiac or abdominal sonography, as well two year degrees in other disciplines.

Applicants must have an AAS - a 2 year degree in a related health science, such as radiography, to enter the sonography program. Community college programs account for 45% of the accredited sonography programs in the U.S (CAAHEP, 2011). MWCC’s sonography program, like the university program, also operates within 16 week semesters with summer session coursework required in between semesters. Lab and clinical contact hours vary markedly from the university program. In the first semester, MWCC students have 15 scheduled lab hours and 288 clinical hours. The second semester, they have 15-18 scheduled lab hours and 408 clinical hours. In total, for the two semester learning period of the study, MWCC students have about 30 hours of lab time and 676 hours of clinical time.

*Atlantic Coastal Community College (ACCC)*

ACCC community college offers the associates of applied science degree (AAS) for abdominal and vascular specialties in medical sonography. In contrast to MWCC, the sonography program is integrated within the two - year degree. Similar to MWU and MWCC, the semester is 16 weeks in length, with the first two semesters devoted to abdominal sonography. Lab and clinical time, again, vary significantly to MWU and

MWCC. The students have 143 hours of lab time for the first semester, with 48 hours of clinical time. For the second semester, the students have 120 hours of lab time and 256 hours of clinical time. In total, for the two semester learning period, the students have 263 hours of lab time, and 304 hours of clinical time.

### *The Proprietary School (PS)*

The proprietary school (PS) is a privately owned corporate school, operating within a for-profit business model. Proprietary schools currently comprise 37% of the accredited sonography programs in the U.S (CAAHEP, 2011). Their sonography program is 20 months long, set in modules rather than in semesters, and are based on 2,442 clock-hours of instruction. Overall, one module has the same amount of instructional time as the traditional semester – 16 weeks.

Corporate schools, in general, have a long history of providing educational programs to military personnel, adult learners seeking vocational training, and newly admitted US citizens from foreign countries seeking vocational training. Proprietary school students are more likely to be female, from minority groups, and poor. They are able to pay tuition through heavily subsidized federal student grant and loan programs (Apling, 1993).

These programs are corporate owned entities charged with making a profit for their shareholders. They have tuition and fees nearly twice as expensive as the previously mentioned four year and two year state supported colleges. The PS offers business, medical and technical programs leading to a certificate of completion or a diploma. The medical ultrasound program is a 20 month, 2,442 hour long term of study

in which abdominal, OB/GYN, and cardiac specialties are offered. The school only admits candidates for the sonography program who already have a bachelor's degree or two - year associates degree, which allows the graduate to sit for the national registry exam after obtaining the diploma.

As with the other schools, lab and clinical times are different. For each module, students are in lab for 50 hours and in clinical for 240 hours. In total, for the two semester learning period of the study, the students have 100 hours of lab time and 480 hours of clinical time. See Table 1 for a summary of the lab and clinical hours required of the students from each program.

Table 1  
*Summary of Lab and Clinical Hours by Site*

<b>Site</b>	<b>First Semester</b>	<b>Second Semester</b>	<b>Total</b>
MWU	Lab 128 Clinical 0	Lab 128 Clinical 64	Lab 256 Clinical 64 Total 320
ACCC	Lab 143 Clinical 48	Lab 120 Clinical 256	Lab 263 Clinical 304 Total 563
MWCC	Lab 15 Clinical 288	Lab 15-18 Clinical 408	Lab 30-33 Clinical 696 Total 726-729
PC	Lab 50 Clinical 240	Lab 50 Clinical 240	Lab 100 Clinical 480 Total 580

The programs vary greatly in the amount of available lab and scanning time for the beginning students. MWU classes have more didactic coursework during the first two semesters than the other sites, and therefore has less time allowed for lab and clinical time. MWU classes have much more lab and clinical time during the summer

months in between their first and second year of study. The other sites have much less coursework and spend the large majority of their time scanning during the first two semesters. It is important to note here that the amount of true scanning time available at the clinical sites vary greatly also. Exactly how much time each student actually scans during their lab and clinical time is impossible to assess accurately.

### Sample

Eleven abdominal students from the exploratory study were included in the expanded study, which excluded the six cardiac students. This was done because all of the rest of the sites had only abdominal students, for a total N of 79 who contributed data that included the pre instructional spatial test scores, the first 30 hours SCAN scores, and the two semester averaged SCAN scores. However, six students dropped out of their sonography programs before the study ended – five from MWCC, and one from ACCC for an N of 73. Table 2 shows the breakdown of study participants by site, number of students, specialty, and year of study after the six students dropped.

Table 2  
*Expanded Study Samples*

<b>Study</b>	<b>School</b>	<b># of Students</b>	<b>Specialty</b>	<b>Year of Study</b>
Exploratory	MWU1	11	Abdominal	2008-2009
Expanded	MWU2	14	Abdominal	2009-2010
Expanded	MWU3	19	Abdominal	2010-2011
Expanded	PC	11	Abdominal	2010-2011
Expanded	MWCC	11	Abdominal	2010-2011
Expanded	ACCC	8	Abdominal	2010-2011

Question one asked what was the range of the spatial test scores and scanning test scores of the study participants. For the pre instructional spatial test scores, data

from the original 79 students were used in the analysis. After the six students dropped out after completion of the spatial test, the 73 remaining students' data were used for the scanning competency scores. The second question looked at the relationship between the remaining 73 student test scores and their scanning scores at two time of measure – after the first thirty hours of instruction, and then averaging the scores for the two semester learning period.

For the third research question, which asked if spatial ability increased throughout the learning period, 43 participants from MWU3, PS, MWCC, and ACCC sites provided data comparing their pre and post spatial test scores. (MWU1 and MWU2 data were gathered before the proposal, so the students did not complete the post spatial test for this study). The fourth question regarding the relationship of spatial ability and retention rates included data from the original 79 participants. Additional demographic data such as gender, educational background, and aptitude scores were also considered in the analysis. It was not permissible to obtain some of this information from all sites.

#### Variables in the Study

The independent variable was the students' spatial test scores on the Revised Minnesota Paper Form Board Test. The dependent variable was the students' scanning scores. Additional independent variables analyzed were gender, and educational background. For MWU classes, incoming GPA, and aptitude test scores were analyzed.

## Data Collection

### *Instrumentation - RMPFBT - Independent Variable*

Spatial ability tests are designed to evaluate a person's ability to mentally manipulate diagrams of objects into alternate formations. The original Revised Minnesota Paper Form Board Test (RMPFBT) was developed in the late 1920's by Likert and Quasha (1995) and was the first psychometric test assessing visual-spatial ability. The test measures an ability that predicts performance in jobs requiring the capacity to visualize and mentally manipulate objects in space. The RMPFBT has been used to assess applicants in a wide range of jobs, including electrical and mechanical positions in industrial plants, mechanics at utility companies, draftsmen, industrial machine operators, and many others (p.39). The test used for this study was updated in 1995. It is a 65 question, 20 minute, paper and pencil test that evaluates spatial relations abilities (Likert & Quasha, 1995). The range of possible score is 0 to 64.

### *RMPFBT Reliability and Validity*

The RMPFBT has a split-half reliability measuring internal consistency of .93, and a test - retest score of .85, measuring stability over time. There are four alternate forms of the test, with a reliability of .85. Criterion related validity, which means to provide an educated guess about an examinee's potential for future success, has not been established for ultrasound, but comparatively for a medical occupation that has used spatial ability testing since the 1940s is .61 for dentistry. Construct validity, or the extent to which a test measures the trait (spatial ability) it was designed to measure, which in

this case is visual spatial ability, is .75, see Appendix C for test sample (Lickert & Quasha, pp. 33-48).

*Instrumentation - The SCAN - Dependent Variable*

The Sonographer's Clinical Assessment Notebook (SCAN) was devised by the International Foundation for Sonography Education and Research (2000-2010) with initial funding provided by the Society of Diagnostic Medical Sonographers (SDMS) Educational Foundation. It is an evaluation tool designed to aid in the assessment of clinical proficiencies of the sonography students. It is competency based and designed in such a way that a student's proficiency for each specialty in ultrasound can be assessed.

Student achievement in sonographic imaging for this study is assessed by the student's instructor/preceptor at each site using a 1-5 Likert scale on the SCAN competency form, with the following description for each level of competency:

- 5 = Optimal execution of the specific competency - competent
- 4 = Executed well but some improvements can be made – competent
- 3 = Satisfactory execution of the competency but several improvements can be made – competent.
- 2 = Unsatisfactory execution of the competency with several errors adversely affecting the diagnostic quality of the competency – not competent.
- 1 = Non-diagnostic quality of the competency – not competent.

Each participant in the study had their scanning competency scores recorded for the following competencies: aorta, liver, abdominal Doppler, pancreas, kidneys, gall bladder, and spleen. Two sites – MWU and ACCC -included the pelvis competency. The other two sites – MWCC and PS, did not include the pelvis competency, because they cover that competency in the OB section. Each scanning competency was scored on a



scale of 1-5, as explained in the definitions section in Chapter One. Global scores for each competency were totaled and then averaged for a percentage score (see Appendix B). The procedure for administering the spatial tests and scoring the competencies, as well as the logistics of handling each follows.

### *Procedure*

This study was approved by the MU Internal Review Board (see Appendix D) for each year that it was renewed (2008-2010). At each learning site, the informed consent was reviewed with the participants by a proctor not involved with the scoring of the RMPFBT (see Appendix E). Each participant was allowed to ask questions, and then was asked to sign the consent form. A copy of the signed consent was given to each participant. The Revised Minnesota Paper Form Board Test (RMPFBT) was administered to each study participant prior to the start of lab instruction.

The front page of the test booklet with the student's name was numbered, as well as the test booklet itself. The front page was then torn off and filed with the site's preceptor. The signed consent forms and numbered test booklets were then mailed to me, the primary investigator. In this way, no individual student identification information was made available to me, and the site's preceptor had no knowledge of the study participant's spatial test score.

I scored the students' spatial tests at the end of the two semester learning period in order to alleviate any teaching or testing bias by myself or the site instructors, ensuring that they had no prior knowledge of their students' RMPFBT score during the instructional period. The instructors kept track of the scanning competency scores using

the SCAN notebooks for each student provided by the principal researcher. Results were collected by the instructor and sent back to me for further analysis. All test results were sealed in an envelope and mailed to each instructor to disseminate to the students at the end of the study.

### Data Analysis

Each research question was analyzed within four categories: overall, by site, by gender, and by educational background. Educational background for the beginning ultrasound students for the four sites varied greatly. According to the RMPFBT authors, studies on the relationship between age and educational level indicate that there is a tendency for younger test takers to score higher than older test takers and that scores increase slightly as the level of education increases (Likert & Quasha, 1995). Ages of the MU students were not allowed to be included in the demographic data, but educational background for all sites was attainable.

MU classes consisted of both undergraduates, who began the program in their junior year, and older graduate students. The other sites all had students with either a two – year AS or AAS degree, or a bachelor’s degree. Since ages for all participants could not be obtained, educational background was the only other obtainable student demographic. For this study, educational background was defined as the student having, or not having, a bachelor’s degree prior to participating in the study. Data provided by the four study sites were imported into IBM SPSS Statistics Version 19 (2010) and analyzed according to the demands of each of the following research questions.

Question 1: What is the range of the spatial and scanning ability test scores amongst the sonography students from the four sites? I am interested to see the range of spatial ability of all participants to see if the sonography classes were “homogenized” by selecting students who all may have similar spatial abilities through the screening procedures done by the admissions committees. As in the exploratory study, I am studying whether or not low spatial ability students are being “weeded out” during the admissions process.

For the quantitative analysis of this question, I utilized descriptive statistics, histograms, and one-way ANOVA’s to explore the range of spatial ability before beginning lab instruction, and scanning ability for both times of measure (Hegarty, Keehner, Khooshabeth & Montello, 2009). Individual percentile normative comparisons were made according to information provided in the RMPFBT manual (Likert and Quasha, pp. 23-30).

Question 2: What is the relationship between spatial ability and learning sonographic scanning? Using bivariate correlation analysis, the students’ spatial test scores were compared to their scanning competency scores in the four categories. Simple regression with one independent variable was used which correlated the spatial test scores with the scanning scores in the four categories. Then, multiple regression analysis was performed in analyzing spatial and scanning scores with the additional student demographic information. A strong correlation was expected between the scanning scores and the spatial test scores in the initial stages of learning, which for this

study was after 30 hours of lab instruction. The two - semester averaged scores may or may not be as strong.

Question 3: Does spatial ability improve throughout the two semester learning period? Each category was again analyzed, this time using a repeated measures dependent –means  $t$  –test. Hegarty, Keehner, Khooshabeh, and Montello (2007) studied this question amongst dental students and found no improvement in spatial abilities over a two year learning period. It will be interesting to see if this is also the case in learning an imaging skill, such as sonography.

Question 4: Is spatial ability a predictor for student retention? Binary logistical regression analysis was used for this question. No previous studies in the medical domain could be found researching this question, but there have been studies performed on students in engineering regarding student retention. One study found that by using various interventional methods for improving spatial ability for students in an engineering graphics course, academic performance improved with pass rates increasing from 64% to 76% annually (Potter & van der Merwe, 2001). Interventional practices included remedial activities involving modeling, copying, sketching and drawing, which were organized in a series of exercises in a workbook designed by the authors (p.2). Their measure of retention was student enrollment from one academic year to the next. In this study, retention is defined as the student as having stayed or dropped out of the sonography program before the end of this study.

## Reliability, Statistical Power, and Validity

### *Reliability*

Reliability refers to whether or not the results can be interpreted consistently over different situations (Field, p.11). Sample data from a population are always subject to error. There is always a chance that data derived from a sample population will not be representative of the general population, since there is never a final account of all possible data. Therefore, researchers cannot be absolutely sure that their theory or hypothesis is true or false. In light of this concern, the expanded study increased the N to 79, initially; up from 17 participants used in the exploratory study, and drew the sample from four very different learning situations. For the analysis of question one, this enhancement provided a more broad and diverse sample, and was more reflective of the general population of sonography students nationally.

### *Statistical Power*

The power of a statistical test is the probability that the test will reject the null hypothesis when the null hypothesis is false, or will not make a type II error (Field, 2009). As the power increases, the chance of making a type II (false negative) error decreases. Statistical power may depend on many factors, but usually is influenced by three main factors: the statistical significance or criterion used in the test (usually either .01 or .05); the effect size, or the measure of the strength of the relationship between the two variables in the population (Pearson's R); and the sample size.

Power analysis can be done either before (*a priori*), or after (*post hoc*) the data are collected. *A priori* is used to estimate the sufficient sample sizes to achieve an

acceptable statistical power of at least .80. Post hoc analysis is used after the data collected and the study completed to determine what the power was in the study. The most common way to increase the statistical power of a study is to increase the sample size. The expanded study increases the sample size to include 73 participants, thereby increasing the a priori statistical power to .99. The exploratory study's N of 17 yielded a post hoc statistical power of .78. The expanded study will obviously reduce the chance of making a type II error. In essence, the sensitivity of the study is greatly enhanced.

### *Validity*

Validity is defined as to whether or not an instrument actually measures what it states it measures (Field, p. 11). Construct validity for the RMPFBT for the independent variable was discussed earlier in this chapter and is stated as being .75 for measuring spatial ability. Criterion validity, or whether the RMPFBT is appropriate for measuring spatial ability for the field of sonography, has not been established.

The dependent variable instrument of measure, or the SCAN, has also been discussed previously in this chapter. No established values of validity for the SCAN have been established.

### Limitations

The expanded study addresses several limitations of the exploratory study. It will be a more sensitive study through increasing the sample to where N=73. Also, through inclusion of the community colleges and proprietary school participants, a broader, more representative sample of the general student population will be enhance the ability to generalize the results. Finally, in the exploratory study, it was necessary to

combine two different classes, the abdominal students and the cardiac students, to gain an acceptable N of 17 to reach an acceptable statistical power near .80. Two different classes, having two different instructors each teaching different subjects with differing number of tests and subjectivity in grading, were also limitations to the exploratory study. The expanded study alleviates this limitation by utilizing same specialty classes of abdominal students taught by one instructor at each site.

As with the exploratory study, however, there some limitations to this study. The test only looks at spatial ability, which can be masked by other variables such as poor hand-eye coordination or psycho-motor skills. Perhaps even the effect of having a high cognitive load during the initial learning stage of skill acquisition, as described by Ackerman's theory of skill acquisition could have masked the SCAN performance scores of even the high spatial ability learners.

Class sizes of the sites other than MWU were under 15, which affected the statistical power of the analysis by site. ACCC and PS had class sizes of 11, and MWCC had a class size of only 8. One cannot, therefore, generalize the analyses within the category by site to the general population specific to each school, such as to all community colleges or all proprietary schools, because of this.

### Summary

The present study is an expanded version of the exploratory study, which provided the framework and empirical evidence that a relationship does exist between a student's spatial ability and learning to scan sonographic images. By incorporating multiple sites, the number of participants was increased, and also broadened the

demographic nature of the sample, which better reflected the general population of beginning sonography students in the U.S.

Utilizing analytical techniques such as descriptive statistics, histograms, one way ANOVA's, simple and multiple regressions, bivariate correlations, and logistical regression analysis enhanced the overall analysis of the study. Breaking down and analyzing the sample into the four categories of overall, by site, by gender, and educational background further enhanced the analysis of the study.

The first question was expanded to include the range of scanning scores along with the range of spatial test scores of the participants. The addition of a third research question required re-administering the RMPFBT after the instructional time period, and explored whether or not spatial ability improved. A fourth question was added also, which looked at the possible relationship between spatial ability and student retention. Finally, the exploratory study's results needed further re-examination and validation. These elaborations to the exploratory study's design greatly enhanced the analysis of the relationship between spatial ability and sonography. The results from the study are presented in Chapter Four.



## Chapter Four

### RESULTS

#### Introduction

In this study, 79 beginning sonography students studying abdominal ultrasound from the four sites mentioned in Chapter Three were initially consented to participate in the study. Six dropped out after completing the pre instructional RMPFBT – five from MWCC, and one from ACCC, leaving 73 total participants for the rest of the study, including 11 of the students from the exploratory study (MWU1).

