DISSERTATION

# SPATIAL ABILITIES OF CONSTRUCTION AND RELATED PROFESSIONALS


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# ABSTRACT

## SPATIAL ABILITIES OF CONSTRUCTION AND RELATED PROFESSIONALS

Researchers have established that spatial ability is a predictor of success in science, technology, engineering, and mathematics (STEM). Unknown are the differences of spatial abilities among Construction Professionals comparative to other STEM and Non-STEM Professionals. The purpose of this study is to discover if there are specific activities, experiences, or education that are perceived to improve mental rotation abilities among practicing professionals in construction and related fields. Participants for this study were coded into four groups of professionals consisting of Construction Professionals, Construction Related Professionals, STEM Professionals and Non-STEM Professionals (N = 238). The population from which the sample was drawn came from a purchased national email list organized by Standard Industry Classification (SIC) codes.

Utilizing a survey instrument and the Purdue Spatial Visualization Test: Rotations (PSVT:R), differences in spatial ability were measured among these groups of professionals. A statistically significant difference was found between the mean scores of Construction Professionals and Non-STEM Professionals ($p = .016$), and an effect size of .031 was reported. No other statistically significant differences in mean scores exist among the four groups.

Test results facilitated comparisons of ability with self-attributed activities that enhanced spatial ability. Analysis showed that drawing was attributed more frequently among high scoring individuals (52%) than low scoring individuals (15%) as a useful activity enhancing spatial ability. PSVT:R scores were also compared with the amount of time per day participants made use of their spatial abilities. No statistically significant difference was found.

Findings from this study suggest that higher spatial abilities are present among Construction Professionals and add an important dimension to industry recruitment with the potential implementation of spatial ability testing. Construction education curriculum likewise benefits from these findings that suggest drawing as an important activity increasing one's spatial ability.

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# CHAPTER 1: OVERVIEW

One indicator of success within construction management education is dependent upon the ability to read and correctly interpret construction drawings (Bhattacharjee, Ghosh, Young-Corbett, & Fiori, 2012). Since a certain level of mental rotation ability (a sub-factor of spatial intelligence) is required to mentally picture a two-dimensional (2-D) drawing in three-dimensional (3-D) completed form, improvement of these skills is important to the advancement of construction management pedagogy. Discovery of specific activities, experiences, or education that are perceived to improve mental rotation abilities is the primary goal of this dissertation.

Research has shown spatial intelligence (the brain's ability to perceive and interpret visual stimuli) to be a predictor of future success within Science, Technology, Engineering and Mathematics (STEM) (Uttal et al., 2013). Those employed within STEM disciplines have been shown to score higher than those in other academic fields on mental rotation tests (Wai, Lubinski, & Benbow, 2009). For the purpose of this dissertation, only those subjects that are specifically aligned or named: science, technology, engineering or mathematics will be identified as STEM, rather than the incomplete and often sub-sectioned occupational STEM definitions used by universities, government institutions, and in research papers and books. Classification of Instructional Programs (CIP) codes commonly list 40 separate STEM categories. These academic classifications are comparatively limited and focus mainly on career development rather than on occupational workforce development (Koonce, Zhou, Anderson, Hening, & Conley, 2011).

What appears to be missing from present literature is what type of experiences may be most effective in improving mental rotation abilities. To this end, identifying occupational groups with higher levels of mental rotation abilities may help isolate specific activities, education, or experiences that can help inform effective teaching pedagogies within construction management education.

One of the challenges of construction management education is creating a curriculum that provides graduates with a practical skill set aligned with the interests of the construction industry. Diversity of purpose within the industry exists among residential, commercial, heavy civil, and industrial construction and may create problems when considering effective course development at the university level. Industry preferences in organizational procedures, leadership styles, building techniques as well as a host of proprietary business practices make it difficult for construction education programs to create a one size fits all curriculum. Possibly due to this diversity, consensus between industry and academia was sought regarding the need for key technical skills required by construction graduates. In a survey conducted by Ahn, Kwon, Pearce, and Shin (2010), 148 respondents consisting of general contractors, project managers, project engineers and human resource managers from fourteen eastern states agreed that construction estimating and scheduling were both key competencies for construction graduates.

Program accreditation within construction management education is dependent upon certain credit hour accumulation in both construction estimating and scheduling. The American Council for Construction Education (ACCE) as well as the Accreditation Board of Engineering and Technology (ABET) are examples of two prominent U.S. accreditation bodies that require both estimating and scheduling (Document 103, 2014)

In a similar study to the one conducted by Ahn et al., Bhattacharjee et al. (2012) found that both construction industry expectations and construction education student perceptions ranked construction estimating first among 28 possible skills required by construction managers. More precisely, the construction knowledge listed for this skill was the ability to interpret construction documents (i.e., read plans). The sample consisted of students from two universities who were approaching graduation. The construction industry was represented by members of the participating universities' advisory boards consisting of general contractors, subcontractors, architectural, engineering, and consulting and design build firms (Bhattacharjee et al., 2012).

The precision of construction estimates and schedules are largely dependent upon the accuracy, detail, and completeness of construction designs (Gould & Joyce, 2009). The ability to read construction drawings and interpret construction specifications are considered two of the most basic and necessary skills for anyone involved in the construction industry (Jackson, 2010). In addition to the review and practice of these skills, it has been posited that a high degree of visual-spatial (specifically mental rotation) ability is helpful for successful visualization and comprehension of construction assemblies and components (Clevenger, Glick, & del Puerto, 2012). When acquired, high spatial ability is believed to help construction management students grasp newly introduced construction concepts. Conversely, the absence of spatial rotation ability makes learning difficult and frustrating for students in the construction management discipline (Glick, Porter, & Smith, 2012).