The six drop outs, who were all female undergraduates, did not complete any scanning competencies, but their spatial test scores were retained in the study for some of the analysis in questions one and four. Categories analyzed included overall, by site, by sex, and by educational background. The sites were chosen to represent the various types of educational institutions where sonography programs in the U.S. are found.

Three classes of MU students (N = 43) represented about 59% of the total number of study participants for questions one and four. ACCC and MWCC admit students with at least a 2 year degree and offer certificates in diagnostic medical ultrasound. Representing the community college category by site, together they represented about 25% of the study's total sample. The PS, representing the proprietary schools within the site category, also only admits those students with at least a 2 year degree into their sonography program. They had 11 students participate, which represented about 15% of the total sample. Table 3 summarizes the demographics of the remaining 73 students from the four sites (does not include the six drop outs). The

“BS” category indicates those students having completed a bachelor’s degree before starting the sonography program.

Table 3  
*Student Demographic Information by Site*

Site	Male	Female	BS	No BS	Total	% Total
MWU1	2	9	0	11	11	15
MWU2	3	10	4	9	13	18
MWU3	2	17	5	14	19	26
MWCC	0	11	2	9	11	15
ACCC	2	6	4	4	8	11
PS	2	9	10	1	11	15
<b>Totals</b>	11	62	25	48	73	100%

Question one utilized descriptive statistics, histograms, and one - way ANOVAs in the analysis of the range of spatial ability of the beginning sonography students. The second question analyzed the range of scanning abilities for both times of measure - after the first thirty hours, and then the two semester average of the SCAN scores. Then, bivariate correlation, as well as simple and multiple regression analyses for the four categories was used in analyzing how the spatial ability scores related to the scanning scores, also for both times of measure. ACT scores and incoming GPA data were available for the three MU classes and thus were added to the analysis. The other sites were not open to providing that information.

Question three asked whether or not spatial ability improved throughout the 2 semester learning period. Each category was analyzed using a repeated measures dependent-means *t*-test, along with histogram skew and kurtosis analysis. Finally, question four, which asked if the student’s level of spatial ability was a predictor for student retention in the sonography program, was analyzed using binary logistical

regression. Results for each of the four research questions are presented and discussed below.

### Question One

*What is the range of spatial ability of beginning sonography students?*

To answer question one, descriptive statistics and histogram graphs, and a one way ANOVA were produced and analyzed for each category. The analysis of the spatial test scores for all 79 consented participants who completed the initial RMPFBT of spatial ability prior to lab instruction included participants from the exploratory study (MWU1) and MWU2. Notice that even with all of the pre-screening criteria that admission committees require of applicants, such as incoming GPA, SAT/ACT scores, and interviews, a wide range of spatial ability existed amongst the beginning sonography students. While admitted students have to meet certain thresholds of admission standards for those criteria, students with low spatial ability are being admitted along with students of high spatial ability. The descriptive statistics for the original 79 participants are provided in Table 4 and in the histogram in Figure 3.

Table 4

*Descriptive Statistics for 79 Pre Spatial Test Scores*

Measure	N	Mean	St. Dev	Minimum	Maximum
Pre Spatial All	79	47.76	8.168	28	64

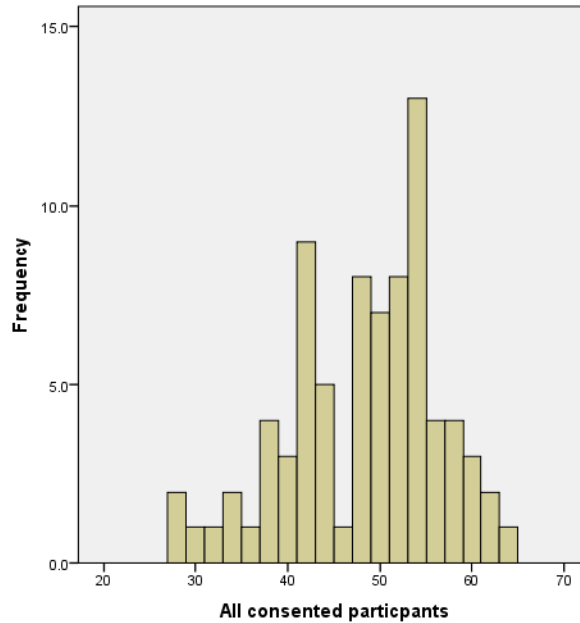


Figure 3. Histogram for the initial spatial test scores for all 79 consented participants.

When evaluating a histogram, measures of skewness and kurtosis are important in determining whether normal distribution is evident in the sample frequency distribution. Normal distribution means that the sample reflects reality, whereby the majority of scores lie around the center of the distribution, and is characterized by a bell shaped curve. Skewness can be defined as the measure of the symmetry of a frequency distribution. Kurtosis is defined as a measure of the degree to which the scores cluster in the tails of a distribution (Field, 2009, p.139).

Converting these measures into z-scores allows for comparing the skew and kurtosis values against values that can be gotten by chance alone. To convert to a z score, simply divide the skew or kurtosis by its standard deviation. An absolute value greater than 1.96 is significant at  $p < .05$ , greater than 2.58 is significant at  $p < .01$ , and greater than 3.29 are significant at  $p < .001$ . The value (or z-score) for this sample's

distribution for skew was -1.84, and the value for kurtosis was -.422, both of which are less than the absolute value of 1.96, so they are not significant. Therefore, overall normal distribution is evident in the histogram of the spatial scores for all consented participants.

Shortly after agreeing to participate in the study, six individuals dropped out of their programs of study - five from Carl Sandburg, and one from Cape Fear, leaving 73 total participants. It is important to have enough participants in the study to be able to generalize the results from a sample to the general population – in this case, to all sonography students. The descriptive analyses shown below in Table 5 and the histogram in Figure 4 reveal that for the remaining 73 participants, a normal frequency distribution is evident with even less positive skew to the right. The z value of skew (-1.47) and kurtosis (-.580) are insignificant. Essentially, the results are very similar to results above, with the 73 participants still generating a statistical power over .80. The expanded study’s raw scores ranged from 28 to 64, which corresponded to a range from the 10<sup>th</sup> to 99<sup>th</sup> percentile, where N = 73.

Table 5  
*Descriptive Statistics for 73 Pre Spatial Test Scores*

Measure	N	Mean	St. Dev.	Minimum	Maximum
Pre Spatial All	73	47.47	8.345	28	64

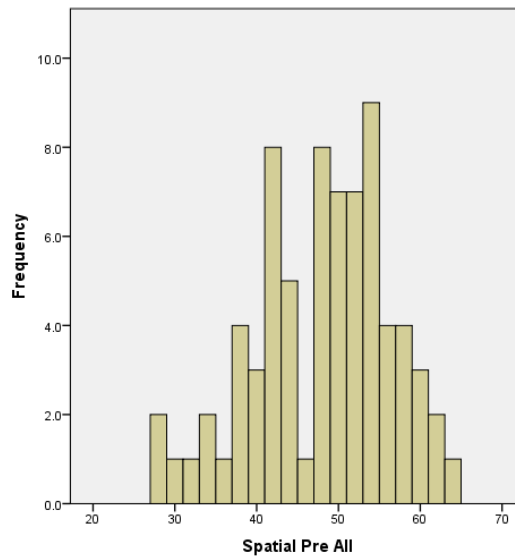


Figure 4. Histogram for pre spatial test scores for the remaining 73 study participants.

#### Pre Spatial Range by Site

Table 6 shows the results of the descriptive statistics for the pre spatial test scores of the remaining 73 participants by site before initiating lab instruction. The first year MWU students (MWU1), who were the 11 abdominal students who participated in the exploratory study, as well as MWU2, have been included in the results for comparison to each other, and to the other sites. The four sites represent very different learning situations and have different student body demographics, as was previously discussed in Chapter Three, so differences between the mean spatial test scores should be expected.

Table 6  
*Descriptive Statistics for Pre Spatial Test Scores by Site*

Measure	N	Mean	St. Dev.	Minimum	Maximum
MWU1	11	44.55	5.429	34	52
MWU2	13	48.08	5.722	39	57
MWU3	19	51.11	7.745	34	64
ACCC	8	52.25	10.264	29	61
MWCC	11	47.18	8.424	31	58
PS	11	40.18	8.256	28	54

Notice there are marked differences between the mean spatial test scores between all sites, with Hunter having the lowest mean (40.18), and Cape Fear the highest (52.25). Mean scores for the three classes of MU students also varied between each other, but the standard deviations for all three MU classes were lower than the other sites, and are rather similar to each other. This again reflects a wider range of scores for the other sites than for the MU classes.

A one way analysis of variance (ANOVA) or an F - test was performed with site as the independent variable to see if the differences between the means of all the sites were statistically significant. Results indicated that there was a significant difference between the means of the pre spatial test scores between sites,  $F(5, 67) = 3.8, p < .05, w = .47$ . The “w” statistic is called “omega squared” and represents the effect size, similar to  $r^2$  in a regression model. A result over .50 represents a large effect size. In this case, at .47, it very nearly is (Field, p. 389).

#### Pre Spatial Range by Sex

The following are the results for the pre spatial test scores of the remaining 73 participants by gender before lab instruction are shown in Table 7 and Figure 5. The

descriptive statistics and histograms presented side by side for ease of comparison between the 11 males and 62 females.

Table 7  
*Descriptive Statistics for Spatial Pre Test Scores by Sex*

Measure	N	Mean	St. Dev.	Minimum	Maximum
Spatial Pre Female	62	47.74	8.470	28	64
Spatial Pre Male	11	46.00	7.810	34	59

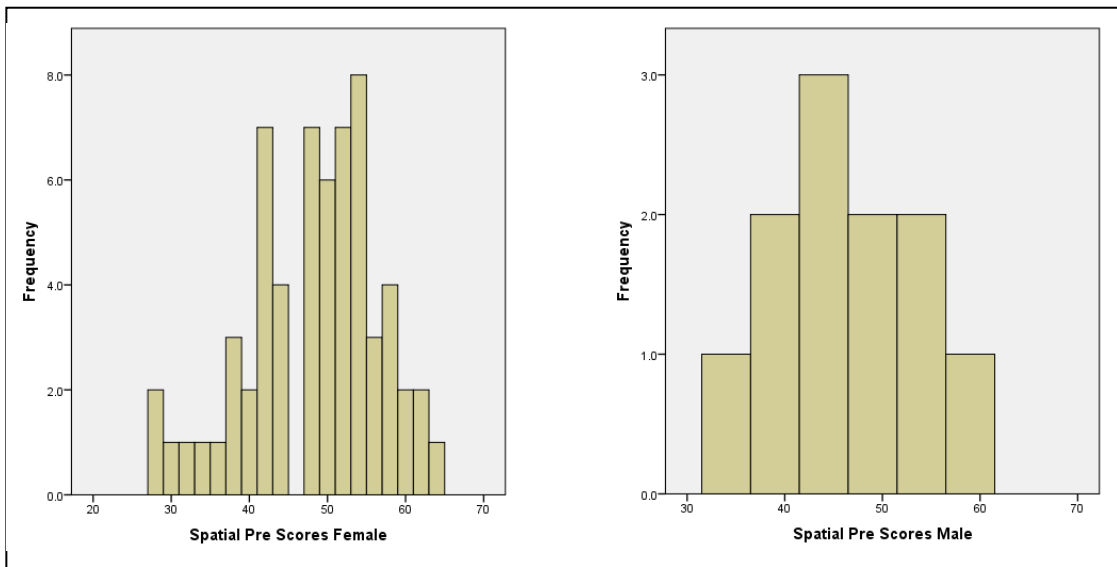


Figure 5. Histograms for the pre spatial test scores by sex.

Notice that the means and standard deviations were very similar. A one way analysis of variance (ANOVA) was performed with gender as the independent variable. There was not a significant difference between the means of pre spatial test scores between genders,  $F(1, 71) = .396, p > .05, w = .005$ . Histogram measures for skew (-1.65) and kurtosis (-.30) for the females were not significant, nor were measures of skew (.18) and kurtosis (.65) for the males, indicating normal distribution for both



sexes. These results will be compared to the post spatial test scores by sex later in question three.

#### Pre Spatial Range by Degree

Twenty five students had a bachelor’s degree and forty eight did not have a bachelor’s degree prior before lab instruction. Table 8 shows the descriptive statistics for the spatial test scores by degree. Both degree categories are included in side by side analysis for ease of comparison.

Table 8  
*Descriptive Statistics for Pre Spatial Test Scores by Degree*

Measure	N	Mean	St. Dev.	Minimum	Maximum
Spatial Pre No BS	50	48.42	7.445	31	64
Spatial Pre BS	23	45.39	9.894	28	61

The means are relatively close, as are the standard deviations. A one way analysis of variance (ANOVA) was performed with degree as the independent variable. There was no significant difference between the means of pre spatial test scores by degree,  $F(1, 71) = 2.11, p > .05, w = .03$ . Again, the  $w$  statistic indicates effect size, which for category of educational background is insignificant. Histograms are presented for each group in Figure 6.

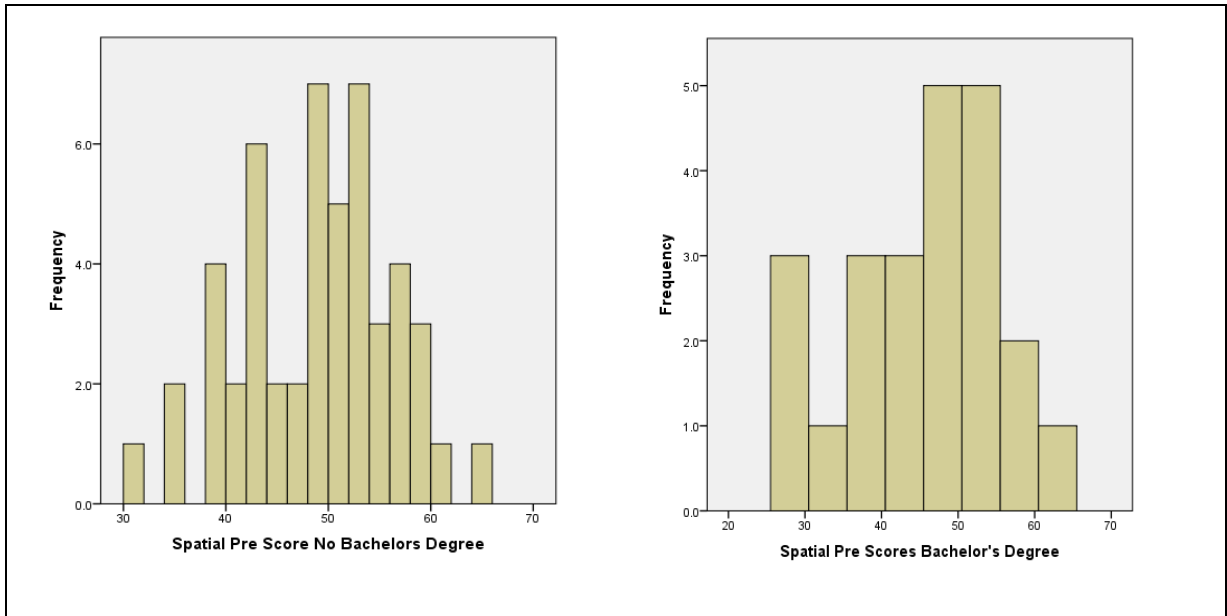


Figure 6. Histograms for spatial pre test scores by educational background.

For the no bachelor's degree category, skew was (-.85) and kurtosis was (-.50), and for those having a bachelor's degree, skew was (-.67) and kurtosis was (-.81). No values were significant, indicating both histograms show normal distribution of the spatial scores. In sum, there was no difference between the means of the spatial ability of the test scores for educational background.

### Question Two

*Is there a relationship between spatial ability and learning sonographic imaging?*

The students' scanning competency scores were recorded on their SCAN forms throughout the two-semester learning period. The following discussion describes the range of the students' scanning scores after 30 hours of instruction, and then averaging the scores over the 2 semester learning period. Then, the relationship between the spatial ability and the scanning scores is analyzed.

## SCAN Score Analysis

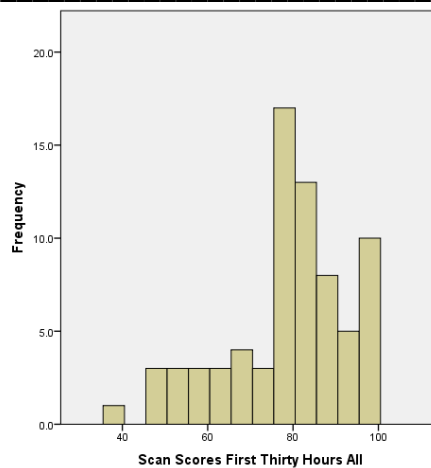
### First 30 Hours SCAN Scores

#### *Overall*

The scores of the remaining 73 students were recorded at two times of measure: after the first 30 hours of lab instruction, and then the 2 semester averaged score. The results for the remaining 73 participants after 30 hours of lab instruction are shown in Table 9 and Figure 7.

Table 9  
*Descriptive Statistics for 73 Scanning Scores after 30 Hours of Instruction*

Measure	N	Mean	St. Dev.	Minimum	Maximum
Scan 30 Hours All	73	79.15	14.707	38	100



*Figure 7.* Histogram for the scanning scores after 30 hours of instruction for the expanded study.

The scanning scores for the first 30 hours are positively skewed to the left, indicating more high scores than low. This is confirmed with a z - score value of (-2.66), which is statistically significant at  $p < .01$ . All sites report that the first scan is that of an easy anatomical structure to find. More difficult structures are scanned later as the

students gain confidence. MWU, ACCC, and PS programs all started with scanning the aorta, while MWCC states they start with the gall bladder.

*Scan Scores First 30 Hours by Site*

Table 10 shows a summary of the results for scores after 30 hours of instruction for each class by site.

Table 10  
*Summary of Descriptive Statistics for 73 Scanning Scores after 30 Hours of Instruction*

Measure	N	Mean	St. Dev.	Minimum	Maximum
MWU1	11	87.45	5.336	80	95
MWU2	13	80.23	6.220	67	89
MWU3	19	78.21	4.263	68	84
ACCC	8	96.75	4.862	86	100
MWCC	11	82.91	18.743	52	100
PS	11	54.50	9.324	38	69

In evaluating the means, again there is marked variation, with PS having the lowest mean score (54.50) and ACCC having the highest (96.75). This is consistent with the results shown in Table 6, which presented the mean pre spatial test scores by site, whereby PS had the lowest mean scanning scores.