Spatial Ability is defined as: "…the ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object" (McGee, 1979, p. 893). The term "spatial ability" does not refer to these abilities as innate, but suggests they are acquired (Sorby, 1999). Mental rotation is a cognitive process and sub-factor of the spatial ability construct that allows one to mentally rotate two or three-dimensional objects to whatever direction at will. Mental rotation accurately represents the skill set required to read construction plans in a 2-D format and then envision those same plans as a finished product in 3-D.

The individual's perceptions of their ability to mentally rotate an object is the primary focus of this study. The definition of mental rotation has historically been limited to an intrinsic and static view of spatial skills. Sub-categories of spatial ability utilized within differing STEM fields, professions, and industries have been frequently labeled and re-labeled dependent upon the research focus of the authors. An example is the definition of spatial visualization offered by Newcombe and Shipley (2015): "Piecing together objects into more complex configurations or visualizing and mentally transforming objects, often from 2-D to 3-D or vice versa" (p. 7). A definition similar in some aspects to mental rotation and therefore applicable to this study.

Both construction and engineering education have recognized spatial abilities as an indicator of future academic success (Glick, Porter, & Smith, 2012; Sacks & Barak, 2009; Sorby, 2007). Success is defined as greater conceptual understanding and academic achievement (Uttal et al., 2013; Wai et al., 2009). This realization has led some within engineering education and construction management education to focus on the creation of a spatial abilities improvement pedagogy for their students (Glick et al., 2012; Sacks & Barak, 2009; Sorby, 2007). This development has taken several forms. In the case of construction management, the use of 3-D models in place of simple 2-D plans or pictures to explain multifaceted component integration has shown promise in increasing students' understanding of complex construction problems (Clevenger et al., 2012). Robust spatial training was implemented and measured within engineering education. Sorby (2007) tested incoming engineering freshmen and developed an engineering graphics course at Michigan Tech, Houghton, MI to help students improve their spatial ability (specifically mental rotation) and increase their confidence. These courses ultimately increased student retention rates within engineering (Sorby, 2007).

To improve the mental rotation abilities of construction education students, a fundamental understanding of spatial intelligence and skill development are required. According to the developmental psychologist Piaget, spatial skills are developed in three progressive levels of understanding (Bishop, 1978). Level one encompasses the acquisition of topological skills. The second level consists of the ability to visualize an object in 3-D and imagine what it will look like from different reference points, as well as being able to mentally rotate that object. The third level of spatial understanding is most complex. Level three is considered to be a combination of measurement concepts and visualization skills (Sorby, 2007). Because of the added measurement component, this third, or higher, level of spatial ability aligns with the skills necessary to correctly read and interpret 2D construction documents.

Testing for individual spatial ability varies depending upon the specific factors of spatial abilities being measured. Several spatial abilities tests are available and include the Mental Cutting Test (MCT) used for complicated, multistep manipulations of presented stimuli; the Mental Rotations Test (MRT) used to compare or match 3-D objects; and the Revised Minnesota Paper Form Board Test (RMPFBT) for testing imagery capacity, part-whole relationship skills, and the ability of individuals to manipulate objects in space (Maeda & Yoon, 2013b). Other spatial ability tests include the Differential Aptitude Test: Spatial Relations (DAT:SR) used to measure everyday physical forces and principles recognition ability; and the Purdue Spatial Visualization Tests: Visualization of Rotation (PSVT:R) used to measure 3-D mental rotation abilities. The MRT and DAT:SR along with the PSVT:R have been used to predict student success within engineering education (Maeda & Yoon, 2013b).

Detailed studies measuring student spatial abilities (specifically mental rotation) are limited within construction education, yet other academic disciplines such as engineering (Sorby & Veurink, 2010), mathematics (Wai et al., 2009), chemistry (Bodner & Guay,1997), and medicine (Keehner, et al., 2004) have produced several studies identifying strong spatial (mental rotation) ability as a predictor of success within their domains. Much of the spatial ability research in engineering, as that conducted by Sorby (2007), has acknowledged that while individuals differ in spatial performance, spatial ability can be improved through training and practice. Research findings and opinions vary on what types of practice are most beneficial.

A related question to what type of spatial ability training is most beneficial to construction education, is whether specific groups of individuals displaying a high level of innate mental rotation ability cluster in groups (communities of practice) within specific career fields, and if so, which ones? If individuals or groups with high spatial abilities could be identified, common practices, education, or shared experiences could provide insight into more effective instructional methods.

The term "Communities of Practice" (CoP) was first coined by Etienne Wenger (2009) and Jean Lave. Wenger (2009) and Lave define CoP as "…groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (p. 1). More important to this study, Wenger's research lists groups of engineers who are engaged in solving similar problems as a definitive CoP. Reflecting upon engineering, architecture, construction, or manufacturing design departments, not to mention hospitals or other scientific research facilities, it becomes easy to envision these groups as uniquely creative and productive communities.

Measuring the mental rotation abilities of individuals within STEM disciplines is limiting. Higher spatial abilities (including mental rotation abilities) of individuals employed within STEM are well documented (Wai et al., 2009), yet assuming that all people who display higher spatial abilities are all employed with STEM disciplines is highly presumptuous. To identify activities or groups that necessitate or develop greater mental rotation abilities, comparisons among both STEM and non-STEM CoPs would be beneficial.

**Research Problem**

To identify specific activities that might improve individual mental rotation ability and help facilitate the development of effective construction education curriculum, identification of groups or individuals who exhibit high levels of mental rotation ability is required. Educational studies indicate that individuals employed within STEM occupations are inclined to higher levels of spatial ability (Kell & Lubinski, 2013). Missing from the literature are measurements of mental rotation ability among those who regularly make use of similar skills sets, but fall outside the academic STEM definitions (CIP codes); one example being dentistry (Koonce et al., 2011). Also missing are mental rotation ability measurements from construction industry and related specialists who are believed to make regular use of spatial abilities within their professions (Glick et al., 2012).