The three MWU classes have similar results with ACCC, while MWCC and PS have much wider score ranges and larger standard deviations for both the pre spatial test scores and first 30 hour scanning test scores. A one way analysis of variance (ANOVA) was performed with site as the independent variable. There was a significant difference between the means by site,  $F(5, 67) = 24.3, p < .05, w = .64$ . Again, the omega squared value ( $w$ ) signifies a large effect has been identified.

### *Scan Scores First 30 Hours by Sex*

The results of the scanning scores after the first 30 hours of instruction by gender are presented in Table 11.

Table 11  
*Descriptive Statistics for First 30 Hours Scanning Scores by Sex*

Measure	N	Mean	St. Dev.	Minimum	Maximum
First 30 Scan Female	62	78.58	14.63	38	100
First 30 Scan Male	11	82.36	15.42	56	100

Again, scores after the first 30 hours were skewed to the left, as by site. A one way analysis of variance (ANOVA) was performed with sex as the independent variable. There was not a significant difference between the means by gender,  $F(1, 71) = 1.209$ ,  $p > .05$ ,  $w = .01$ .

### *Scan Scores First 30 Hours by Degree*

The results for the first 30 hours of scanning by degree are shown in Table 12.

Table 12  
*Descriptive Statistics for First 30 Hours Scanning Scores by Degree*

Measure	N	Mean	St. Dev.	Minimum	Maximum
First 30 No BS	50	82.00	12.005	49	100
First 30 BS	23	71.65	17.65	38	100

A one way analysis of variance (ANOVA) was performed with degree as the independent variable. There was not a significant difference between the means by degree,  $F(1, 71) = 9.796$ ,  $p > .05$ ,  $w = .12$ .

## Two Semester Averaged Scan Scores

### *Overall*

A second time of measurement for the student's scanning score was that of averaging all scanning scores for each participant over the two semester learning period for the remaining 73 study participants. The results are show in Table 13 and Figure 8.

Table 13  
*Descriptive Statistics for 73 Two - Semester Averaged Scores*

Measure	N	Mean	St. Dev.	Minimum	Maximum
Two Semester Ave All	73	80.86	11.426	46	99

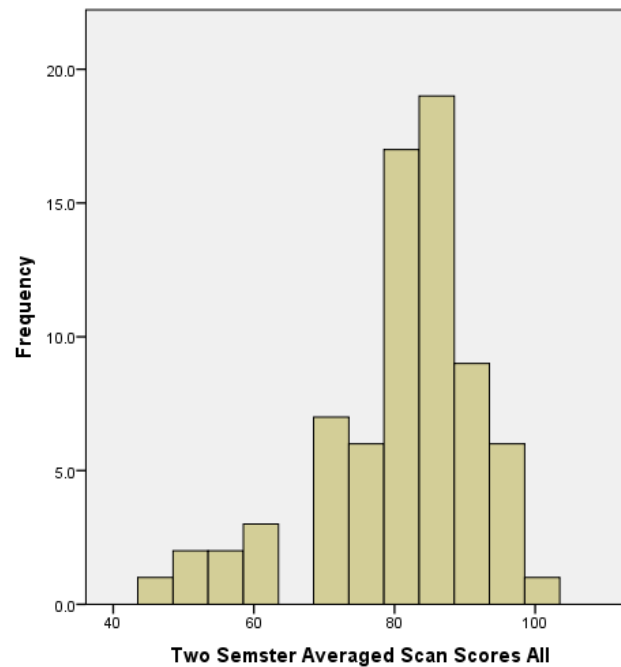


Figure 8. Histogram for 2 semester averaged scan scores for the 73 participants.

Measuring for skewness results in a (-.92) z-value, while measuring for kurtosis results in a (2.18) z-value. The results are not significant for skewness, but are significant at  $p < .05$  for kurtosis. The positive value of Kurtosis (2.18) indicates a pointy and heavy

tailed distribution. Normal distribution requires that both skew and kurtosis be less than 1.96. Another test for normality is called the Kolmogorov-Smirnov test, or K-S test. The results of the K-S test indicate a statistical significance of (.000). Since the value is less than .05, it means that the distribution of the two semester averaged scan scores is not a normal distribution.

*Two Semester Averaged SCAN Scores by Site*

Table 14 presents a summary of the 2 semester averaged scan scores by site for the 73 participants.

Table 14  
*Summary by Site of Descriptive Statistics for 73 Two - Semester Averaged Scan Scores*

Measure	N	Mean	St. Dev.	Minimum	Maximum
MWU1	11	87.45	5.336	80	95
MWU2	13	80.23	6.220	67	89
MWU3	19	78.21	4.263	68	84
ACCC	8	96.75	4.862	86	100
MWCC	11	80.33	17.726	49	99
PS	11	64.36	9.469	46	77

As shown in Table 14, once again, the scores for MWCC and PS students showed the widest score range and largest standard deviations. A one way analysis of variance (ANOVA) was performed with site as the independent variable. There was a significant difference between the means of the 2 semester averaged scanning test scores between sites,  $F(5, 67) = 12.31, p < .05, w = .48$ . A comparison of the overall scanning scores after the first 30 hours of instruction and for the 2 semester averaged scores is shown in Figure 9.

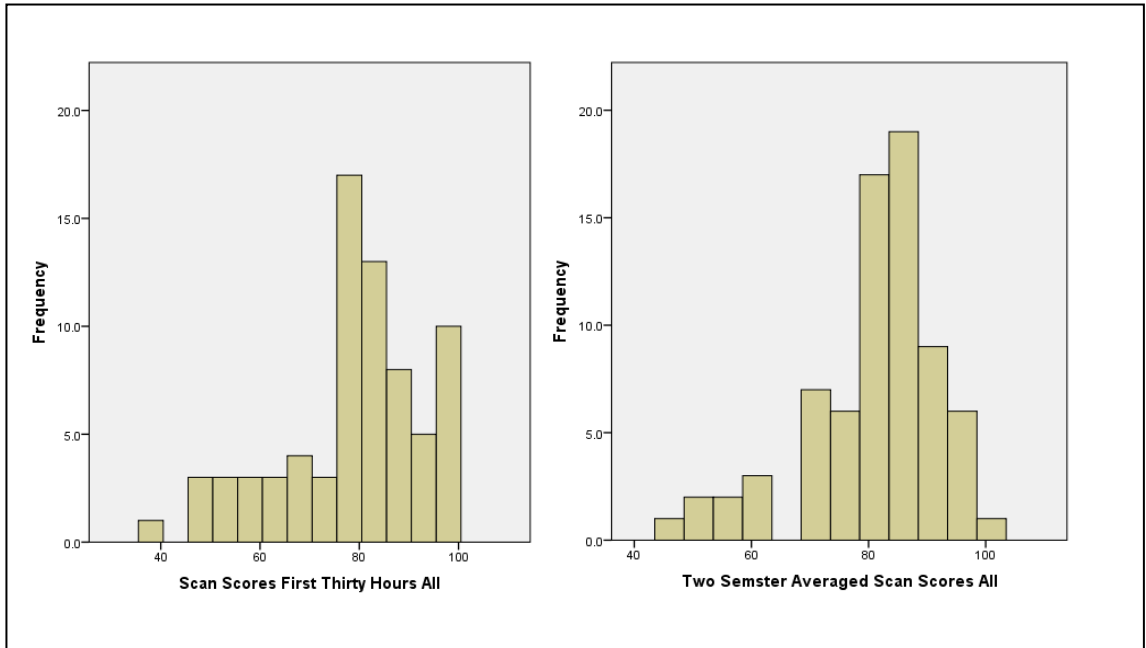


Figure 9. Comparison of the 2 times of measure for the scanning scores.

Notice that the positive skew to the left is less for the 2 semester averaged time of measure than for the first 30 hours. All sites reported that the scanning competencies start with the easiest first, then progress to more difficult scans throughout the semester, with the most difficult scans being last. This may account for the “normalization” of the histogram when averaging the scores over two semesters. As stated above, the skew of the histogram was significant for the first 30 hours, but became insignificant for the two semester averaged measure. The measure of kurtosis remained significant for both, which is how the scores bunch up at the tails of the histograms-but much less so for the two semester averaged time of measure.

*Two Semester Scan Scores by Sex*

The following results in Table 15 are the descriptive statistics for the 2 semester averaged scanning scores by sex.



Table 15  
*Descriptive Statistics for First Thirty Hours Scanning Scores by Sex*

Measure	N	Mean	St. Dev.	Minimum	Maximum
Two Sem Ave Scan Female	62	80.84	11.93	43	99
Two Sem Ave Scan Male	11	81.00	8.47	69	98

A one way analysis of variance (ANOVA) was performed with sex as the independent variable. There was not a significant difference between the means by gender,  $F(1, 71) = .002, p > .05, w = .000$ . While females greatly outnumbered the males, females had a larger range of scanning scores compared to the males, and a larger standard deviation.

*Two Semester SCAN Scores by Degree*

The results of the descriptive statistics for 2 semester average of scanning scores by degree are presented in Table 16.

Table 16  
*Descriptive Statistics for Two Semester Averaged Scanning Scores by Degree*

Measure	N	Mean	St. Dev.	Minimum	Maximum
Two Sem Ave Scan No BS	50	83.04	10.10	49	99
Two Sem Ave Scan BS	23	76.13	12.88	46	98

A one way analysis of variance (ANOVA) was performed with degree as the independent variable. While range and standard deviation were similar, there was a significant difference between the means by degree,  $F(1, 71) = 6.174 p < .05, w = .08$ .

In sum, the results from the analysis of the descriptive statistics and histograms for pre spatial test scores, for the overall categorical measures of the original 79, the remaining 73, and the 49 expanded study participants showed normal distribution in frequencies of test scores that show a wide range of spatial ability. Sites outside of MU had larger ranges of spatial test scores and had larger standard deviations. There was no statistical difference seen between the means of the spatial test scores in the categories of gender or educational background.

The descriptive statistics and histograms for the scanning score after the first 30 hours of instruction resulted in high scores overall, and at all sites, with a significant skew to the left. This may reflect the practice of the sites giving an easy scan test for the first scanning test. When averaging the scanning scores over a two semester period, the scores very nearly show normal distribution, though not quite. Differences in the scanning test mean scores by gender were not significant, but were slightly significant for degree, in which those participants with no degree had slightly higher scanning test scores than those who had a bachelor's degree.

#### Analysis of Spatial and Scan Scores

##### Correlations

Bivariate correlations were performed for the remaining 73 participants. Their pre-instructional spatial test scores were compared to their first thirty hours SCAN scores, and then to their 2 semester averaged SCAN scores. A bivariate correlation is a measure of the relationship between two variables, in this case, between the independent variable of the student's pre spatial test scores and the dependent variable

of their scanning scores at two times of measure. Table 17 shows the results of the correlations.

Table 17  
*Correlations between Pre - Spatial Test Scores and the Two Times of Measurements*

Site/Category	(n)	First 30 Hours	2 Semester Averaged
All Students	73	.46**	.49**
MWU1	11	.07	.43
MWU2	13	.11	.60*
MWU3	19	.42	.29
ACCC	8	.90**	.69
MWCC	11	.42	.44
PS	11	.64*	.51
Female	62	.47**	.49**
Male	11	.42	.50
Degree-No BS	50	.53**	.31*
Degree-BS	23	.46**	.66**

Not significant ( $p > .05$ ), Significant = \*  $p < .05$ , \*\*  $p < .01$

The exploratory study found that after the first 30 hours of instruction, a weak correlation of .20 was found, and the 2 semester averaged correlation was a strong .60. The weak initial correlation did not fit the expectations of Ackerman's theory of skill acquisition which predicted a strong correlation. The strong correlation (.60) after practice and instruction coincides with the studies noted in Chapter Two which found continued strong spatial correlations throughout the learning period.

The expanded study repeated the same procedure as in the exploratory study. The pre spatial test scores were again correlated to the scanning competency scores at the same two times of measure – after thirty hours of instruction, and then the 2 semester averaged scores. As noted in previously in Table 17, the first 30 hours correlation was a moderate .46, and the two semester averaged scores a slightly

stronger .49 for the overall category of 73 participants. Both findings were statistically significant at  $p < .01$ .

The expanded study's finding is comparable to the findings of the exploratory study in that there was an increase in correlations from the two times of measure. For the first 30 hours time of measure, the exploratory study found a .20 correlation, whereas the expanded study found a .46 correlation. For the 2 semester averaged time of measure, the exploratory study found a .60 correlation, whereas the expanded study found a .49 correlation. This result may suggest that spatial ability is important in all three learning stages for acquiring skills specific to sonographic scanning. A further discussion of these findings will be presented later in Chapter Five.

While the overall findings of the expanded study remain somewhat consistent with the exploratory study's results, when breaking down the analysis by site, the results become very inconsistent. MWU1 and MWU2 show marked increases in the strengths of the correlations between the two times of measure, while MWU3, ACCC and PS showed a decrease in the strength of the correlations. Females and males both showed a slight increase in the strength of the correlations. By contrast, those not having a bachelor's degree showed a marked decrease in the strength of the correlations from the two times of measure, while those having a bachelor's degree showed a marked increase. Statistically significant results for both times of measure were found for overall, female, and educational background categories.

## Simple Regression Analysis

### *After First 30 Hours*

Simple regressions and scatter-plot graphs were performed for the spatial test scores and the two times of measurement. For the first thirty hour time of measurements, Pearson  $r = .46$ , and  $r^2 = .21$ . A scatter-plot graph for the first 30 hours time of measurement is shown in Figure 10.

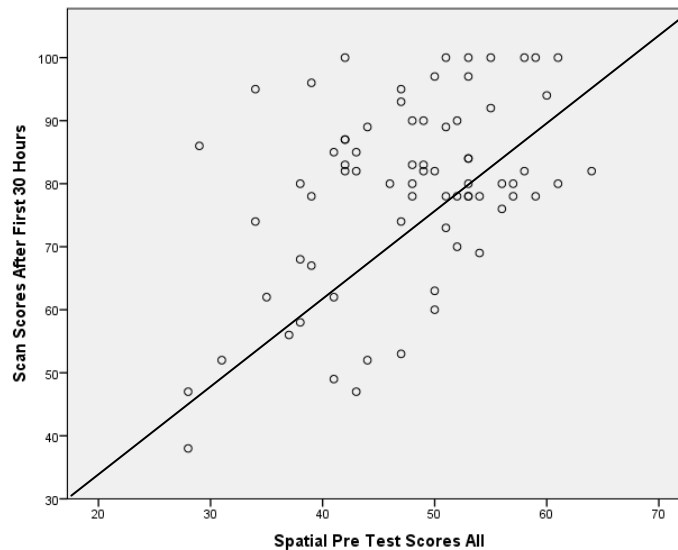


Figure 10. Scatter plot graph after 30 hours of lab instruction.

### *Two Semester Averaged*

Regression analysis was done to assess the linearity of the results to the regression model. With a Pearson  $r$  correlation of  $.46$ , this indicates a moderate effect. The coefficient of determination, or  $r^2$ , of  $.21$  indicates that about 21% of the variance in the scanning competency scores can be attributed the spatial test scores. For the two - semester averaged time of measurement, Pearson  $r = .49$ , and  $r^2 = .23$ . A scatter-plot graph for this time of measure is shown in Figure 11.

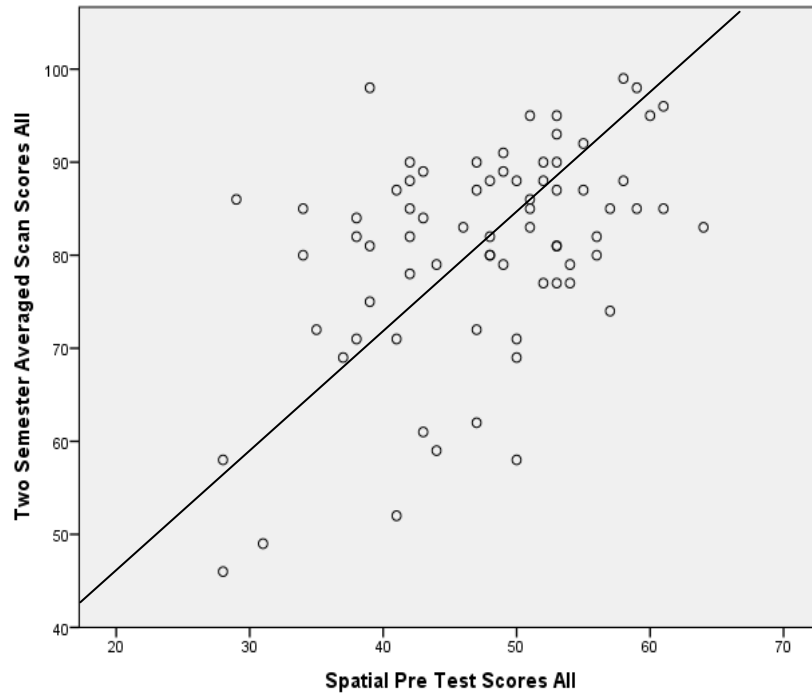


Figure 11. Scatter plot graph for 2 semester averaged measure of lab instruction.

#### Multiple Regression Analysis

Multiple regression analysis was performed for both times of measure for each of the designated categories. For multiple regression, there are several categories being analyzed in this study – overall, gender, degree and site - and a similar equation is derived in which each predictor has its own coefficient (see column *B* in Table 18).

*First 30 Hours*

Table 18  
*Multiple Regression Analysis for N = 73 First 30 Hours SCAN*

Variable	<i>B</i>	<i>SE B</i>	$\beta$
(Constant)	57.91	7.61	
Male or Female	-4.01	2.90	-.10
BS or No BS	1.32	2.60	.04
MWU1	12.31	3.42	.30*
MWU2	2.85	3.10	.08
ACCC	17.12	3.64	.37*
MWCC	7.04	3.28	.17
PS	-19.70	3.88	-.48
Spatial Pre Scores	.46	.14	.26*

Note:  $r = .46$ ,  $r^2 = .21$  for Spatial Pre First 30 Hours Scores All. \*  $p < .05$ .