**General Research Questions**

For the purpose of this study mental rotation ability will be measured using the Purdue Spatial Visualization Test: Rotations (PSVT:R). The PSVT:R is specifically designed to test the mental rotation ability of individuals aged 13 and over (Bodner & Guay, 1997). This test will be used to help answer the three following questions: 1) Is there a difference in mental rotation abilities among Construction Professionals, Construction Related Professionals, other STEM

Professionals, and Non-STEM Professionals? 2) What shared experiential activities are related to higher or lower than average mental rotation abilities? 3) Is there a difference between PSVT:R scores and the regular use of spatial skills among all respondents?

It is the intent of this study to discover if different groups of professionals have differing PSVT:R scores than the other groups. Research has shown that individuals with certain skill sets tend to cluster in groups, specifically identified as CoP (Wenger, 2009). Identification of particular CoP with higher mental rotation abilities may help isolate educational or life experiences that can be simulated in the classroom and help build a more robust, spatial intelligence enhancing syllabus for construction management students.

**Significance of the Study**

The purpose of this study is to add to the body of quantitative research on spatial intelligence and improve overall understanding of the subject, a rationale that fits well into the post-positivist paradigm (Gliner, Morgan, & Leech, 2009). Research has shown that through repeated practice, certain aspects of spatial abilities can be improved; principally mental rotation ability (Sorby, 2007). Identification of mental rotation ability among certain groups of professionals may help isolate work related activities that either require or improve these skills. Presently, academia is attempting to determine which pedagogies improve spatial abilities. Predominately, academia is developing spatial ability training based upon the results of classroom interventions and repetitive measurement of students' spatial ability scores (Sorby, 2007).

Utilizing the PSVT:R within professional fields provides comparisons with academia and adds to the validity of testing across diverse samples. Additionally, introduction of specific mental rotation abilities testing such as the PSVT:R among a wide range of professionals allows a more specific analysis of mental rotation abilities.

**Constructs Relevant to Study**

**Building Information Modeling** (BIM): Intelligent, model based process that provides insight to help architects, engineers, and other design professionals plan, construct, and manage buildings and infrastructure.

**Communities of Practice (CoP)**: Groups of people who share a concern or a passion for something they do and learn how to do better as they interact regularly (Wenger, 2009).

**Construction documents:** Written specifications and drawings that provide the requirements of a construction project (Smit, 2000).

**Construction Professional:** Individuals who regularly design, develop, manage, organize or control a construction project.

**Construction Related Professional:** Individuals who support construction professionals by providing, selling, or offering expert advice on construction components, equipment, unique or task specific sub-components or designs.

**Mental rotation:** Cognitive process to mentally rotate 2-D or 3-D objects to whatever direction at will.

**Non-STEM Professionals:** Individuals who might regularly make use of similar skill sets common to STEM, but remain outside of the narrow definition of the STEM acronym, meaning only those subjects that are specifically aligned or named: science, technology, engineering or mathematics.

**Spatial ability:** General term that refers to an individual's mental abilities to visualize, transform, and manipulate nonverbal information, such as symbols, figures, and 2-D and 3-D objects based on visual stimuli (Carroll, 1993; Linn & Petersen, 1985; McGee, 1979).

**Spatial Cognition:** Spatial features, properties, categories, and relations perceived, stored and remembered objects, persons, events to construct explicit, lexical, geometric, cartographic and artistic representations (Olson, Bialystok, & Erlbaum, 1983).

**Spatial perception:** ". . . is the ability to sense the size, shape, movement, and orientation of objects" (McAuliffe, 2003, p. 1).

**Spatial visualization:** Mental manipulation and integration of stimuli consisting of more than one part or movable parts (Olkun, 2003).

**STEM:** Acronym referring to varied academic disciplines grouped as science, technology, engineering and mathematics.

**Success**: Greater conceptual understanding and academic or professional achievement (Uttal et al., 2013; Wai et al., 2009).

**Delimitations**

This dissertation is restricted to the psychological construct of spatial intelligence and its utilization as a predictor of success within construction, STEM, and related professions. For the purposes of this study, success is defined as a greater conceptual understanding and academic or professional achievement (Uttal et al., 2013; Wai, Lubinski, & Benbow, 2009). Participants for this study were chosen from four of the ten SIC categories based on probable interaction with the construction industry.

## Assumptions

It is assumed individuals who responded to this study answered the PSVT:R questions honestly and without maliciously intending to skew their responses. Also postulated is that groups of particular STEM professionals such as engineers, architects, construction managers, etc. constitute CoP and will mimic the relevant literature and include individuals with high mental rotation ability. The possibility of disconnected emails`, transferred, terminated, or promoted employees likely decreased the number of potential respondents.

# CHAPTER 2: REVIEW OF LITERATURE

This chapter presents a literature review on spatial ability to provide a general conceptual understanding of the construct of spatial ability and 3-D mental rotation, measured by the Purdue Spatial Visualization Tests: Visualization of Rotations (PSVT:R). The first section reviews the construct of human intelligence, its beginnings and the discovered importance of spatial ability as a sub-factor of general human intelligence. The literature review incorporates how spatial ability factors have been identified and defined in other pertinent studies. The second section of this review focuses on spatial ability as a predictor of success within STEM education and specifically construction management education. The third section is devoted to communities of practice as clusters of professionals with potentially high levels of spatial ability.

## Human Intelligence Measurement

Simple intelligence tests (or mental tests) were initially created in the mid-19$^{th}$ century as an offshoot of eugenics, the science dealing with the improvement of human hereditary qualities through controlled breeding. Although different from current intelligence tests, Francis Galton's "Anthropometric Laboratory" began as a London Museum sideshow in 1884. Participants paid a small fee to have their abilities observed and recorded as they worked an assortment of unusual mechanical devices. Harmonizing with the science of his day, Galton was measuring the differences in individual attributes in an attempt to discover a "superior breed" of human. Galton (a half-cousin of Charles Darwin) was a hereditarian, a strong advocate for nature over nurture in the ongoing academic debate of his era. By designing his "Anthropometric Laboratory", he was attempting to establish a set of principles, which could be used to predict the natural abilities of young adults (Fancher, 1985).

The question as to whether intelligence quotient (IQ) is mainly hereditary or can be influenced by environment is an ongoing debate. However, driven in part by the popular but controversial book published in 1994 by Richard Herrnstein and Charles Murray titled *The Bell Curve*, critical reviews by academic leaders in the field of intelligence research were forthcoming. A review of *The Bell Curve* was completed by a task force of academics hand-picked by the Board of Scientific Affairs (BSA). The chair for this project was Ulric Neisser, Professor of Psychology from Emory University, Atlanta, GA. Their paper titled: *Intelligence: Knowns and Unknowns* was published in 1996 and provided some clarity and consensus on the subject of human intelligence (Neisser et al., 1996). Due in part to ongoing research on the subject of intelligence, an update of the Neisser paper was produced in 2012. Nisbett et al., (2012) came to consensus regarding the following subjects: heritability (genes), the effect of environment, gender, and race. While neither gender nor race are within the scope of this study, they are of major interest within the field of intelligence research (Fancher, 1985).

Referencing Galton (1822-1911), heritability has been linked to intelligence differences from its conception. According to Nisbett (2012), "Most studies estimate that the heritability of IQ is somewhere between .4 and .8 (and generally less for children)…" (p. 132), or more simply put, heritability is responsible for somewhere between 40 and 80% of our intelligence. However, the authors state that awarding a single value (or percentage) for heritability of intelligence makes no sense because this trait depends on the variance of both genotype and environment, neither of which can be under the complete control of the experimenter (Nisbett et al., 2012). Additionally, Gottfredson indicates both genetic and environment affected intelligence, which can be altered if one considers diabetes or poor vison for genetics and injuries or neglect for environment (1997).

### Factors of Intelligence

In 1927, Charles Spearman published his work on the nature of individual intelligence and on the structure of human abilities in which he proposed the two factor theory of intelligence (Lohman, 1996). For statistical measurement, factors are variables (or groups of variables) of interest that are identified and then measured against response variables. Spearman labeled the first part as a "general factor" or *g*. This meant that all correlated ability variables always remained the same for the individual being tested. The second part was labeled as the specific factor or *s* and varies from individual to individual and varies among differing abilities of the individual (Spearman, 1927).

While the construct of *g* is theoretical, *g* is often expressed as the general factor that correlates on all IQ tests. However, it should be mentioned that theorists express highly varying views on this subject. Because *g*(*v*) or spatial ability is a main focus of this study, it is necessary to offer an explanation of general intelligence. Therefore the following summation and synthesis of prevailing opinions offered by Mackintosh (2011) provide a broad explanation of *g*:

> Although Fluid Ability (the ability to think abstractly, solve problems, and discern relationships) g(f) is closer to g than other second-stratum factors in the Cattell-Horn-Carroll (CHC) model, the two are probably the same.
>
> The general factor extracted from one large and diverse test battery is effectively the same as that extracted from another.
>
> Working memory, speed of processing, and learning ability are all relevant to performance on a variety of IQ tests: whether they are sufficient to explain *g* remains uncertain.
>
> *g* is more important at low levels of intelligence that at high levels.
>
> Whether or not there is any process or processes common to performance on all IQ tests (the jury is still out), *g* could arise from the overlap of processes engaged by different tests, or from differences in the strategies different people use to solve the same test (p. 165).

According to Lohman (1996), Spearman may have helped create a paradox in spatial abilities research in regard to the two factor approach. Spearman considered spatial abilities as an unreliable measurement of *g*. Spatial intelligence studies suggest that in reality, performance tests of spatial abilities such as blocks, form boards, or paper folding are among the best indicators of *g* (Lohman, 1996). Spatial abilities are often cited as key indicators of higher, creative intelligence as applied in the fields of science and mathematics. Conversely, spatial abilities are equated with concrete, lower level thinking. These abilities are requisite for the prediction of success in the practical and technical fields of mechanics and carpentry (Lohman, 1996). The potential paradox lies in the point that hierarchical models of human abilities give *g* priority over the measure of spatial ability. This means that once the effects of g are accounted for in the statistical model, the majority of the systematic variance is gone. Other than in human ability tests, specific tests of spatial ability are not widely used except as predictors of job performance, most prominently within the fields of science, technology, engineering, and mathematics (Lohman, 1996; Uttal et al., 2013).

During the 1940s, Raymond Cattell expanded on the two-factor concept and is credited with developing the constructs of Fluid Intelligence *g*(*f*) and Crystallized Intelligence *g*(*c*). Fluid Intelligence was described as “the ability to solve unfamiliar problems using logical reasoning” (Schneider & McGrew, 2013, p. 772). It has been suggested that people with a high degree of fluid intelligence are able to solve problems with limited instruction. Conversely, crystallized intelligence is referred to as acquired knowledge and refers to knowledge acquired from the learning and experience of others (Schneider & McGrew, 2013).

John Horn continued to expand Cattell’s *g*(*f*)-*g*(*c*) theory to include Auditory Processing *g*(*a*) and Visual-Spatial Ability *g*(*v*). The Cattell-Horn-Carroll (CHC) theoretical model of intelligence is a blending of the former analytical factor processes and of Carroll's Three-Stratum theory. The CHC theory resulted in a model that includes nine broad stratum abilities and over seven times that may narrow abilities. The nine include the abilities listed above along with crystallized intelligence $g(c)$, fluid intelligence $g(f)$, quantitative reasoning $g(q)$, reading and writing ability $g(rw)$, short term memory $g(sm)$, long-term storage and retrieval $g(lr)$, and processing speed $g(s)$ (Kozhevnikov, Kosslyn, & Shephard, 2005).