The numbers in column *B* are the unstandardized coefficients for the respective predictor variable. This number reflects the slope, or gradient, of the regression line and the strength of the relationship between the predictor and the outcome variable. For example, the pre spatial test scores' *B* value is .46. Because it is a positive number, this means there is a positive relationship between the spatial test scores and the scanning scores. As spatial test scores increase, the scanning test scores also increase. The value of .68 also indicates that as spatial test scores increase by one unit, scanning test scores increase by .46 units, or in this case, .46 of one point of the score.

The second number to interpret is the *SE B* value, or standard error. The standard error values are used to determine whether or not the *B* value, or slope coefficient differs significantly from zero, or horizontal. The number is used in deriving the t-statistic for significance of whether the slope is different from horizontal. This

significance is indicated by an asterisk for the spatial test scores and site categories. In Table 19, the pre spatial test scores and site categories had statistically significant results.

The third number to interpret is the  $\beta$  value, or standardized beta value. This number tells us the number of standard deviations that the outcome will change as a result of one standard deviation change in the predictor variable. For the pre spatial test scores then, the  $\beta$  value of .26 indicates that as the spatial scores increase by one standard deviation (8.35), the scanning scores increase by .26 standard deviations. The standard deviation for scanning scores was 14.71. Multiplying 14.71 by .26 results in a 3.82 score increase in the scanning scores. Only the overall and site categories were statistically significant. MWU3 was dropped due to multi-collinearity. All of the coefficients for the sites are interpreted as a difference from the MWU3 site.

#### *Two-Semester Averaged SCAN Scores*

Table 19 shows the multiple regression results for the two - semester averaged scores. When controlling for the various site categories, spatial pre scores were statistically significant, and slightly stronger than for the first time of measure.



Table 19

*Multiple Regression Analysis for N = 73 Two - Semester Average SCAN scores*

Variable	<i>B</i>	<i>SE B</i>	$\beta$
(Constant)	58.62	7.25	
Male or Female	.12	2.76	.00
BS or No BS	.63	2.48	.03
MWU1	8.79	3.26	.28
MWU2	3.04	2.95	.10
ACCC	10.93	3.47	.30
MWCC	1.51	3.12	.05
PS	-12.27	3.70	-.39
Spatial Pre Scores	.43	.13	.32*

Note:  $r = .49$ ,  $r^2 = .23$  for Spatial Pre Two Semester Averaged Scan Scores All. \*  $p < .05$ .

*Multiple Regression Results for MWU Scan Scores*

MWU Analysis

The multiple regression results for the three classes of MWU participants (MWU1-3) after first 30 hours SCAN scores of instruction are shown in Table 20, and then the two semesters averaged SCAN scores are shown in Table 21. None of the results were statistically significant. Since the overall category was statistically significant, the results indicate that the data from the other sites contributed more significantly than the MWU data.

Table 20  
*Multiple Regression Analysis for First Thirty Hours SCAN Scores MWU1-3*

Variable	<i>B</i>	<i>SE B</i>	$\beta$
Spatial Pre Scores MWU1-3	0.03	0.15	.03
Gender	-4.67	2.82	-.28
Degree	-3.06	2.43	-.20

Table 21  
*Multiple Regression Analysis for Two - Semester Averaged SCAN Scores MWU1-3*

Variable	<i>B</i>	<i>SE B</i>	$\beta$
Spatial Pre Scores MWU1-3	0.06	0.11	.10
Gender	0.86	2.07	.07
Degree	-3.53	1.78	-.31

*Multiple Regression Comparing Spatial, ACT, and GPA Data for MWU1-3*

Demographic information for age of participants was not available for MWU, and complete data for ACT scores and incoming GPA was not available from the sites other than MWU. Therefore, only the three MWU classes who supplied spatial test scores, ACT or GRE scores, and incoming GPA could be analyzed to compare which variable was more predictive of the scanning scores.

The following are results from multiple regression analysis for MWU1-3 undergraduates for first thirty hours SCAN scores in Table 22, and then 2 semester averaged SCAN scores in Table 23, comparing the means between their spatial test scores, their ACT scores, and their incoming grade point average (GPA).

Table 22  
*Multiple Regression Analysis for First Thirty Hours SCAN Scores MWU1-3 Undergraduates*

Variable	<i>B</i>	<i>SE B</i>	$\beta$
Spatial Pre Scores MWU1-3 undergrad	-0.14	0.15	-.17
MWU Undergrad ACT Score	0.12	0.26	.09
Undergrad Incoming GPA	2.05	3.91	.10

Table 23  
*Multiple Regression Analysis for Two Semester Averaged SCAN Scores MWU1-3 Undergraduates*

Variable	<i>B</i>	<i>SE B</i>	$\beta$
Spatial Pre Scores MUY1-3 undergrad	0.03	0.08	.06
MWU Undergrad ACT Score	0.08	0.14	-.10
Undergrad Incoming GPA	5.41	2.07	.44*

Note:  $r = .69$ ,  $r^2 = .47$  significant for Undergraduate Incoming GPA (\* $p < .05$ ).

Notice in Table 23 that for the 2 semester averaged time of measure, a statistically significant result occurred for incoming GPA at  $p < .05$ . A “*B*” value of 5.41 indicates that as GPA increases by one unit, scanning scores increase by 5.41 units. The units for GPA (4.0, for example), are measured in tenths. These results mean that incoming GPA is a more valuable predictor of success in learning sonographic scanning than spatial test scores or ACT scores.

The following are results from multiple regression analysis for MWU1-3 graduate students for first thirty hours SCAN scores in Table 24, and then 2 semester averaged SCAN scores in Table 25. Interestingly, while GPA was the best predictor of scanning

scores for the undergraduates, GPA is also seen below as a strong predictor in comparison to GRE and spatial test scores, but was not statistically significant.

Table 24  
*Multiple Regression Analysis for First Thirty Hours SCAN Scores MWU1-3 Graduate Students as Dependent Variable*

Variable	<i>B</i>	<i>SE B</i>	$\beta$
Spatial Pre Scores MWU1-3 Grads	-0.37	0.37	.31
MWU Grad GRE Score	0.02	0.01	.51
Grad Incoming GPA	8.09	5.62	.42

Table 25  
*Multiple Regression Analysis for Two Semester Averaged SCAN Scores MWU1-3 Graduate Students*

Variable	<i>B</i>	<i>SE B</i>	$\beta$
Spatial Pre Scores MWU1-3 Grads	0.13	0.55	.10
MWU Grad GRE Score	0.01	0.01	.34
Grads Incoming GPA	6.18	8.47	.30

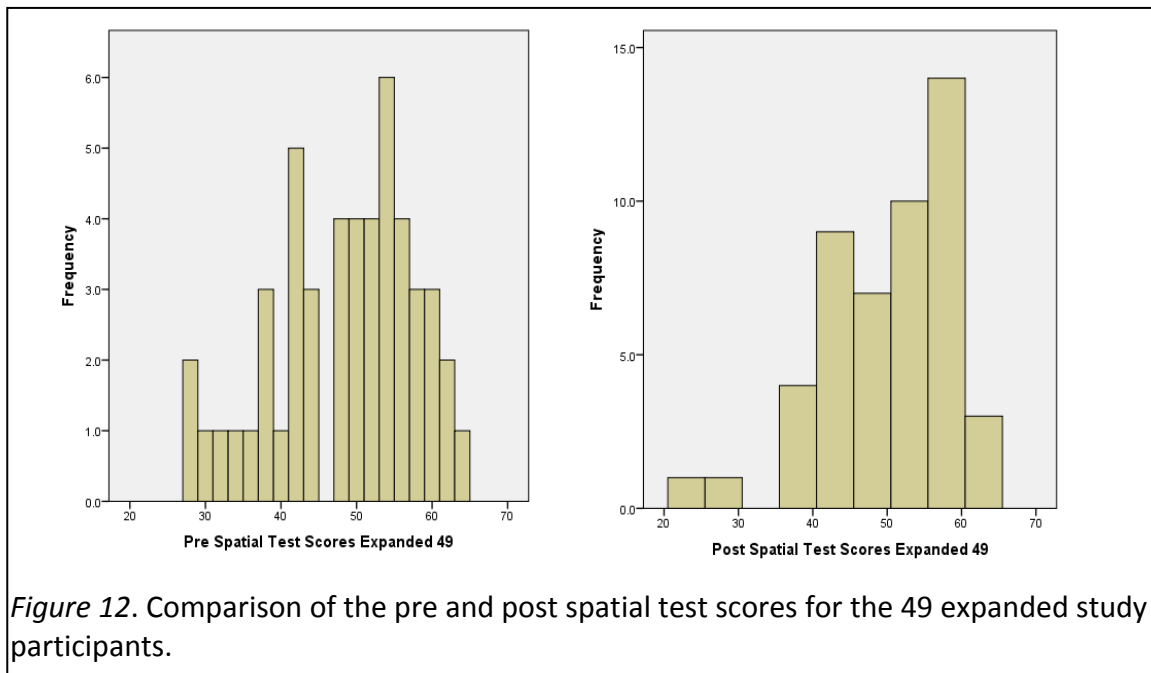
### Question Three

*Does Spatial Ability Improve Throughout the Two Semester Learning Period?*

Question three was analyzed by importing the data from the expanded study's four sites (MWU3, ACCC, MWCC, and PS) whose participants completed the pre and post spatial tests (N=49). Repeated measures dependent- *t* tests were performed for each site and category with the following results. Histograms of pre and post spatial test scores were also compared.

*Spatial Improvement Overall – (MWU3, ACCC, MWCC, PS)*

On average, participants overall (N=49) experienced a significant change in their post spatial test scores ( $M = 49.88, SE = 1.24$ ) from that of their pre spatial test scores ( $M = 47.96, SE = 1.34$ ),  $t(48) = -2.31, p < .05, r = .32$ . See Figure 12 for histograms of the pre and post spatial test scores for the 49 expanded study participants.



The histogram in Figure 12 for the pre spatial test scores for the overall category of 49 participants shows normal distribution, with insignificant values of skew (-1.50) and kurtosis (-.814), which are  $< 1.96$ . By contrast, the histogram for the post spatial test scores shows a leftward negative skew of -3.03, significant at  $p < .01$ , with the value of kurtosis (1.80) being insignificant. The  $t$  - value of -2.31 can be converted to an  $r$  - value, or effect size, of .32 (Field, 2009, p.332),  $p < .05$ , which indicates a moderate improvement in spatial ability for the expanded study participants.

While results of the combined data from all sites indicated a moderate improvement of the students' spatial ability, when analyzing the data by site, no individual site shows improvement that is statistically significant. Each site, except for MWU3, had a small number of participants, well under the usually acceptable number of 15 for statistical evaluation. When aggregated together, the analysis becomes clearer.

#### *Spatial Improvement by Site*

##### Midwestern University (MWU3)

On average, the third year class of MWU students (N=19) who participated in the expanded study (MUY1-3) did not experience a significant change in their post spatial test scores ( $M = 51.11, SE = 1.78$ ) from that of their pre spatial test scores ( $M = 52.00, SE = 1.56$ ),  $t(18) = -.787, p > .05$ .

##### Atlantic Coastal Community College (ACCC)

On average, the participants from ACCC (N=8) did not experience a significant change in their post spatial test scores ( $M = 53.25, SE = 2.98$ ) from that of their pre spatial test scores ( $M = 52.25, SE = 3.63$ ),  $t(7) = -.615, p > .05$ .

##### MWCC

On average, the participants from MWCC (N=11) did not experience a significant change in their post spatial test scores ( $M = 51.64, SE = 1.42$ ) from their pre spatial test scores ( $M = 47.18, SE = 2.54$ ),  $t(10) = -.1840, p > .05$ .

## Proprietary School (PS)

On average, the participants from PS (N=11) did not experience a significant change in their post spatial test scores ( $M = 42.00$ ,  $SE = 3.29$ ) from their pre spatial test scores ( $M = 40.18$ ,  $SE = 2.49$ ),  $t(10) = -1.12$ ,  $p > .05$ .

## *Spatial Improvement by Sex*

### Female

On average, participants from all sites who were female (N=43) did not experience a significant change in their post spatial test score ( $M = 49.51$ ,  $SE = 1.33$ ) from their pre spatial test scores ( $M = 47.77$ ,  $SE = 1.46$ ),  $t(2) = -1.86$ ,  $p > .05$ .

### Male

On average, participants from all sites who were male (N=6) did experience a significant change in their post spatial test score ( $M = 52.50$ ,  $SE = 3.57$ ) from their pre spatial test scores ( $M = 49.33$ ,  $SE = 3.39$ ),  $t(2) = -3.80$ ,  $p < .05$ ,  $r = .86$ . See Figure 13 for histograms comparing the pre and post spatial test scores for the six males.

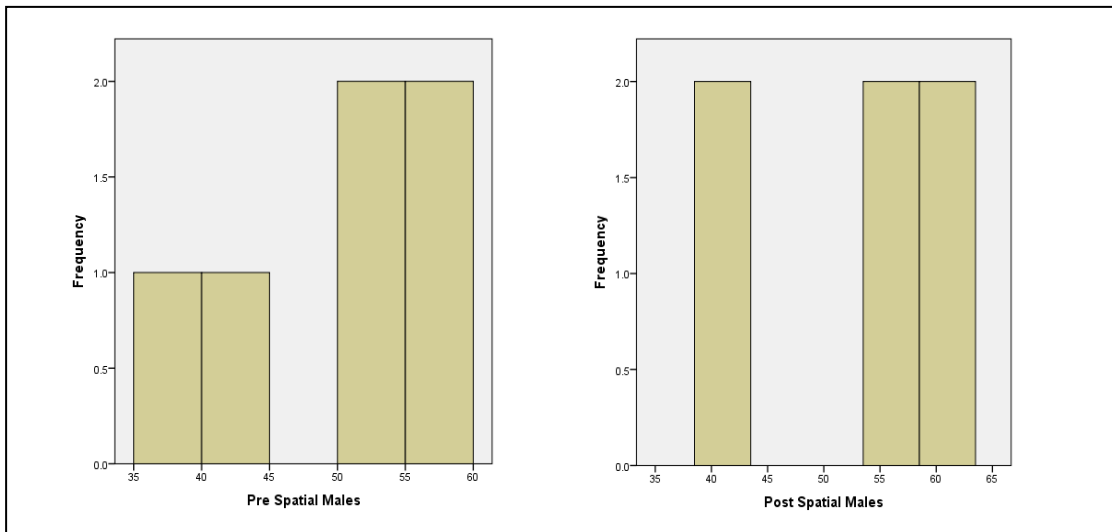


Figure 13. Comparison of the pre and post spatial test scores for expanded study males.

### *Spatial Improvement by Degree*

#### No Bachelor's Degree

On average, participants from all sites who did not have a bachelor's degree (N=30) did not experience a significant change in their post spatial test score ( $M = 51.43$ ,  $SE = 1.12$ ) from their pre spatial test scores ( $M = 49.53$ ,  $SE = 1.51$ ),  $t(29) = -1.66$ ,  $p > .05$ .

#### Bachelor's Degree

On average, participants from all sites who did have a bachelor's degree (N=19) did not experience a significant change in their post spatial test score ( $M = 47.52$ ,  $SE = 2.63$ ) from their pre spatial test scores ( $M = 45.47$ ,  $SE = 2.44$ ),  $t(8) = -1.63$ ,  $p > .05$ . Table 26 shows a summary of the results for each category.

Table 26

*Summary of Dependent t – test results for Improvement of Spatial Ability*

<b>Category</b>	<b>N</b>	<b>t value</b>	<b>Sig.</b>	<b>r</b>
Overall	49	-2.31	.025*	.32
MWU3	19	-.787	.441	
ACCC	8	-.787	.558	
MWCC	11	-1.84	.096	
PS	11	-1.12	.289	
Female	43	-1.86	.070	
Male	6	-3.80	.013*	.86
No BS	30	-1.66	.107	
BS	19	-1.63	.120	



## Question Four

*Is the student's level of spatial ability related to student retention in the sonography program?*

Question four was analyzed by importing the data from the expanded study's four sites (MWU1-3, ACCC, MWCC, and PS) that included the original 79 consented participants. MWU and PS had no drop outs, MWCC had five drop outs, and ACCC had one drop out. Binary logistical regression analysis was performed for each site and category with the following results shown in Table 27.

### *Retention Overall*

Table 27  
*Logistical Correlation between Spatial Test Scores and Drop Outs - Overall*

	B	(SE)	95% CI for Odds Ratio		
			Lower	Odds Ratio	Upper
Constant	-5.84	(0.06)			
Pre Spatial All	.07	(3.15)	.949	1.07	1.206

Note:  $R^2 = .03$  (Hosmer & Lemeshow),  $.02$  (Cox & Snell),  $.04$  (Nagelkerke). Model  $\chi^2 (1) = 1.37$ ,  $p > .05$ . Wald = 34.62,  $p > .05$ .

The B term in the table is the value for  $b_0$  in the equation that predicts the probability of Y, or the outcome (retention). The B value for the constant (-5.84) represents the Y intercept and (.07) represents the coefficient value for the X variable, or spatial score. The odds ratio represents the change in odds from an event occurring (retention) resulting from a unit change in the predictor (spatial ability). In this case, the value for the odds ratio is 1.07. Since the value is greater than 1, it indicates that as the predictor (spatial ability) increases, the odds of the outcome (retention) occurring

increases also. In this case, however, the odds of a student dropping are only 1.07 times the odds of a student staying, which is not significant (Field, 2009).

The 95% confidence interval is also reported for the odds ratio. A confidence interval is a limit constructed in which for 95% of the time, the true value of the population mean will fall within these limit of -1.96 and 1.96, which are z - scores. A “z” value is a score from a normal distribution with a mean of 0 and a standard deviation of 1 (p.45). The lower boundary is the mean minus 1.96 times the standard error, and the upper boundary is the mean plus 1.96 standard errors. For interpretation, if the interval is small, the sample mean must be very close to the true mean. In this case, the interval between .949 and 1.206 is very small, and the odds ratio fits in between.

If both upper and lower limit values are greater than one, this would indicate that as the predictor variable increases (spatial ability), then the odds of the outcome increases (retention). In this case, however, the lower limit value is less than one (.949), which means that there is a chance that the spatial ability would not be a reliable predictor of the outcome.