Due to the ongoing debate about the legitimacy of these abilities or sub-factors, one can easily be swept down a rabbit hole while attempting to decipher which factors best represent general intelligence. Yet some level of definition is required to provide validity to intelligence metrics. Gottfredson (1997) provided an easily understood definition of intelligence in a statement that was a clarification of many of the concepts presented in the *Bell Curve* (Herrnstein & Murray, 1994). This definition best represents the intended construct for this study:

> Intelligence is a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings--"catching on," "making sense" of things, or "figuring out" what to do (p. 13).

Although somewhat removed from the early reasoning of intelligence pioneers (i.e., Galton, Seguin, and Spearman), many divisions of academia, industry, and government still conduct intelligence testing. It has been repeatedly demonstrated that $g(c)$ is an effective predictor of future learning and performance (Lohman, 1996). While knowledge of general intelligence can be helpful, specific tests for factors of general intelligence are commonly used for prediction within particular disciplines.

## Measuring Spatial Intelligence

Contrasting the nature versus nurture opinion held by Galton, physician Edouard Seguin developed the form board test during this same time period to assess and train cognitively impaired children (Boake, 2002). The form board test was designed to measure 2-D spatial ability by showing individuals geometric shapes, and then asking which of several provided designs could be created from those shapes. Seguin's form board test was an early spatial ability test, as it was developed to test associational skills using different shapes in different colors (Dearborn, Anderson, & Christiansen, 1916). The form board tests are still a popular method of spatial ability assessment. In addition to the early form board tests, Galton developed a set of line bisection tests, which were designed to measure a person's visual perceptions. These tests and others were added to the tests used by Galton for research on American college students in the 1890s. It was from these tests that the term "mental tests" was coined. Acknowledging that the purpose of mental testing has changed over time, the metrics have not. Even the Wechsler intelligence scales that were originally developed in 1939 dominate the majority of individual intelligence measurements (Boake, 2002).

The evolving purposes of many of the original intelligence tests were twofold: to help identify school children who had difficulty handling the curriculum, as was the case with the Binet-Simon test, and the second was to help predict success in particular occupations. The latter reason was promoted by the U.S. Army during the First World War. They wanted to know if potential recruits were fit for military service (Boake, 2002).

Some challenges that the Army and their Committee on the Psychological Examination of Recruits had to deal with were illiteracy and speaking English as a second language, as well as speaking no English. The Army's original Alpha intelligence test analyzed math abilities, information processing, and practical judgment. All questions on the Alpha test were provided in a written format. If a recruit failed the Alpha test, the Beta test was given. The Army's Beta test was primarily pictorial, with an instructor providing the necessary instructions verbally (Boake, 2002).

Spatial intelligence scores made up a significant portion of these early mental tests. Spatial ability tests can be categorized into four subgroups: performance tests, paper and pencil tests, verbal tests, and film or (more recently) dynamic computer-based tests (Lohman, 1996). The earliest of these performance tests were used by Binet and Simon and consisted of the form board, block manipulation, and paper folding tests. An early and highly original performance test popular with Binet was to blindfold chess players and analyze their playing abilities. Not surprisingly, Binet discovered that the majority of the players could not continue the game, yet, a select few could. Those who succeeded explained they could visualize the chess pieces and remember their relationships to the board as well as the positions of their opponent's pieces. Amazingly a few of the blindfolded players could play multiple games simultaneously (Lohman, 1996)! The ability to mentally envision multiple items and their potential interactions is the primary reason performance based spatial ability tests are appropriate for individuals working in fields that require visualization skills such as engineering, construction, and medicine.

While simplicity may be a key component in Binet's chess experiments, the discovered differences in the players' abilities correlate well with modern definitions of spatial ability, one definition being "…the ability to generate, retain, retrieve, and transform well-structured visual images" (Lohman, 1996, p. 98). An additional definition provided by McGee (1979) specifically indicates the actions required for a high level of spatial intelligence and was aptly demonstrated by Binet's most impressive chess players is "…the ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object" (p. 893).

More practical and refined spatial tests were created during the first half of the $20^{th}$ century. Testing for future success within the field of engineering was the passion of Clair V. Mann. Professor Mann taught in the Department of Engineering Drawing (Missouri School of Mines) between the years of 1920-1946 and was responsible for creating a great number of spatial visualization tests. Mann claimed these visualization tests were indisputable as indicators of specific abilities due to the necessity of engineers to mentally visualize a completed project or component (Deno, 1995; Miller, 1996). The tests implemented by Mann in 1930 included: Mann's Mutilated Cubes Test, Mann's Drawing Aptitude Test, Mann's Dynamicube Test, Mann's Straticube Test, and McCauley's Tetrahedron Test (Miller, 1996). The construct being measured in these performance tests was generalized simply as visualization ability.

One of Mann's objectives was to establish national norms for performance on visualization tests to predict the future success of engineering students (Miller, 1996). Others were developing standardized tests for use in predicting success in the fields of drafting, design, and several other STEM fields. Many of these tests, such as the Minnesota Paper Form Board Test, the Link Spatial Relations Test, and the Packing Block Test, are still being used (Linn & Petersen,1985; McGee, 1979).

While the exact definitions for spatial ability have changed and evolved over time, Linn and Petersen (1985) were extremely helpful in aggregating spatial ability into three categories: *spatial perception*, *mental rotation*, and *spatial visualization*. Spatial perception is described as the ability to determine spatial relationships concerning the position of one's own body. An example of this ability would be that used by gymnasts or airplane pilots with regard to their location above a balance beam or an aircraft's attitude (roll, pitch, and yaw). Mental rotation tasks deal with a participant's ability to mentally rotate one object to align it with another, and then make a judgment as to whether or not the two objects are alike (Linn & Petersen, 1985). An example of mental rotation ability are those visualization skills used by architects and engineers who look at construction plans and need to recognize the same component from a different view or perspective.