The Hosmer & Lemeshow  $r^2$  measure is comparable to the coefficient of determination ( $r^2$ ) in linear regression. It is calculated by dividing the model’s chi square value (1.372) by the original -2 log likelihood from the iteration history (46.957). The iteration history is the log-likelihood of the baseline model that represents the fit of the most basic model to the data. The Hosmer & Lemeshow value of .03 is not significant (.304), meaning that the predictor variable, spatial ability, is not a significant contributor

in predicting the outcome of retention. This measure, along with Cox & Snell (.017), and Nagelkerke (.041) are essentially effect size measures for the model, which are negligible.

Another number reported is the model chi square statistic ( $\chi^2$ ), which measures the difference between the model including the spatial variable and the model when only the constant is included. It is similar to an *F*-test for linear regression. Here, the chi square value is 1.372 and is not significant (.241) at the .05 level, meaning that the model with the spatial variable is not predicting the retention outcome any better than the model with just with the constant (Field, p.286).

Finally, often reported in logistical regression is the Wald statistic (p.270). This number indicates whether or not a variable is a significant predictor of the outcome. In this case, the Wald statistic for the spatial ability coefficient (.067) is 34.62, and is not significant, meaning that spatial ability is not a significant indicator for predicting retention. Tables 28 and 29 also show no correlation between spatial test scores and drop outs by site. All drop outs were female and undergraduates, so those results would be the same as by site.

*Retention by Site – only ACCC and MWCC had drop outs.*

ACCC (N=9) with one drop out.

Table 28  
*Logistical Correlation between Spatial Test Scores and Drop Outs – ACCC*

	B	(SE)	95% CI for Odds Ratio		
			Lower	Odds Ratio	Upper
Constant	-3.40	(7.52)			
Pre Spatial CF	.03	(.138)	.78	1.025	1.34

Note:  $R^2 = 1.30$  (Hosmer & Lemeshow), .004 (Cox & Snell), .008 (Nagelkerke). Model  $\chi^2(1) = .037$ ,  $p > .05$ . Wald = .033,  $p > .05$ .

MWCC (N=16) had five drop outs.

Table 29  
*Logistical Correlation between Spatial Test Scores and Drop Outs – MWCC*

	B (SE)	95% CI for Odds Ratio		
		Lower	Odds Ratio	Upper
Constant	-4.58			
Pre Spatial CS	.08	.78	1.08	1.23

Note:  $R^2 = .05$  (Hosmer & Lemeshow), .06 (Cox & Snell), .08 (Nagelkerke). Model  $\chi^2(1) = .909$ ,  $p > .05$ . Wald = .798,  $p > .05$ .

*Retention by Sex*

All drop outs for ACCC and MWCC were female, therefore, same as by site.

*Retention by Degree*

All drop outs for ACCC and Carl MWCC were undergrads, therefore, same as by site.

## Summary

### Question One

Question one utilized descriptive statistics, histograms, and one way a ANOVA to analyze the data from the four sites in exploring the range of spatial and scanning ability for the study participants. Initially, 79 students initially participated at the four sites. Then, six dropped out of their programs, leaving 73 students, which included MWU1 from the exploratory study, MWU2 -3, ACCC, MWCC, and PS.

These 73 students' data were available for pre-instructional spatial test score analysis, as well as for the two times of scanning measures – after 30 hours of instruction and with two semesters of averaged scanning scores. Four different demographical categories - overall, site, gender, and degree were considered in the analysis.

#### *Pre Spatial Scores*

Measures of skew and kurtosis of the respective histograms of the initial 79, and then the remaining 73 participants indicated that both groups exhibited normal distribution. A one way ANOVA was performed, which resulted in a moderate (.47) statistical difference between the mean scores by site. Sites other than MWU had a larger range of spatial scores than the MWU classes. Descriptive statistics and histograms were performed for the categories of gender and degree. Both categories showed normal distribution by measures of skew and kurtosis and there was no statistical difference between the means for each category.

## Question Two

Question two explored the relationship between spatial ability and learning to scan sonograms. First, the descriptive statistics and histograms for the two measures of scanning scores were utilized for analysis.

The overall frequency distribution for the range of scanning scores for the 73 participants after 30 hours of lab instruction showed marked negatively leftward skew to the left and negative kurtosis, indicating high scanning scores for the students' first scan. The one way ANOVA showed that there was a significant difference between the means by site. The ANOVA for sex and degree showed no statistical difference between the means.

The overall frequency distribution for the range of scanning scores after having been averaged over the 2 semester learning period again show a less pronounced leftward skew than the first 30 hour measure, and less pronounced negative kurtosis. Although not quite in normal distribution, the scores gravitated more toward the mean. The one way ANOVA shows that there was moderate statistical significance between the means of the 2 semester averaged scan scores by sites (.48). ANOVA analysis for sex showed no significant difference between the means, but the ANOVA analysis for degree did show a significant difference between the means by degree.

Bivariate correlations were performed for each site and category between the pre spatial test scores and the two times of measurements. For the first 30 hours time of measure, significant correlations at the .01 level were found for the overall (.46), ACCC (.90), Female (.47), and both degree categories – BS (.53), and no BS (.46).

Significance at the .05 level was found for PS (.64). For the 2 semester averaged time of measure, significant correlations at the .01 level were found for the overall (.49), female (.49), and having a BS degree (.46) categories. Significance at the .05 level was found for MWU2 (.60) and not having BS categories (.31).

Simple regressions and scatter-plot graphs were then performed for the overall categories at the two times of measure. For the first thirty hours time of measurements, Pearson  $r = .46$ , with  $r^2 = .21$ , which indicates that spatial ability accounts for 21% of the variation in scanning scores for the after the first thirty hours of instruction. For the two semester averaged time of measurement, Pearson  $r = .48$ , with  $r^2 = .23$ , indicating a slight increase in the variance (23%) accounting for spatial ability.

Multiple regression analysis was then utilized for each category with scanning scores for the two times of measurement for spatial, gender, degree, and site as independent variables for the overall 73 participants. Results showed that after 30 hours of instruction for overall, spatial and site categories were statistically significant at the .05 level. For the 2 semester averaged scores for overall, again, spatial and site categories were statistically significant. Then, for MWU1-3, undergraduate GPA scores were found to be the best predictor of scanning scores, in comparison to their ACT scores or their spatial test scores.

### Question Three

Question three explored whether or not spatial ability improved for the 49 participants in the expanded study (MWU3, ACCC, MWCC, and PS). A repeated measures dependent  $t$ -test was performed for all sites and categories. Statistically

significant results were obtained for the overall category (.03),  $r = .32$ , and males, (.01),  $r = .86$ , indicating that spatial ability did improve overall. For the six males in the study, one showed improvement, which was statistically significant.

#### Question Four

Question four explored whether or not a student's spatial ability is a predictor for student retention. Six students dropped out of their sonography program before the study was completed, but all six had taken the pre spatial test. Binary logistical analysis revealed that spatial ability was not a reliable predictor for student retention. The Wald statistic and 95% confidence interval results concurred, and measures of effect from Hosmer & Lemeshow, Cox & Snell, and Nagelkerke values were miniscule. The model chi square value was also insignificant.



## Chapter Five

### DISCUSSION OF RESULTS

#### Introduction

I have observed over years of teaching sonographic scanning that some students learn to scan more quickly than others. Anecdotally, upon observation, it seems that the ability to learn sonographic scanning does not coincide with success in didactic studies. Some students who perform very well on tests during their course of study struggle with learning to scan. Conversely, others who have struggled on testing during their coursework have learned to scan very quickly.

This quantitative study analyzed the relationship of the students' level of spatial ability and student achievement in sonographic scanning. Data gleaned from 73 students enrolled in four sonography programs, representing different educational institutions commonly found in sonography education in the U.S., were compiled and analyzed. The four sites included: A large Midwestern research university (MWU), a small Midwestern two - year college (MWCC), an Atlantic Coastal community college (ACCC), and a Northeastern proprietary school (PS). Categories analyzed included overall, site, gender, and degree background of the student participants. Incoming GPA and ACT scores also were incorporated in analyzing the three classes of MWU students.

The results of the four research questions presented in Chapter Four are summarized and discussed below, with comparisons to the exploratory study's results reported earlier in Chapter Three. Limitations of the study and implications for future research and potential institutional policy will then be presented.

## Discussion of Results

As reported in Chapter Two, similar studies on spatial ability and skill acquisition for certain medical techniques, such as learning laparoscopic surgical skills (Keehner et al, 2004; Wanzel, Hamstra, Caminiti, Anastakis & Resnick, 2003), dental skills (Evans, 2003; Risuci, 2002), and general surgery (Keehner et al, 2006; Wanzel et al, 2002), showed that those with high spatial ability learned the skill faster than others with lower spatial ability, as measured utilizing various pen and pencil spatial ability tests. They also found that with additional practice and instruction, low spatial ability learners eventually caught up in performance of the skill to the level of the high spatial ability learners. Some studies found that spatial ability remained a significant factor throughout the three phases of learning (Keehner, Lippa, Montello, Tendrick & Hegarty, 2006; Ackerman, 2007).

Each of the aforementioned researchers and research groups used a different spatial abilities test, but all agreed that having high-level spatial ability correlated strongly with high initial student achievement. To this date, the exploratory study conducted by Clem et al, (2010) remains the only study that explored the relationship between sonographic scanning and sonographic skill acquisition. This expanded study sought to validate the findings of the exploratory study. It also addressed several limitations of that study by (a) expanding the scope of the sample to include the different types of educational institutions commonly found in sonography education in the U.S., (b) increasing the sample size from 17 to 73, (c) expanding the data analysis to include four demographic categories, (d) adding a post spatial test for additional

investigation, (e) incorporating student demographic information in the analysis, and (f) exploring the relationship between spatial ability and student retention. A discussion on each of the four research questions is presented below.

*Research Question One: What is the range of spatial ability and scanning ability of the beginning sonography students?*

The exploratory study found a wide range of spatial ability amongst the 17 students. In that study, the range of RMPFBT test scores varied from a low raw score of 34, to a high of 55. Referring to the RMPFBT test manual's table of normative data for educational groups (Lickert & Quasha, 1995, p. 59), the spatial test scores ranged from the 25<sup>th</sup> to 95<sup>th</sup> percentile. The expanded study's raw scores ranged from 28 to 64, which corresponded to a range from the 10<sup>th</sup> to 99<sup>th</sup> percentile, where N = 73. ACCC had the highest mean, while PS had the lowest.

Overall, the descriptive statistics for the expanded study showed a wide range of spatial ability amongst the students, and histogram analysis revealed normal distribution for the groups of the initial 79 participants, and then for the 73 remaining expanded study participants. Sonography program admissions committees use various forms of student demographic information in selecting candidates for admission. The results suggest that even with all of the screening practices of the admissions committees who seek to find the best possible candidates by requiring such information, there remains marked differences in spatial ability amongst the beginning sonography students. In other words, there does not appear to be any "weeding out" of students with low spatial ability during the screening process.

A moderate relationship between spatial ability and learning to scan was demonstrated in both the exploratory and expanded studies. Therefore, sonography program admission committees are admitting people with low spatial ability who may be at a disadvantage in learning to scan, compared to those people with high spatial ability. If admission committees are screening for the best possible candidate, then administering a spatial ability test would be appropriate. This would be especially prudent for certificate programs, community colleges, and proprietary schools that may not have enough time built in their curriculums to allow for low spatial learners to catch up to the high spatial learners.

Bachelor degree programs such as MWU may believe that they have the time and resources to work with low spatial ability learners. These types of programs offer multiple specialties over several years of study. This allows all learners time to hone their scanning skills, and to choose which ultrasound specialty suits them best individually. In this study, MWU offered all four specialties over a span of two and half to three years of study, whereas PS, MWCC and AWCC offered only one or two ultrasound specialties over an 18 month learning period. A spatial ability test for the bachelor program may be better utilized to identify low spatial learners in order to individualize their course of study and allow them extra practice and instruction.

#### Sex and Degree Categories: RMPFBT Scores

It is well documented in the literature that, overall, males perform better on most visual-spatial tests than females (Halpern, 1986, in Likert & Quasha, 1995). However, mean spatial test scores in this study for females (47.74) were slightly higher

than that of the males (46.00). This finding is consistent with the RMPFBT test manual's declaration that significant performance differences between males and females are not common with the RMPFBT (p.29). The test authors report a difference in the means from several studies comparing gender on the RMPFBT, on average, of only one point in favor of the males. In one study, Guay (1980) suggested the reason for this may be due to the fact that the test *may* be more a measure of analytical spatial ability, rather than that of pure spatial ability (as cited in Likert & Quasha, 1995). A study done by Evans and Dirks (2001), which looked at the relationship between spatial ability and the psychomotor performance of dental technology students, found that male students scored significantly higher than females on the RMPFBT, contrary to the test manual author's assertions as stated above.

The RMPFBT authors state that younger people and those with more education tend to score higher than older, less educated people (Likert & Quasha, 1995, p.29). Actual ages were not available for MWU students in this study. The university bachelor degree program in this study admits traditional aged juniors in their early 20's, with two years of college experience. The two community colleges and the proprietary school sonography programs admitted classes that exhibited wide ranges of age and educational backgrounds.

One cannot make the assumption that the younger students had no BS degree and the older students had a BS degree, since many older students in the community colleges had only AAS degrees. When comparing RMPFBT results amongst those having or not having a bachelors degree, there was a difference between the means of those

with no bachelor's degree ( $M= 48.42$ ) and those having a bachelor's degree ( $M= 45.39$ ). This difference was not statistically significant, however.

In sum, the study participants' spatial test scores exhibited overall normal distribution with a wide range of low and high levels of spatial ability, indicating that pre-admissions screening does not homogenize a class into same-level spatial abilities. There was little difference in spatial scores between genders. All sites' 2 semester averaged mean scanning scores were higher than the first 30 hours mean scores, indicating a certain level of skill acquisition. The proprietary school (PS) had marked lower spatial and scanning scores than the other sites, possibly indicating lower admissions criteria, thereby gleaning lower capable students in comparison to the other sites, at least in this study.

*Research Question Two: Is There a Relationship between Spatial Ability and Learning to Scan Sonographic Images?*

The range of scanning ability was analyzed for the four sites at two times – after the first 30 hours of lab instruction and then averaging all scanning scores after 2 semesters of lab instruction. The first 30 hours represents the amount of lab time from the beginning of lab instruction to the first scanning competency, and is representative of the scores within the cognitive phase of skill acquisition from Ackerman's (1988) model. Averaging all scores over the learning period *may* represent scanning scores throughout more of the three stages of skill acquisition (cognitive, associative, and autonomous).

Ideally, to assess skill acquisition through all three phases, the participants would be followed learning to scan one task (one specific organ) throughout the learning period, with all competency testing made at the same time intervals at all sites. The final scan would thus indicate the level of scanning ability attained for that particular organ. A study that included a repeated measures ANOVA design could then be used for analysis to explore the students' progress in relation to their spatial ability in all three phases of skill acquisition.

In this study however, different organs were scanned from the onset to the end with increasing degree of difficulty from start to finish. Competency testing was not done at the same time at all sites, except for the first 30 hours measurements, and there were an unequal number of competency tests. All sites started with the aorta scan as the first lab competency. MWCC, however, started with a gall bladder competency. It is unknown if one competency is more difficult than the other. All sites do report, however, that they start with the easiest scans first, and progress to more difficult scans throughout the learning period. The gall bladder scan is the second scan for the other three sites. So, for the for the student's first scan, three sites were tested on the aorta, while one site tested on the gall bladder, for the first 30 hours time of measure.

Therefore, the next best measure of assessing learning throughout the 2 semester period was to average all the competency scanning scores. This measure includes all scanning scores from start to finish, but since the last scan is much more difficult than the first scan, this time of measure may or may not represent the students' level of skill attainment. In the exploratory study, it was the two semester averaged

score that showed a significant correlation between spatial ability and skill acquisition of scanning (.60) – not the initial first 30 hours (.26). In the expanded study, both times of measure were significant, (.43 and .49, respectively).

Histogram analysis revealed that the SCAN scores for all sites were skewed negatively to the left, indicating high test scores for the first competency. These high scores are probably reflective of the practice of starting with the easiest scans first, in order to enhance student confidence in learning. Once again, as with the spatial test scores, PS students, by far, had the lowest scanning competency scores ( $M = 54$ ) of all the sites. Scores from the other sites all had means above 80. There was no significant statistical difference between the means of gender or degree categories.

Mean two semester scores were higher than the mean scores for the first scanning score for all sites. PS, again, was the lowest at 64.36. One cannot compare the first SCAN scores with the last, because the competencies are testing different anatomical structures throughout the course of study. There was no significant statistical difference between the means for sex. There was, however, a small significant statistical difference between the means of those having or not having a bachelor's degree.

In Chapter Two, it was reported that spatial ability was an important ability determinant in skill acquisition for several disciplines in medicine. For example, in surgical training, Anastakis et al (2000) found a correlation of  $r = .58$  between the RMPFBT and general surgery ability. Other examples of spatial ability and skill acquisition included: acquiring colonoscopy skills (Luursema, Buzink, Verway &



Jakimowicz, 2009) finding  $r = .61$  correlation with spatial ability; laparoscopy skills (Keehner et al, 2004)  $r = .39$  correlation; and dental skills (Gray & Deem, 2002),  $r = .50$  correlation.

Several studies mentioned previously in Chapter Two found that strong correlations exist between high spatial ability learners and initial high competency scores (Keehner, Lippa, Montello, Tendrick, & Hegarty, 2006). Kheener et al. also found that through additional practice and instruction, the low spatial ability learners eventually caught up with the high spatial ability learners. In these studies, strong correlations of spatial ability remained throughout all three stages of skill acquisition.

For the exploratory study, it was expected that a strong correlation would be seen after the first 30 hours of instruction. Instead, the study found a much weaker correlation (.26) after the first 30 hours, than for the overall 2 semester averaged scores (.60). It was unclear at the time why this result occurred, and was a point of emphasis for the expanded study to validate this finding.

The expanded study of 73 participants included the 11 abdominal students' scores from the first study. The six cardiac students were dropped, because all of the other sites were abdominal students. For the first 30 hours,  $r = .46$ , which is much stronger than the  $r = .26$  correlation found in the exploratory study. For the two semester averaged scores,  $r = .49$ , which showed a slight increase from the initial correlation, but was not as strong as the  $r = .60$  from the exploratory study. The expanded study's initial correlations were similar to the findings from other studies in the medical skill acquisition literature noted above. The 2 semester averaged correlation

(.49) agreed with other studies that spatial ability may be important in the latter stages of skill acquisition as well.