While sometimes used synonymously with spatial ability, spatial visualization is more precisely defined by Linn and Petersen (1985) as skills "associated with those spatial ability tasks that involve complicated, multistep manipulations of spatially presented information" (p. 1484). While not exclusive of the same mental process required for mental rotation, spatial visualization lacks specificity and often requires more than a single mental process (Uttal et al., 2013).

**Levels of Spatial Ability**

According to the developmental psychologist Piaget, spatial skills develop in three progressive levels of understanding (Bishop, 1978). Level one encompasses the acquisition of topological skills. These skills are visualizing in 2-D and are usually acquired at a young age (3-5 years). Of the three levels discussed, this is the only level not measured by the PSVT:R. Associated with this initial skill level is the recognition of an item's relationship to other objects, as well as its separation or inclusion in the larger environment. The second level consists of the ability to visualize an object in 3-D and imagine what it will look like from different reference points, as well as being able to mentally rotate the object. Typically, most children have acquired this skill by adolescence. However, some individuals, including college age students, have trouble with this level of spatial ability if an object is unfamiliar. The third level of spatial understanding is most complex. At this level people are able to visualize the concepts of area, volume, and distance in combination with the skills of translation, rotation, and reflection. Level three is considered to be a combination of measurement concepts and visualization skills (Sorby, 2007). This level of spatial ability is required to obtain full understanding (visualization) of the intricacies and interworking of complex, large scale projects or problems. It is this level of spatial ability that technical educators aspire to have students acquire (Huk, 2006).

As explained by Piaget's levels of skill acquisition, the upper range of spatial ability is multifaceted and complex allowing individuals to combine high levels of spatial skills (Bishop, 1978). The lower range of spatial ability (specifically visualization) has a new and unfortunate benchmark of no ability, which appears to remove the capacity to mentally visualize any images. Research conducted by Zeman, Dewar, and Della Sala (2015) provides insight into this phenomenon known as aphantasia. Possibilities of causation range from trauma to psychological conditions.

Mental rotation accurately represents the skill set required to read construction plans in a 2-D format and then envision the same plans as a finished product in 3-D. Arguably, this is one of the most important cognitive skills a construction manager can obtain. It would be difficult to imagine proper coordination of a large-scale construction project without being able to mentally picture the construction site, construction sequence, building, or the proper flow of resources.

### Spatial Ability and STEM

Cross sectional studies repeated, such as those conducted by Sorby and Veurink (2010) have shown that spatial abilities increased among entering engineering students during a 14 year period due in part to specific spatial training. Research conducted over several decades has shown that spatial abilities assessed during adolescence indicate future success within STEM related fields of education and occupation (Wai et al., 2009). One such study concluded that spatial abilities had a unique role in the development of creativity beyond the normally measured intelligence constructs. This was apparent when the spatial ability of 563 participants, who were all published in the fields of the arts, humanities, law, the social sciences, as well as the STEM fields of biology and medicine, were compared. Those in STEM had the highest spatial ability scores overall, commonly scoring above the sample's mean. However, participants outside of STEM who had acquired patents within their fields had similar spatial ability scores suggesting that familiarity and experience with the regular practice of these skills enhanced individuals' ability (Kell, Lubinski, Benbow, & Steiger, 2013).

Inventors like Nikola Tesla and James Watt as well as generalists like Benjamin Franklin, Francis Galton, and James Watson claimed that their spatial abilities played a significant role in their greatest accomplishments (Lohman, 1996). The self-assessing opinions of these prominent intellectuals correlate closely with Thomas Armstrong's (2009) inventory of high spatial ability individuals. Dr. Armstrong's list includes Frank Lloyd Wright, Andy Warhol, Orville and Wilber Wright, and Amelia Earhart. Admittedly, Armstrong's definition of spatial ability on multiple intelligence is broader than most, he has noted the abilities of highly creative individuals to "Perceive the visual-spatial world accurately and perform transformations upon those perceptions" (Armstrong, 2009, p. 7).

Armstrong's observations provide assurance that not all high spatial ability individuals cluster in one field any more than artists prefer one medium of expression. Visualization or imagination is a human ability, articulated at varying levels of complexity and understanding. Accepting the variance in approach to visualization is helpful to divide STEM competencies into cognitive and non-cognitive domains (Carnevale, Smith, & Melton, 2011). The cognitive competencies include knowledge, skills, and abilities (KSAs), many of which are learned through instruction, schooling, and experience. Conversely, non-cognitive STEM competencies, according to the author, include work interests and values. Carnevale et al. claim that non-cognitive competencies help determine a person's success and interests within a STEM related career field and help explain workplace clustering of people within particular talent fields (2011).

Research conducted by Carnevale et al. (2011) made a distinction between STEM and management disciplines. Because management is the control of both people and resources, management skills are inarguably a component of construction management education. However, by the authors' definition construction management education also falls under the STEM umbrella due to students doing "STEM work" as they make use of skills required for plan reading, surveying, computer aided design (CAD), and materials science. In a study by Bhattacharjee et al. (2012), members of two U.S. university advisory boards consisting of contractors, subcontractors, architectural, engineering, consulting, and design build firms were surveyed about the construction industry's required skills and knowledge and compared with those universities' construction students' perceptions of industry's required knowledge and skills. Of 28 required skills listed by the construction advisory council member, both councils members and the university students ranked the ability to interpret construction documents (this includes plan reading as a major component) as the most important skill. The ability to visualize 2-D drawings in 3-D must be acquired to fully comprehend construction plans and written project specifications; two core abilities for accurate project estimates and schedules. When acquired, spatial skills are believed to help students grasp newly introduced construction concepts. Conversely, the absence of these skills makes learning difficult and lessens (or removes) the ability to visualize the construction process. In rare cases, such as individuals with aphantasia, the entire absence of the mental visualization process is a possibility.