One possible hypothesis for lower correlation after the first thirty hours of instruction may be that cognitive overload and/or under-developed psycho-motor skills are masking the effect of having high spatial ability for the first 30 hours scan scores. But then, why is there such a difference between the two studies? This remains unclear.

Navigating the manipulations of the transducer, operating the machine, and concentrating on image acquisition presents a significant challenge of general ability for beginning sonography students initially to manage all at once. As previously stated in Chapter Two, there is a direct link between spatial ability and the development of psychomotor skills. Because psychomotor skills were not assessed in this study, this may be a direction for further research.

The exploratory study and the expanded study both showed that spatial ability is a significant ability determinant for skill acquisition in learning sonographic scanning, especially when considering the 2 semester averaged time of measure. The ( $r^2$ ) of .24 for the 2 semester averaged scores for the expanded study means that spatial ability accounted for 24% of the variation in the two semesters averaged scanning scores. This finding is consistent with a study done by Gray and Deem (2002) who found that scores on the Perceptual Ability Test (PAT), a spatial visualization test like the RMPFBT used for admission into dental schools, accounted for 25% of the variability of the final grades in the dental pre-clinical technique courses. This may mean that use of a spatial ability

test like the RMPFBT would be appropriate for use in admissions to sonographic programs as well.

In the exploratory study, the six cardiac students were combined with the 11 abdominal students to generate a sufficient N of 17 for analysis. The 2 semester averaged score time of measure resulted in a .60 correlation with spatial ability. For the expanded study, the six cardiac students were dropped, so the resultant MWU1 class consisted of the 11 abdominal students alone. Taking out the six cardiac students dropped the correlation from .60 to .49. This may imply that cardiac students rely more on spatial ability than abdominal students, but there were only six cardiac students in the study, so this may or may not hold true. It does raise the question as to which of the many different specialties in sonography rely more or less on spatial ability. This also may be another issue for future study.

The weak MWU1 and MWU3 correlations in the expanded study may indicate that the other sites' contribution to the overall correlations for both times of measure were greater than the MU class's contribution. Perhaps spatial ability is more important as a skill acquisition determinant for the community college and proprietary school than for the large research university, since the correlations between the spatial test scores and the scanning scores are stronger in those institutions than for the MWU class results. This may also indicate that a spatial ability test such as the RMPFBT may be especially important for community colleges and proprietary schools for admission purposes. With such small class sizes, though, one should caution against generalizing

this finding to their respective populations, since an adequate statistical power of .80 requires a sample of 15-20 participants.

Finally, using MWU1-3 data, multiple regression analysis was utilized to compare incoming GPA scores, ACT scores for the undergraduates/GRE scores for the graduates, and their pre-instructional RMPFBT spatial test scores with their scanning test scores for both periods of measure. Evans and Dirks (2001) found that GPA was the strongest admissions criteria factor in predicting student success – greater than spatial ability, interviews, and other personality measures. In this study, for the MWU1-3 undergraduates (N = 34), incoming GPA (.44\*) was confirmed again as being the greatest factor for predicting scanning success for the two semester averaged SCAN scores.

In sum, in validation of the exploratory study, spatial ability was again determined to be a moderately strong predictor of scanning scores for the two semester averaged SCAN scores. The expanded study's strong initial correlation of .43 is more in line with other studies on medial skill acquisition. Incoming GPA was stronger than ACT scores or spatial test scores in predicting the students' scanning scores for the three MWU classes, which may indicate the use of ACT scores as inconsequential for candidate selection.

*Question Three: Does spatial ability improve throughout the two semester learning period?*

Hegarty, Keehner, Khooshabeh, and Montello (2009) found no evidence that dental education improved the dental students' spatial ability throughout a 2 year

course of instruction. This study explored the same question within the context of sonography education. The RMPFBT was administered to the participants (MWU3, ACCC, MWCC, and PS), after the 2 semester learning period was completed. The pre-learning period spatial test scores were compared to the post learning period spatial test scores, and a statistically significant change in their post spatial test scores was realized. This is likely due to having practice and instruction over the two semester learning period.

In the exploratory study, the 2 semester averaged score correlation (.60) was much stronger than the first 30 hours correlation (.26). In the expanded study, once again, the 2 semester averaged correlation (.49) was stronger than the first 30 hour correlation (.43), although not dramatically so. This result, coupled with an obvious increase in spatial scores from beginning to end, may suggest that spatial ability seems to be an important ability determinant in the success for scanning competency throughout all phases of learning.

*Question Four: Is there a relationship between the students' level of spatial ability and student retention?*

No previous studies could be found that explored the relationship between a student's level of spatial ability and student retention. MWU3, and PS had no drop-outs – all students stayed in the sonography program throughout the course of this study. ACCC, had five drop outs, and MWCC had one. No correlation was found between the drop outs and their spatial ability, using binary logistical regression analysis. All six drop outs were undergraduates, female, and had no bachelor's degree.

## Limitations

Four significant limitations were highlighted in the above discussion. One was that assessment of the participants' psychomotor skills was not included in the study. In a study that explored individual differentiation in learning ability, visual and spatial perception, and personality measures, Evans and Dirks (2001) found that all three factors do affect psychomotor learning. Effective and appropriate manipulation of the ultrasound machine probe is an important step in the development of sonographic image acquisition and requires the development of specific psychomotor skills. Poor transfer of psychomotor skills to image acquisition could mask having high spatial ability as a determinant of skill acquisition.

A second important limitation to the study, as discussed above, was the small N for the individual classes when breaking down the analysis by site: MWU1 (11), MWU2 (13), MWU3 (19) ACCC (8), MWCC (11), and PS (11). Any size sample below 15 will have an unacceptably low statistical power. Therefore, the small sample sizes from individual classes and sites make it difficult to generalize findings by site to a specific general population, such as for all community colleges, or all proprietary schools. For example, even though PS has low mean spatial test scores and low mean scanning scores, it does not mean that all proprietary schools are similar to PS. Due to the small sample size where  $N = 11$ , an *ad hoc* statistical power of .386 is realized when looking at the correlation between spatial ability scores and the 2 semester averaged scan scores. The results can only be applied to that specific site.

A third limitation to the expanded study is inter-rater variability in the deriving the competency SCAA scores. All preceptors at all the sites were professionally registered sonographers by ARDMS who understand the expectations set by industry standards prescribed by the various individual sonography conventions. Given that, however, none have gone through any sort of formal teacher education program. The proprietary school preceptor was an adjunct teacher/sonographer with no formal educational teaching background. The other three sites' preceptors were full time instructors with many years of teaching experience in sonography, yet had no formal training for teaching. The site preceptors had no common training in scoring of the competencies or calibration of scoring.

As described in Chapter Three, a five point Likert scale was used to score the scanning competencies on the SCAN forms. While each level on the scale has distinct qualifications, there will always some inter-rater discrepancy. Anecdotally, my experience with subjective ratings using Likert scales, what merits a score of "3" versus a "4" out of five points becomes problematic for consistency. Also, inter-site variability as to the order of anatomical competencies varied somewhat. MWU, ACCC, and PS competency tests were given in the same order. MWCC had a somewhat different order of testing, which may have affected the first thirty hours scanning period of measure. Two of the sites did not include the pelvic competency, which resulted in an unequal number of scanning competencies.

Finally, a fourth limitation arises regarding question four, which asked whether or not spatial ability is a predictor for student retention. The six students who dropped

out of their sonography programs did so before any scanning competency scores were recorded. They did, however, complete the initial RMPFBT spatial test, so logistical regression was used to analyze if there was a possible relationship between the two variables. While no relationship was found, this is a very limited study of student retention.

### Conclusions

In this study, there were five results that need to be addressed:

- 1) The results indicated that students with low spatial ability were not being “weeded out” with the use of traditional admissions criteria. If sonography program admissions committees wish to accept the very best candidate, traditional admissions criteria are inadequate in assessing the total individual’s aptitude for scanning.
- 2) A moderately strong relationship between spatial ability test scores and scanning competency scores that may exist in all phases of skill acquisition. Since low spatial ability students are not being screened through admissions, and at least a moderately strong relationship exists between spatial test scores and scanning competency scores, low spatial ability learners may struggle throughout their course of study, and not keep up, or fail altogether. Eighteen month certificate programs found in proprietary schools and community colleges may not have the time to allow low spatial ability learners to catch up to the high spatial learners. These individuals may end up dropping out of the sonography program, having incurred large sums of school debt without obtaining a degree. Even worse, they may graduate with insufficient skills to enter the workforce.



3) Incoming grade point average was a stronger predictor of scanning scores than spatial ability test scores or ACT scores. While there was a moderately strong relationship seen between the spatial test scores and the scanning scores, it was shown that incoming grade point average was an even stronger predictor of student scanning scores. Coupled with a spatial ability test, like the RMPFBT, should replace ACT scores, which were largely irrelevant, and should possibly not even be a part of admissions criteria.

4) The students' spatial ability did improve throughout the learning period. This finding is a bonus, at least, for low spatial ability learners who need to improve their spatial ability in order to keep up with the high spatial learners. The results show that spatial ability can be improved, and that sonography programs should identify low spatial learners and work with them to improve their spatial ability, as previously discussed in Chapter Two.

5) No relationship was found between spatial ability and student retention. Unfortunately, the six students who dropped out did so before the first 30 hour scan competency, so it was not possible to study whether or not the students dropped out due to having low spatial ability. My experience in having taught for three years in a proprietary setting, and having matriculated through a community college setting,

showed me that student retention is a significant problem and needs to be addressed for future research.

#### Implications for Future Research

The results of this study suggest several directions for future research. The expanded study only included students studying abdominal ultrasound. Other specialties, such as cardiac, OB, vascular ultrasound and others, may or may not prove to have the same relationship between spatial ability and learning to scan.

Both studies reported a lower correlation for the first 30 hours than for the 2 semester averaged scanning scores, which may indicate that sonographic scanning is highly spatial in content, whereby correlations for spatial ability would remain strong throughout the learning period. For future study, it may be important to do a repeated - measures ANOVA study in which like classes with similar competencies are compared throughout all three stages of skill acquisition. Further research is also needed in assessing how spatial ability and psychomotor skills are related to acquiring sonographic scanning skills.

Finally, a much broader, more intense study is needed for answering question number four, which looked at the relationship between spatial test scores and student retention. With only six drop outs from of the initial 79 consented participants, six is too small of a sample to generalize to the entire population. They also dropped out very early in their program of study. Individual reasons for dropping out were not available for analysis, neither were incoming GPA, SAT/ACT scores or other pertinent

demographic information. Following students on a semester by semester basis would be a much better measure of retention.

#### Implications for Institutional Policy

The findings of this study have two major implications for institutional policy. First, it is well documented that dental schools have been using scores from the Perceptual Aptitude Test (PAT), a sub test on the Dental Admission Test (DAT), since the 1940s in their assessment of candidates for admission into dental school. Recent studies have generally supported spatial ability's effect on student achievement ( $r = .50$ ) for dentistry (Gray & Deem, 2002; Hegarty, Keehner, Khooshabeh, & Montello, 2008). As reported in Chapter Two, mixed results from several recent studies have surfaced for deciding whether or not spatial ability testing is appropriate for the selection and training of general surgical, laparoscopic, and colonoscopy surgical candidates.

The expanded study validated the exploratory study's finding that spatial ability is a significant ability determinant in predicting sonographic scanning competency scores. Sonography program candidates with high spatial ability would learn to scan faster than the candidates with low spatial ability. In view of the fact that the coefficient of determination (.24) is at least as strong as in dentistry, sonography schools should consider including a spatial ability test, such as the Revised Minnesota Paper Form Board Test, in order to admit the strongest candidates, especially if the program believes that it does not have time for low spatial learners to catch up to high spatial learners.

Another use for the spatial test would be to identify those students with low spatial ability and view them as students requiring additional practice time and instruction to help them in overcoming their deficiency. Examples of specific teaching methods, computer aided instructional software and other specific coursework abound in the literature, as described in Chapter Two, for improving spatial ability is available as well.

In conclusion, spatial ability is an important ability determinant for student achievement in sonographic scanning. This study has shown that spatial ability testing may be an appropriate additional component of admissions data to be used in selecting candidates for admission to sonographic programs across the country, depending on the type of program and needs of the individual students. It is also appropriate for identifying low spatial ability students who may require extra time for practice and/or additional instruction and remediation for success.

Inevitably, adding a spatial ability test to admissions criteria might increase the level of competency of sonographers graduating from sonography educational programs and entering the workforce. Schools admitting poorly equipped individuals and graduating low level, low performing beginning sonographers are doing a disservice to the medical community, and ultimately, to the general population. Bringing in highly qualified individuals with the capacity to learn to scan quickly and effectively raises the level of competence of the graduates entering the workforce, which in turn enhances patient care and quality of service to the medical community.

## An Exploratory Study of Spatial Ability and Student Achievement in Sonography

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### Abstract

Spatial ability refers to an individual's capacity to visualize and mentally manipulate 3D objects. Since sonographers manually manipulate 2D and 3D sonographic images to generate multi-viewed logical, sequential renderings of an anatomical structure, it can be assumed that spatial ability is central to the perception and interpretation of these medical images. However, little is known about the relation between spatial ability and performance of sonographers. This study explores this possible relationship. Seventeen first-year sonography students were administered a spatial abilities test prior to their initial scanning lab coursework. The students' spatial ability scores were compared with their scanning competency performance scores after the first 30 hours and after two semesters of instruction. A significant relationship between the students' spatial ability scores and their scanning performance scores was found. This study suggests that the use of spatial ability tests for admission to sonography programs may improve student selection as well as assist programs in adjusting instruction and curriculum for students who demonstrate low spatial ability.

### Keywords

spatial ability, sonography scanning, spatial ability testing

Sonography is a developed skill in which sonographers perform sonography scanning to produce sonographic images called sonograms. Sonographers image anatomical structures within patients to produce diagnostic images for the physician to interpret. Unlike other imaging modalities where the technologist positions the patient and the machine performs the imaging automatically, sonography is more subjective. It is an acquired skill that requires manual manipulation of the probe, or transducer, to produce the images while, at the same time, operating the ultrasound machine. The sonographer creates images that are 2D representations of 3D anatomical structures that are "slices" of the anatomical structure. These slices are commonly presented in a logical sequence to create a representation of the region of interest. In light of this task analysis, it can be assumed that learning sonography scanning may require a high level of spatial ability to create the sonograms.

Educational programs for sonographers often use traditional admissions criteria such as SAT or ACT scores, as well as grade point averages (GPA), or GRE scores, in selecting candidates for admission to their programs of study. However, through several years of observation of

students in our program of study, we noted that some students learn to scan much faster than others, regardless of their academic achievement or aptitude scores. Although measures of aptitude and achievement may predict future success in didactic work, they did not illuminate a candidate's aptitude for sonography scanning. Consequently, it can be assumed that all sonography schools may be faced with admitting candidates with high SAT or ACT scores and with exceptional incoming GPAs who perform well in didactic coursework yet struggle with learning sonography scanning.

An exploratory study focused on finding empirical evidence that an individual's level of spatial ability may contribute to the process of learning sonography scanning was performed. The intent of the study was to examine the relationship between a student's spatial test score and

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the student's sonography scanning performance scores. If a positive relationship is found, then perhaps administration of a spatial ability test would be an appropriate predictor of a student's aptitude for success in sonography scanning.

### Visual-Spatial Ability

Visual-spatial ability refers to the neuro-psychological processing of spatial relations of image properties.<sup>1</sup> Furthermore, it is defined as the "ability to generate, retain, retrieve, and transform well-structured images. Complex in nature, it is not a unitary construct, but rather exists in several forms," with each emphasizing different aspects of the process of image generation, storage, retrieval, and transformation.<sup>2</sup> Sonographers create relationships among the sonography images produced and give meaning to the anatomical structures they see on sonographic images. However, they rarely see the entirety of the anatomical object being scanned. Therefore, sonographers must be able to construct a series of images that logically represents the whole object. This requires an ability to mentally rotate and transform 2D images and create a series of views that represents the 3D structure.

The ability to perceive spatial properties occurs in a number of stages, from simple edge and surface encoding to more complex whole-object processing. Studies within the realm of neurophysiology have shown there is a hierarchy of visual-spatial abilities. The general classifications of visual-spatial abilities from low to high are as follows: (1) edge and surface extraction, (2) edge orientation encoding, (3) whole-object recognition, (4) imagery involving the spatial relations of object parts in 2D, and (5) imagery involving 2D and 3D whole-object spatial rotations and translations.<sup>3</sup>

Some authors believe that spatial cognition is central to understanding medical images, including those produced by computed tomography (CT), magnetic resonance imaging (MRI), and radiography or x-ray.<sup>4</sup> However, as of this writing, no empirical evidence has been identified in the literature that supports this assumption for sonography. The purpose of this study was to provide foundational empirical evidence in support of these assumptions, in which the following research questions were addressed: (1) what are the levels and variations of spatial abilities among the sonography students, and (2) what is the relationship between innate spatial ability test scores and student achievement in sonography scanning?

### Conceptual Framework

The framework of this study embraces cognitive learning and constructivism with an emphasis toward generative

learning.<sup>5,6</sup> Constructivism is a philosophical explanation about the nature of learning. Some authors have extended this philosophy into a theory of learning, which has its roots in cognitive and social cognitive learning theories but with significant differences.<sup>5</sup> In general, constructivists assert that the world can be viewed by individuals in many different ways. Knowledge is not something imposed on people from the outside; rather, it is formed from within. Therefore, each individual's construction of knowledge is unique, based on personal beliefs and prior experiences. All knowledge is thus subjective to personal perceptions, worldviews, and innate abilities. There are many varieties of learning theories along the constructivist continuum, one of which is generative learning.

Generative learning theory is a cognitive approach to learning that draws from the constructivist philosophy and is most applicable to this study.<sup>7</sup> First described by Wittrock,<sup>7</sup> generative learning is a form of constructivism that is based on the neural aspects of brain functioning and the cognitive process of knowing. Learning strategies are those that create relationships and meaning through mental processes that "reorganize, elaborate, and reconceptualize information." Mental structures formed by the learner that reflect reality are coupled with the learner's prior knowledge and experiences, which then assist in the understanding and creation of relationships.<sup>6</sup>

Generative learning is related to this phenomenon in that each time a study is generated, the sonographer must "learn" the anatomical configuration being studied and conceptually reorganize, elaborate, and reconceptualize the information provided by the acquired sonographic images. This study explores the relationship between an individual's level of spatial ability and the student's achievement in learning to scan.

### Visual-Spatial Ability Testing and Its Role in Occupations

Spatial visualization tests are designed to evaluate an individual's ability to mentally transform objects into alternate formations. Research on visual-spatial abilities (VSA) in relation to occupational aptitude has been done by a host of researchers.<sup>8</sup> High scores on spatial ability tests have high correlation values within careers such as dentists, artists, engineers, industrial machine operators, draftsmen, designers, electricians, surgeons, and many others. Many of these careers require high scores on spatial ability tests for admission to their educational programs or prior to hire. Numerous studies from previous and recent research have linked the role of spatial cognition in medicine, especially in general surgery,<sup>9</sup> laparoscopic surgery,<sup>10</sup> and dentistry.<sup>11</sup>

Several recent studies have looked at the role of innate spatial perception abilities among students in dentistry and general surgery. Wanzel et al.<sup>9</sup> examined the influence of spatial abilities and manual dexterity on performance among dental students, surgical residents, and staff surgeons. Each group was administered the Vandenberg Mental Rotations Test<sup>11</sup> to assess high-level spatial abilities and the Surface Development Test (SDT) for low-level spatial abilities.<sup>12</sup>

Test results confirmed that high-level VSA is related to and could potentially predict initial student performance and product quality on spatially complex procedures, especially in laparoscopy procedures. High-level VSA test scores were more predictive of performance than the low SDT test scores, as well as the manual dexterity tests. Interestingly, those general surgery students who were identified with low spatial ability achieved results equal to surgical residents and staff surgeons after supplementary instruction on the specific technical tasks.

This important finding indicates that even though a novice with low spatial ability may initially exhibit low performance scores, additional instruction and deliberate practice can overcome low spatial ability and eventually increase the level of performance on the assigned tasks equal to the level of those with high spatial ability. In light of this finding, the authors do not support the use of high-level spatial ability testing for the selection of candidates for admission purposes into surgical or dental schools. Rather, the tests would be most beneficial in identifying those novice trainees who might benefit from supplementary instruction during their course of study.

Other recent studies have confirmed Wanzel et al.'s findings<sup>9</sup> in general surgery, laparoscopic surgery, and dentistry.<sup>13-15</sup> All found that high-level spatial ability testing can at least predict initial performance in these fields. Although the researchers used a different spatial relations test, all agreed that the VSA tests correlated most strongly with high initial student achievement. In contrast to Wanzel et al.'s conclusions, Keehner et al.<sup>13,14</sup> and Risucci<sup>15</sup> supported using spatial ability tests for selection of candidates, stating that the extra time and instruction necessary to overcome initial poor student achievement due to low innate spatial ability may not be practical with limited time and resources.

### Spatial Ability Tests

Spatial ability tests are designed to evaluate a person's ability to mentally manipulate diagrams of objects into alternate formations. There exists a wide variety of tests related to each category of spatial ability, as noted above. The original Minnesota Paper Form Board Test was developed in the late 1920s by Likert and Quasha<sup>8</sup> and

was the first psychometric test assessing visual-spatial ability. The test measures the "ability that predicts performance in jobs requiring the capacity to visualize and mentally manipulate objects in space," which correlates to assessing the fifth and highest category of visual-spatial ability of mental rotation and transformation of objects. According to the authors, an individual's score can be marginally improved through specified training, but it is important to note that a dramatic improvement cannot be achieved through "practicing for the test" that affects interpretation of test results on the Revised Minnesota Paper Form Board Test.<sup>9</sup>

A more recent version of the Revised Minnesota Paper Form Board Test (RMPFBT) is a well-designed measurement tool that has been reviewed and evaluated many times in its 75-year history. It is a spatial visualization test that targets the highest level of spatial ability skill category, which logically seems to be appropriate for the tasks necessary for sonography scanning, that of mentally rotating objects and understanding possible transformations. It is, in our opinion, an appropriate tool for assessing visual-spatial ability in sonography scanning.

The test is a 20-minute paper-and-pencil test that evaluates spatial abilities. It has an excellent split-half reliability score of .93, which measures internal test consistency. It also has a "test-retest" score of .85, which indicates high repeatability of the test with the ability to give consistent results over time. There are four alternate forms of the test, with a reliability of .85. Reliability refers to the accuracy and precision of a test and is an indication of the confidence one may place in a test score.<sup>8</sup> Criterion-related validity, which means to provide an educated guess about an examinee's potential for future success, has not been established for sonography but is .61 for dentistry. Construct validity measures the extent to which a test measures the trait it was designed to measure, which in this case is an individual's spatial ability.<sup>16</sup> For the RMPFBT, construct validity is reported to be .75, which means the test is an appropriate measure for spatial ability and would be an appropriate test for use in assessing spatial ability for sonographers.

### Method

After obtaining permission from our institutional internal review board (IRB), a total of 17 sonography students divided into two groups were studied in this project. One group consisted of five first-year students enrolled in beginning cardiac sonography and 12 first-year students enrolled in beginning abdominal and OB/GYN. Fifteen participants were women and two were men. Both groups were studied for two semesters and were taught by different instructors. The RMPFBT was administered to each

**Table 1.** Descriptive Statistics for Aptitude and Achievement Data After 30 Hours of Instruction

Measure	<i>n</i>	Mean	Standard Deviation	Variance	Minimum	Maximum
Aptitude	17	45.9412	5.72790	32.8090	34.0	55.0
Achievement	17	86.7647	10.94035	119.6913	52.0	98.0

participant in both groups at the beginning of the semester by a test administrator who was not associated with instruction or evaluation of the participants.

The students were given the RMPFBT prior to the start of a two-semester period of study. Their spatial ability scores were compared with their scanning competency performance scores at the end of the first 30 hours of instruction and then with the overall average of their scanning scores for two semesters. The results indicated no statistically significant relationship between the scanning scores after the first 30 hours of instruction. In contrast, a very strong correlation occurred when the spatial test scores were compared with the two-semester averaged scores. The latter results indicate that high spatial ability test scores relate to student achievement in sonography scanning.

The tests were hand scored by the primary investigator at the end of each group's respective project period to alleviate any unintended teacher coercion, grading, or scoring bias for the competency examinations of the students. All of the instructors of the participants in the study were blinded from the students' individual spatial test scores at any time throughout the instructional period, as well as testing of the students' scanning competency.

The study looked at two measures of the student's competency scores. First, the students were given scanning competency tests at the end of the first 30 hours of instruction. In group 1, the 5 beginning cardiac students' first competency scan consisted of obtaining the four basic 2D views of the heart, which included the parasternal long-axis, parasternal short-axis, apical, and subcostal views. For the second group of 12 beginning abdominal students, the first competency test was that of a scan of the aorta. The students used each other as models, and the instructor evaluated each student as he or she scanned in the laboratory setting, according to the performance objectives outlined in the Sonographer Clinical Assessment Book (SCAN), which is a commercially available assessment tool developed by the International Foundation for Sonography Education and Research (IFSER). Similarly, evaluations of student scanning were made according to the performance objectives stipulated in the SCAN. The students used each other as scanning models, and the instructor evaluated them in a laboratory setting.

The second portion of the study occurred at the end of two semesters of instruction, when all competency scanning scores were averaged for the entire period. The

scores for both groups were combined and were then correlated with their respective scores on the RMPFBT. The independent variable, *X*, is the spatial aptitude score, and the dependent variable, *Y*, is the achievement or scanning score.

## Results

This study examined the spatial ability of each student to assess how the scores vary among the students. The minimum aptitude score of all the participants for spatial ability was 34, and the maximum score was 55. Normative data have not been established for the occupation of sonography for the RMPFBT. As an example for comparison, normative data for grade 12 women indicate that a score of 34 would be in the 15th percentile and a score of 55 would be in the 90th percentile.<sup>7</sup> Therefore, the beginning sonography students as a whole had a very wide range of spatial ability. The relationship between students' spatial aptitude measure and their achievement was measured at two times: after 30 hours of instruction and two semesters of instruction. The combined performance scores of the two groups after the first 30 hours ranged from 52% to 98% (see Table 1).

Regression analysis was done for student performance after 30 hours and resulted in a marginal Pearson Product-Moment correlation coefficient (*r*) of .264, which is the measure of the linear relationship of the two variables. In other words, it represents the simple relationship between the spatial ability test scores and the scanning competency scores as reflected by their scanning scores. The coefficient of determination, or  $r^2$ , which is the proportion of the total variance in the scanning scores (*Y*) that can be associated with the spatial ability scores (*X*), was .070. This means that the spatial test scores can account for only 7% of the variation in the students' scanning scores, which is quite low. The adjusted  $r^2$  for having a sample  $N < 30$  was .008. The standard error of the estimate was 10.9081.

The standard error of the estimate is the standard deviation of the variance of the residuals along the regression line. The residuals, or deviations, are the departures from *Y* and predicted *Y*, or the difference between the value the model predicts and the value of the observed data on which the model is based.<sup>17</sup> Ideally, we want the departures or residuals to be as small as possible, and therefore, the smallest standard error of the estimate is desirable for



**Table 2.** Analysis of Variance in Scanning Achievement Associated With Spatial Test Scores After 30 Hours of Instruction

Source	Sums of Squares	df	Mean Square (Variance)	F	Sig.
Regression	133.539	1	133.539	1.124	.306
Residual	1781.519	15	118.768		
Total	1915.059	16			

**Table 3.** Descriptive Statistics for Aptitude (Spatial) and Achievement (Scanning) Data for Two-Semester Average

Measure	n	Mean	Standard Deviation	Variance	Minimum	Maximum
Spatial	17	45.9412	5.72790	32.809	34.0	55.0
Scanning	17	88.2941	4.70059	22.096	80.0	96.0

**Table 4.** Analysis of Variance for Scanning Achievement Associated With Spatial Test Scores for Two-Semester Average

Source	Sums of Squares	df	Mean Square (Variance)	F	Sig.
Regression	127.092	1	127.092	8.419*	.011
Residual	226.437	15	15.096		
Total	353.529	16			

\* $P < .01$ .

a predictive test, and in this case, the departures are quite large. The standard deviation of the residuals equals the standard error of the estimate. In essence, it is a measure of how representative a sample is of a population.

Often with regression analysis, an  $F$  test or an analysis of variance (ANOVA) is performed. ANOVA compares the variance of the regression model with the variance of the residuals, or deviations (see Table 2). Traditionally, ANOVA is used in experimental research, and regression is used in correlation research. The ANOVA procedure in regression can be used to test the hypothesis that the independent variable, in this case the spatial test scores, will account for a statistically significant proportion of the variance in the dependent variable, or the students' scanning scores. An ANOVA does not, however, tell anything about the individual contribution of the variables in the model.

Spatial test scores and scanning competency scores for all students in the first part of the study were compared. Ideally, it is desirable to have the results of the "Sig." column of the ANOVA to be less than .05. Our results for this part of the study indicate that because the "Sig." number is very large (.30), the results are not statistically significant (see Table 2).

For the second part of the study, regression analysis was done for the combined student performance after two semesters of instruction. In contrast to results after 30 hours of instruction, the Pearson Product-Moment correlation coefficient was .60. In social science research, .60 indicates a strong relationship between the two variables or between the spatial ability scores and the students' competency scanning scores.

The coefficient of determination,  $r^2$ , was .36. This tells us that spatial ability can account for 36% of the variation in student achievement. In social science research, this statistic is quite significant and also shows a strong relationship between spatial ability and the scanning competency scores. The adjusted  $R^2$  for having a sample less than 30 was .349, and the standard error of the estimate was 3.8859 (see Table 3).

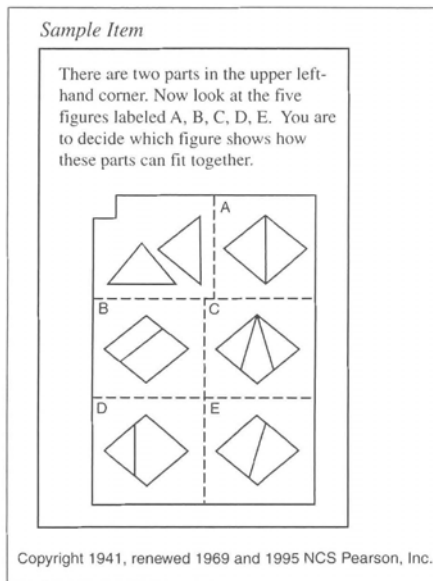
Again, a one-way ANOVA was done to determine if a statistically significant proportion of the variance of the dependent variable, scanning scores, is associated with the independent variable, the spatial ability scores (see Table 4). We found a statistically significant association for the variables after two semesters of instruction (see Table 4).

This suggests a much stronger relationship between the spatial scores and student performance when looking at the two-semester average (see Figures 1 and 2).

The power of a statistical test refers to the ability of a test to detect a hypothesized effect.<sup>18</sup> The value of .80 has generally been accepted as the minimum standard. Power is greatly affected by sample size and can therefore be increased by increasing the sample size. The statistical power of this study is .83, indicating a sufficient sample size for the study.

## Discussion

Our first research question asked, what were the levels and variations of spatial abilities among the sonography students? The first-year students had a very wide range of



**Figure 1.** Sample test question from the Revised Minnesota Paper Form Board Test. Permission granted for use from Pearson, Inc.

spatial ability, ranging from 34 to 55, with the scores being distributed consistently throughout the range. The second research question explored the relationship between the RMPFBT spatial ability scores and the performance scores recorded after 30 hours of instruction and then after averaging all the competency scores for the two semesters. Unexpectedly, a marginal Pearson correlation of .264 was found after the first 30 hours of instruction, whereas a strong correlation of .60 was found with the average of the two-semester performance scores. We had anticipated exactly the opposite result. In the literature, other investigators have reported strong correlations with spatial ability and task performance after initial instruction, then weaker relationships due to mediating aspects of extended instruction and practice.<sup>11</sup>

A potential explanation of our findings is the different experiences of both study groups. Performance scores of the 12 students in the abdominal group were clustered together after the first 30 hours of instruction and then diverged throughout the two semesters as the scanning competencies became more difficult. In contrast, the

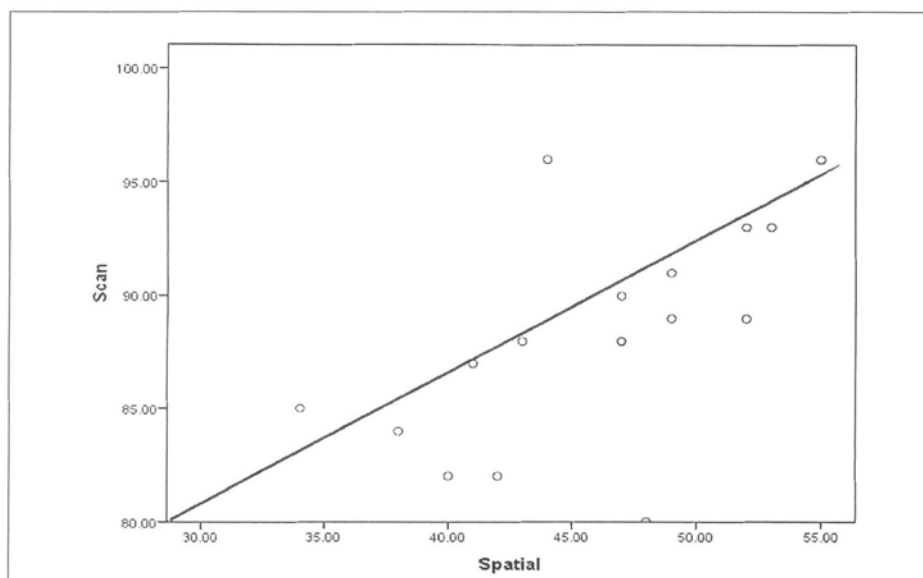
performance scores of the 5 students in the cardiac class varied widely after the first 30 hours and then converged throughout the two semesters as the weaker students caught up with the competency levels of the stronger scanners. This variation in student learning and instructional experiences and associated performance scores may have skewed the scores for the first 30 hours. More study is needed, whereby controls for varied student experiences during the initial instructional period are examined.

A mix of abdominal and cardiac classes was combined in this study to increase the number of participants in order to achieve a sufficient sample size for the number of independent variables in the study, which is one. For simple regression using one independent variable measuring student achievement on scanning scores, the sample size must equal about 15 to 20 participants.<sup>17</sup> Criterion-related validities as low as .20 may justify the use of a test in a selection program.<sup>8</sup> Of central importance to this study was the question regarding the relationship between spatial ability test scores and student achievement in sonography scanning, for which positive results were demonstrated.

There are several significant limitations in this study. One is that only 17 students participated, all enrolled in a single sonography program at one university. Of the 17 participants, 15 were female, with only 2 being male. A more balanced representation would be more advantageous in the role of gender, spatial ability, and cognitive learning. However, recent findings in the literature have shown that men generally perform better than women, with no statistically significant difference between male and female scores on the Revised Minnesota Form Board Test. Research using other spatial ability tests has demonstrated only a one-point difference in favor of males.<sup>8</sup>

The students' scanning scores were averaged over a two-semester period to mediate the myriad potential factors that can affect a student's scanning competency score. Some of these factors may include a student not feeling well the day of competency testing, test anxiety, motivational influences, teacher-student relationships, and a host of other unforeseen factors that can affect college students. Most of the participants were traditional-aged students in their junior year of college.

A final limitation to the study lies in the fact that this research study cannot account for an individual's level of psychomotor skills. Sonography scanning is an acquired skill through many hours of individual diligent practice. An individual's level of eye-hand coordination is certainly a factor in learning how to scan. If a person possesses a high level of spatial ability within the visual system, the level of psychomotor skills could affect an individual's scanning score. The use of a spatial ability test that combines testing for psychomotor skills would be most appropriate for future study. These types of tests usually



**Figure 2.** Regression scatter plot for the students' two-semester averaged scanning scores compared with their spatial ability test scores. The graph shows a strong linear relationship between the two variables.

require a trained professional to administer and were cost prohibitive for this study. Nevertheless, in our opinion, the positive results of this study should not be ignored and provide foundational empirical evidence on which to build for future research.