**The STEM Acronym**

Problems arise when attempting to precisely define or place individuals, industries, or professions within the STEM acronym due to the biases of invested parties. These parties include government officials who direct billions of dollars into public education, interested parents who might struggle to understand how this meta-subject affects their child's curriculum, or a particular industry seeking to improve or grow a more specialized workforce (Breiner, Harkness, Johnson, & Koehler, 2012).

Due in part to the perceived relationship of STEM professions on economic productivity in the workforce (Freeman, Marginson, & Tytler, 2014), there exists concern within the United States that high school students are avoiding consideration of STEM related careers. The U.S. Department of Education reports that 16% of high school seniors who are proficient in mathematics have an interest in STEM careers (U.S. Department of Education, 2014). This disturbing statistic correlates with research conducted at the University of Cincinnati by Breiner et al. found full time, college level faculty (n = 222), 72.5% could accurately identify what the STEM acronym stood for, with 36% of the same group claiming that STEM had no noticeable impact upon their lives (2012). Even more alarming, is the copious amount of funding being distributed by the U.S. government for STEM education. The federal investment in STEM education for the year 2011 totaled more than \$3.7 billion, with an additional \$4.3 billion being invested in the *Race to the Top* competition where STEM was used as the "sole competitive preference priority" (Breiner et al., 2012, p. 5). Unquestionably, it is this level of monetary investment that motivates colleges and departments to self-qualify as STEM education institutions.

## Construction Management within STEM

The struggle for construction management inclusion within the STEM domain becomes more pronounced when reviewing the myriad of STEM sub-categories that may or may not be related to a particular industrial, pedagogical, or academic discipline. The admitted bias of this study is the inclusion of construction management education within the STEM construct. Often construction management education is within university engineering programs and designated as construction engineering, construction engineering management, or construction management technology. Examples of such departments include those located at Purdue (Indiana), California State-Long Beach, Arizona State University, and Oregon State University. These programs have the advantage of being administratively connected to the ‘E” of STEM. Other university systems may designate their construction management programs as stand-alone departments or place them within business or other colleges. Academically, this allows for some debate as to whether or not construction management is a STEM discipline. The ACT College Readiness Assessment has become an advocate by listing construction management within the engineering discipline column (Carroll, 1993). Conversely, construction management has a CIP code of 52.2001 and falls under the category of business, management, marketing, and related support services. These CIP codes are provided for National Center for Education Statistics (NCES) to track and assess specific fields of study (U.S. Department of Education, 2010).

## Expected Differences in Spatial Ability

In the aforementioned work of Kell et al. (2013), analysis revealed that those holding degrees in STEM scored higher on *g* and their spatial scores exceeded their verbal scores.

Conversely, the opposite pattern was found in other fields that included the arts, humanities, law and social sciences. Notwithstanding the participants were all considered to be “successful” in their fields, the groups showed measured differences in ability. While much of the literature suggests that spatial ability can predict success within particular fields, the work of Kell et al. (2013) suggests that differences in spatial ability among groups of professionals can be expected.

Ideas on why individuals with high spatial abilities might gravitate toward particular career fields are presented in a substantial 1979 longitudinal study, Project TALENT. This source was reviewed by Wai et al. (2009) and focused on spatial abilities and interests of adolescents. The majority of these gifted adolescents preferred working with their hands, making repairs, and working with inanimate objects. After eleven years, it was found that these same students had excelled at a higher rate than their peers in earning bachelor’s, master’s, and doctoral degrees. The review suggested that adolescents who liked to disassemble electronic devices might find success performing similar tasks, but at an advanced level in adulthood (Wai et al., 2009).

**Communities of Practice**

According to Carnevale et al., STEM related jobs are clustered in professions commonly associated with high levels of spatial abilities such as engineers, engineering technicians, and manufacturing (46%) (2011). However, this same group of authors indicate that high levels of STEM educated employees are concentrated in traditionally non-STEM related fields such as professional and business related industries (26%) (Carnevale et al., 2011). While spatial abilities are referenced as indicators of success within STEM, limited research has been conducted on the spatial abilities of professionals in non-STEM fields.

The clustering of professionals in organizations, particular industries or groups is likely an age-old occurrence, yet research conducted by Wenger (2009) adds clarification to this phenomenon when he states: “Communities of practice are groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly” (p. 1). Wenger (2009) explains three characteristics are required to meet the definition above: they are the domain, community, and practice. A Community of Practice goes beyond club status. The community’s domain is based upon a shared interest as well as a specific knowledge base, and inclusion within the community requires a commitment to that domain. People who work within a certain profession are not automatically a CoP unless members learn and act together. Wegner (2011) makes the point that the community must actually interact together sharing: “...experiences, stories, tools, ways of addressing recurring problems—in short, a shared practice” (p. 2). Following this definition, this study’s construct of construction professionals who share a high level of regular, complex communication regarding building projects would constitute a CoP.

Detailed studies exploring construction students’ spatial abilities are limited, yet other academic disciplines such as engineering, mathematics, chemistry, and medicine have several studies identifying strong spatial ability as a predictor of success within their domains (Bodner & Guay, 1997; Contero et al., 2005; Hauptman, 2010; Hegarty, Keehner, Khooshabeh, & Montello, 2009). Certain academic fields have made pedagogical adjustments within their curriculum in an attempt to increase the spatial ability of their students. Engineering education has placed renewed emphasis on the importance of entry level engineering graphics courses as an approach to improve students’ visual spatial ability. Much of the spatial ability research in engineering, as conducted by Sorby (2007), has acknowledged that while individuals differ in spatial performance, spatial component skills can be improved through training and practice. Opinions and research vary on what type of practice is most beneficial.

Similar to the work done in the latter half of the 19th century, more recent literature agrees that the measurement and identification of individual intelligence are still important to both education and industry. Gains in the understanding of human intelligence and its contributing factors will continue to play a role in advancing effective pedagogy. Likewise, the capacity to measure spatial ability has shown predictive value for success in fields that demand high creativity, productivity, and the ability to visualize complex problems.