Future study should control subjectivity by having enough participants to be studied as one group, using one instructor, and possibly implementing a spatial ability test that incorporates psychomotor skill evaluation. Use of the SCAN was very beneficial for providing well-accepted performance standards for student evaluation. Drawing the sample population from a single homogeneous study group would reduce instructor and student variances in the rather subjective art of competency scanning evaluations.

### Conclusion

The results of this small pilot study indicate that a positive relationship exists between spatial ability testing and student achievement when comparing student competency scanning scores and spatial test scores over a span of two semesters of instruction. This may imply that spatial

aptitude testing may be appropriate for the screening of candidates for admissions purposes, along with the use of other traditional criteria, such as GPA, SAT, ACT, or Graduate Record Examination scores. It may also be important to adjust instructional pedagogical techniques and even curriculum to address the needs of students with low spatial abilities.

Another study is planned to determine validation of our initial findings, with some of the above-stated limitations being addressed. A much larger, more diverse sample population size will be used, as well as including several different learning environments from a wide variety of sonography educational programs. We invite other educational institutions with sonography programs to join us for further exploration of this interesting phenomenon.

### Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the authorship and/or publication of this article.

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Appendix B

Example: The SCAN (Sonographers Clinical Assessment Notebook)

**ABDOMEN, SUPERFICIAL STRUCTURES AND BREAST**  
 Proficiency #1 - ABDOMINAL DOPPLER

Name: E. [unclear]

Demonstrates, identifies and evaluates abdominal vessels with spectral / color Doppler.

*E = High  
 NA = not tested*

Performance Objectives	Evaluation Period or Number										A = Average	TD = Technically Difficult	P = Pathology		
	1	2	3	4	5	6	7	8	9	10					
Demonstrates, identifies and evaluates flow patterns, directions, and velocities as indicated in the following vessels:															
a. Hepatic veins.	<i>NA</i>														
b. Hepatic arteries.	<i>NA</i>														
c. Portal veins	<i>NA</i>														
d. Aorta	<i>NA</i>														
e. Inferior vena cava	<i>NA</i>														
f. Superior mesenteric artery	<i>NA</i>														
g. Superior mesenteric vein	<i>NA</i>														
h. Splenic vein.	<i>NA</i>														
i. Renal arteries / veins.	<i>NA</i>														
j. Celiac axis	<i>NA</i>														
k. Inferior mesenteric artery	<i>NA</i>														
l. Measures as indicated using appropriate caliper placement.	<i>NA</i>														
m. Demonstrates good judgement in obtaining diagnostic images including nonstandard windows, correct Doppler angles, etc.	<i>NA</i>														
n. Demonstrates critical thinking as pertinent to this proficiency.	<i>NA</i>														
o. Demonstrates, identifies, and evaluates abnormal sonographic findings including venous collaterals.	<i>NA</i>														

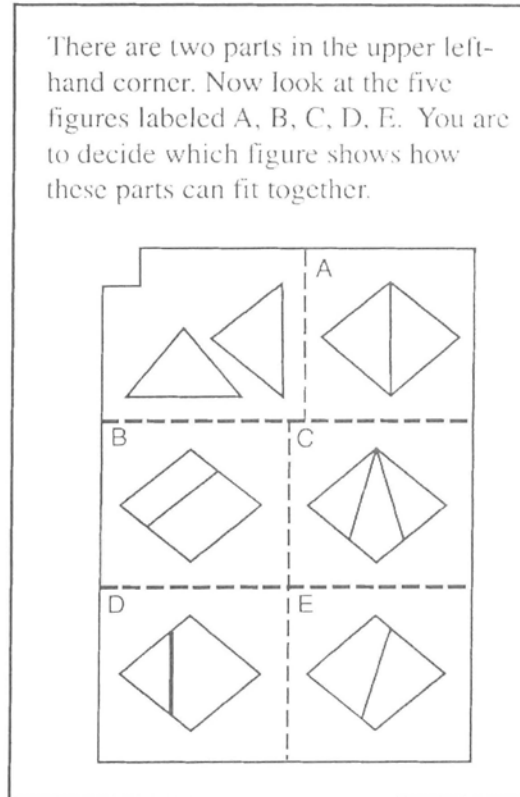
*5/11/11  
 165 passes = 84.6%*

Appendix C

Revised Minnesota Paper Form Board Test Example

*Sample Item*

There are two parts in the upper left-hand corner. Now look at the five figures labeled A, B, C, D, E. You are to decide which figure shows how these parts can fit together.



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Appendix D  
MU IRB Signature Pages

### HS Continuing Review Report (Prior to 6/22/10) Signature Page

Project Number: 1116477

Review Number: 84504

Project Title: Understanding Ultrasound Scanning: Do students with high abilities in spatial realtions master the technique of ultrasound scanning faster and with greater competency than those with less developed spatial abilities?

Principal Investigator: Douglas Wayne Clem

**CERTIFICATION**

The undersigned certifies that the information provided in this document is complete and accurate. The undersigned assures that modifications to the originally approved project will not take place without prior review and approval by HS IRB, and that all activities have been and will continue to be performed in accordance with federal, state, local and University of Missouri - Columbia policies and regulations.

Douglas W. Clem      7/13/2010  
Signature of Principal Investigator      Date

\_\_\_\_\_  
Document Prepared By      Date

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APPROVAL/ACKNOWLEDGED DATE:	<u>7-13-10</u>
APPROVAL EXPIRATION DATE:	<u>7-15-2011</u>

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### HS Continuing Review Report (Prior to 5/5/09) Signature Page

Project Number: 1116477

Review Number: 76401

Project Title: Understanding Ultrasound Scanning: Do students with high abilities in spatial relations master the technique of ultrasound scanning faster and with greater competency than those with less developed spatial abilities?

Principal Investigator: Douglas Wayne Clem

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Douglas W. Clem      6/24/2009  
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### HS IRB Behavioral Sciences Application Signature Page

Project Number: 1116477

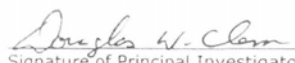
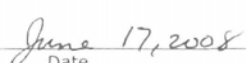

Review Number: 70519

Project Title: Understanding Ultrasound Scanning: Do students with high abilities in spatial realitions master the technique of ultrasound scanning faster and with greater competency than those with less developed spatial abilities?

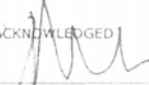
Principal Investigator: Douglas Wayne Clem

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Appendix E  
Informed Consent

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**CONSENT FORM TO PARTICIPATE IN A RESEARCH STUDY**

INVESTIGATOR'S NAME: DOUGLAS W. CLEM, MHS, RDCS, RVT  
PROJECT # 1116477  
DATE OF PROJECT APPROVAL: JULY 15, 2008

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APPROVED	
	8/13/10
HS IRB Authorized Representative	Date
EXPIRATION DATE:	7.15.2011

**STUDY TITLE: UNDERSTANDING ULTRASOUND SCANNING: DO STUDENTS WITH HIGH ABILITIES IN SPATIAL RELATIONS MASTER THE TECHNIQUE OF ULTRASOUND SCANNING FASTER AND WITH GREATER COMPETENCY THAN THOSE WITH LESS DEVELOPED SPATIAL ABILITIES?**

**INTRODUCTION**

**This consent may contain words that you do not understand. Please ask the investigator or the study staff to explain any words or information that you do not clearly understand.**

This is a research study. Research studies include only people who choose to participate. As a study participant you have the right to know about the procedures that will be used in this research study so that you can make the decision whether or not to participate. The information presented here is simply an effort to make you better informed so that you may give or withhold your consent to participate in this research study.

Please take your time to make your decision and discuss it with your family and friends.

You are being asked to take part in this study because you are a beginning student of ultrasound scanning. This study is being sponsored by the Diagnostic Medical Ultrasound Program in the School of Health Professions.

The Principal Investigator, Douglas Clem, and his collaborators have NO financial interests in this research.

In order to participate in this study, it will be necessary to give your written consent.

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#### **WHY IS THIS STUDY BEING DONE?**

The purpose of this study is to determine how an individual's spatial relations abilities affect student achievement in mastering the technique of ultrasound scanning.

This research is being done because traditional admissions criteria to ultrasound programs do not adequately identify those applicants who may excel or struggle with ultrasound scanning. GPA, ACT and GRE scores are usual items reviewed for admittance to ultrasound programs. It has been observed that some students do well in their coursework, but may struggle with ultrasound scanning. Conversely, others may not do as well in coursework, but excel in mastering the techniques of ultrasound scanning.

Ultrasound scanning, performed by sonographers, is a skill that requires diligent practice and is usually taught by a qualified instructor. It takes years of didactic, laboratory and clinical experience to master the techniques of ultrasound scanning in order to produce diagnostic quality images of anatomical objects.

Spatial abilities have to do with how we perceive objects around us. Spatial abilities tests are designed to evaluate a person's ability to mentally manipulate diagrams of objects into alternate positions or formations.

Currently, there is no effective test, procedure or predictor that accurately identifies someone who may have an aptitude for ultrasound scanning. This study examines the relationship between spatial abilities and student achievement in mastering the technique of ultrasound scanning by comparing scores on the Revised Minnesota Paper Form Board Test with beginning ultrasound student's competency scores in ultrasound scanning during their first year of learning ultrasound scanning.

#### **HOW MANY PEOPLE WILL TAKE PART IN THE STUDY?**

About 100 people will take part in this study at several sites around the U.S. Participants will be recruited from sonography programs in their first year of study. Each group will be followed for two semesters or within a certain time period commensurate to each specific program's curriculum guidelines, whether the time frame is measured in clock-hours, quarters, or semester. The time frame will be determined by the principal investigator. We hope to enroll 50 participants at this institution.

#### **WHAT IS INVOLVED IN THE STUDY?**

If you take part in this study, you will complete the Revised Minnesota Paper Form Board Test (RMPFBT) prior to the start of your scanning lab experience, and then again at the end. The tests will not be scored until the end of your learning period.

As part of your coursework, scanning competency tests using the performance objectives outlined in the Sonographer Assessment Notebook (SCAN) will be given after 30 hours of instruction, and then at appropriate subsequent interval throughout your learning period as determined by your instructor and course syllabus. Scanning competencies will be evaluated according to the SCAN protocols and assessed by the course instructor. These tests are part of required coursework, not in addition to, regardless of your

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decision to participate in the study or not. By agreeing to be part of the study, you are giving permission to the investigators to use your scanning competency test scores in their research. All RMPFBT scores and scanning scores will be anonymous to the research investigators. No individual information will ever be used in reporting results. You will have access to your own personal RMPFBT score at the end of the study.

#### **HOW LONG WILL I BE IN THE STUDY?**

Your involvement in the study will consist of taking the Minnesota Form Board test at the beginning and at the end of your learning period. The test takes about 20 minutes. The scanning tests are the regular testing portions of your course of study. Ideally, we will follow you for two semesters of study, however this time period may be adjusted to your particular program's curriculum and course of study.

**You can stop participating at any time. Your decision to withdraw from the study will not affect in any way your grade for any course. If you decide to stop participating in the study, the data gathered will be used to the extent of your participation and may or may not be used in the final analysis.**

#### **WHAT ARE THE RISKS OF THE STUDY?**

There is no reasonable basis for expecting that participation in this research will expose you the risk of serious medical harm or discomfort. Safeguards are in place to minimize the unauthorized release of your confidential information.

#### **ARE THERE BENEFITS TO TAKING PART IN THE STUDY?**

If you agree to take part in this study, the primary benefit you may expect is the satisfaction that you are helping us understand the association between spatial relations abilities and ultrasound scanning aptitude. We are hoping the findings from this study will benefit other students in the future.

After your second semester class has ended, you will receive your Minnesota Form Board test scores so that you will be able to better understand your own spatial relations abilities.

#### **WHAT OTHER OPTIONS ARE THERE?**

An alternative is to not participate in this research study.

#### **WHAT ABOUT CONFIDENTIALITY?**

Information produced by this study will be stored in the investigator's file and identified by a code number only. Information contained in your records may not be given to anyone unaffiliated with the study in a form that could identify you without your written consent, except as required by law. This means that your information, including your decision to participate, will not be shared with other students or faculty without your permission and that your course grades will not be based upon your spatial ability score.



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The results of this study may be published in a medical book or journal or used for teaching purposes. However, your name or other identifying information will not be used in any publication or teaching materials without your specific permission.

In addition, if photographs, audiotapes or videotapes were taken during the study that could identify you, then you must give special written permission for their use. In that case, you will be given the opportunity to view or listen, as applicable, to the photographs, audiotapes or videotapes before you give your permission for their use if you so request.

#### WHAT ARE THE COSTS?

There is no cost to you to participate in this study.

#### WILL I BE PAID FOR PARTICIPATING IN THE STUDY?

You will receive no payment for taking part in this study. You will receive your scores from the Revised Minnesota Paper Form Board Test at no cost to you at the end of your participation in the project.

#### WHAT IF I AM INJURED?

It is not the policy of the University of Missouri to compensate human subjects in the event the research results in injury. The University of Missouri, in fulfilling its public responsibility, has provided medical, professional and general liability insurance coverage for any injury in the event such injury is caused by the negligence of the University of Missouri, its faculty and staff. The University of Missouri also will provide, within the limitations of the laws of the State of Missouri, facilities and medical attention to subjects who suffer injuries while participating in the research projects of the University of Missouri. In the event you have suffered injury as the result of participation in this research program, you are to contact the Risk Management Officer, telephone number (573) 882-1181, at the Health Sciences Center, who can review the matter and provide further information. This statement is not to be construed as an admission of liability.

#### WHAT ARE MY RIGHTS AS A PARTICIPANT?

**Participation in this study is voluntary. You do not have to participate in this study. Your present or future coursework will not be affected should you choose not to participate.** If you decide to participate, you can change your mind and drop out of the study at any time without affecting your present or future in the Diagnostic Medical Ultrasound Program. In addition, the investigator of this study may decide to end your participation in this study at any time after he has explained the reasons for doing so.

You will be informed of any significant new findings discovered during the course of this study that might influence your health, welfare, or willingness to continue participation in this study.

#### WHOM DO I CALL IF I HAVE QUESTIONS OR PROBLEMS?

If you have any questions regarding your rights as a participant in this research and/or concerns about the study, or if you feel under any pressure to enroll or to continue to participate in this study, you may contact the University of Missouri Health Sciences Institutional Review Board (which is a group of people who

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review the research studies to protect participants' rights) at (573) 882-3181. Also, the participant may contact the Department Chair of the Cardiopulmonary and Diagnostic Sciences in the School of Health Professions and/or the Program Director of the Diagnostic Medical Program to express your concerns.

You may ask more questions about the study at any time. For questions about the study or a research-related injury, contact Douglas Clem at 573-884-8058.

A copy of this consent form will be given to you to keep.

#### SIGNATURE

I confirm that the purpose of the research, the study procedures, the possible risks and discomforts as well as potential benefits that I may experience have been explained to me. Alternatives to my participation in the study also have been discussed. I have read this consent form and my questions have been answered. My signature below indicates my willingness to participate in this study.

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Subject/Patient\*

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Date

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Legal Guardian/Advocate/Witness (if required)\*\*

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Date

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Additional Signature (if required) (identify relationship to subject)\*\*\*

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Date

\*A minor's signature on this line indicates his/her assent to participate in this study. A minor's signature is not required if he/she is under 7 years old. Use the "Legal Guardian/Advocate/Witness" line for the parent's signature, and you may use the "Additional Signature" line for the second parent's signature, if required.

\*\*The presence and signature of an impartial witness is required during the entire informed consent discussion if the patient or patient's legally authorized representative is unable to read.

\*\*\*The "Additional Signature" line may be used for the second parent's signature, if required. This line may also be used for any other signature which is required as per federal, state, local, sponsor and/or any other entity requirements.

"If required" means that the signature line is signed only if it is required as per federal, state, local, sponsor and/or any other entity requirements.

#### SIGNATURE OF STUDY REPRESENTATIVE

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UMC, HS IRB: CONSENT  
VERSION 1.4  
NOVEMBER, 2004

REVIEW #:

5 of 6

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I have explained the purpose of the research, the study procedures, identifying those that are investigational, the possible risks and discomforts as well as potential benefits and have answered questions regarding the study to the best of my ability.

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Study Representative\*\*\*\*

Date

\*\*\*\*Study Representative is a person authorized to obtain consent. Per the policies of the University of Missouri Health Care, for any 'significant risk/treatment' study, the Study-Representative must be a physician who is either the Principal or Co-Investigator. If the study is deemed either 'significant risk/non-treatment' or 'minimal risk,' the Study Representative may be a non-physician study investigator.

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## Vita

Doug Clem has been involved in various facets of public schools K-12 and higher education for a number of years. After graduating with a bachelor's degree in music education from Murray State University in 1980, and a master's degree in music performance on trombone from the University of Southern Mississippi in 1983, he taught instrumental music grades K-12 in the Klein School District (Houston, Texas) and the Danville, Illinois School District for a number of years.

In 1990, Doug graduated with an associate's degree in cardiopulmonary technology from Sante Community College in Gainesville, Florida, to pursue a career as a cardiovascular sonographer. Doug worked as a clinical sonographer, hospital department manager, and eventually as a traveling sonographer over the next 13 years. In October, 2003, he joined the Diagnostic Medical Ultrasound Program in the School of Health Professions at the University of Missouri -Columbia as a clinical instructor and clinical coordinator in cardiac and vascular ultrasound.

Doug completed the Masters of Health Science degree in ultrasound in 2005. He was promoted to Clinical Assistant Professor in the DMU program in 2007, and then to Clinical Associate Professor in May, 2012. He began his doctoral work in the Education Leadership and Policy program within the College of Education during the summer of 2005.

Doug has served on the continuing education committee as a reviewer of submitted educational materials, and was also a member of the product review committee for the Society of Diagnostic Medical Sonographers (SDMS). He has also been a member of the American Society of Echocardiographers (ASE) for a number of years.

He currently enjoys working as a clinical sonographer and teacher at the University of Missouri. Music continues to be an avocation in his life by playing trombone in various community musical groups such as the Columbia Civic Orchestra and Columbia Community Band. Future vocational aspirations include teaching, research, writing, and service to the profession of sonography.