# CHAPTER 3: METHODOLOGY

This chapter presents research design rationale including the research questions and the survey instrument used to address these questions. The survey instrument, the PSVT:R, was piloted to inform modifications for the study. The survey instrument was distributed to study participants and the findings analyzed using both descriptive and statistical approaches.

## Research Design

The research philosophy that drives this study is post-positivist. The positivist side of the spatial ability constructs deals with simple observation, the rejection of anything metaphysical, and an unbiased approach designed to measure a given phenomenon (Trochim, 2005). While it is the intention to maintain the focus and rigor common to the positivist view, it is this study's goal to explore people's perception of their mental rotation abilities (visualization), which moves this research into the post-positivist scope of observation. This study rejects positivism and the possibility of one correct interpretation of discernible events or objects. Acknowledging the literature, it is understood that different backgrounds, education, and beliefs of the survey respondents may alter their perceptions (Olson et al., 1983).

Personal observations while teaching as a graduate assistant led me to question why some students had difficulty interpreting construction plans while others excelled. It seemed that certain students interpreted plans by identifying combinations of lines as physical objects, while others only perceived chaos. This in turn led to some preliminary study of spatial ability/visualization literature and the possibility of teaching to improve students' mental rotation abilities. Making use of the literature on spatial abilities, I introduced numerous 3-D models created using Google Sketch-up software into class sessions. Students reported they had an easier time understanding complex combinations of construction assemblies. While this method improved the speed and level of understanding, much of the construction industry still communicates using 2-D documentation, necessitating the improvement of spatial abilities, rather than providing augmentation using 3-D models

The research design was chosen to address specific questions regarding spatial abilities among Construction Professionals, Construction Related Professionals, other STEM Professionals, and Non-STEM Professionals. This study focuses on the attributes of the participants, their spatial abilities, and the relationship between those abilities and time spent utilizing these skills. Therefore this study made use of a quantitative, non-experimental, comparative approach (Gliner et al., 2009). Human subjects' approval was granted on April 11, 2014 (Appendix A).

**Participants and Sampling**

This population was selected for two primary reasons: findings from a pilot study suggested that the experience of college age construction management students was too limited to show a relationship between work experience and mental rotation abilities. Therefore, a more experienced sample was desired. Additionally, a large number of studies utilizing the PSVT:R have drawn samples from STEM fields (Bodner & Guay, 1997; Maeda & Yoon, 2013a; Sorby, 2007). As stated in the literature, both construction industry and education professionals benefit from greater mental rotation abilities (Bhattacharjee et al., 2012). For this reason, and their direct connection to construction education, Construction Professionals and Construction Related Professionals were specifically chosen as two of the sample groups. Similarly, the third group encompasses engineering education, mathematics, and the hard sciences and can be categorized within STEM and whose practitioners benefit from comparably high mental rotation abilities

(Black, 2005; Messner & Horman, 2003; Sorby & Veurink, 2010; Uttal et al., 2013). The final group for this study consists of Non-STEM Professionals who through business affiliations with the construction industry probably make use of higher spatial abilities.

Challenges in specifically defining the divisions within the four groups emerge among Construction Professionals, Construction Related Professionals, and engineers who could be classified as Construction Professionals. The blurring of task responsibility among these three groups can be alleviated with the following clarifications. Construction Professionals included in group one consist of individuals who design, prepare, plan, direct or organize construction projects. Professionals comprising this group will include architects, civil engineers, and construction managers and others who meet the aforementioned criteria. Group two will be Construction Related Professionals required to support the professionals in group one by providing expert consulting, product or construction component installation, or application expertise. Examples within group two include, but are not limited to, product consultants, consulting engineers or others called upon to correct or repair unforeseen problems with the initial project process and design. Group three consists of other STEM Professionals including engineers who are not directly involved with construction design or processes and STEM educators.

Lastly, group four includes other non-STEM professionals who may have ancillary relationships to construction and may regularly make use of higher spatial abilities, but who do not fit the criteria of the first three groups. These include pattern makers, non-construction related crafts persons, and professional organizers as examples.

The coding into the four designated subject groups initially is based upon the individual's employment position and secondly by position within an industry. This follows the logic that an individual using STEM related skills is more closely tied to their role than an industry. The necessity of position before industry sorting can be explained by the following scenario: Both a National Aeronautics and Space Administration (NASA) janitor and aerospace engineer ultimately help launch rockets. However, it is probable that the aerospace engineer regularly applies STEM related skills while the janitor may not.

The sampling for this study was gathered from Lead411.com, a purchased email list. Contacts provided by Lead411 comprise the entire sample. The initial Lead411 email list contained over 120,000 emails. The list was reviewed for the duplication of emails, which resulted in the identification of 41,247 unique email addresses. The email list stated the industry associated with the email. The SIC was used to organize all contacts in order to identify emails associated with the construction industry.

SIC codes are used in empirical research to identify industry membership and were developed in the United States in 1937 (Guenther & Rosman, 1994). SIC codes are used by several government agencies and other countries to classify industry areas (For a list of example SIC codes see Appendix B). Out of the ten SIC categories, four were chosen: construction, manufacturing, finance, and public administration.

Based on the definition of STEM as defined in this study and the literature regarding STEM, four analysis categories were derived: Construction Professionals, Construction Related Professionals, STEM Professionals, and Non-STEM Professionals; referenced as four professional groups.  Once the surveys were returned the respondents were categorized first by current position, and then by industry sector into one of the previously defined four groups for analysis. The coding process is discussed in chapter 4 under instrument validity.

**Survey Measures**

The questionnaire for this study was developed from the literature as well as the lessons learned from initial survey of students (pilot study) to better understand a potential relationship between time in industry and individual mental rotation abilities. This was done to ensure that the email sent to potential respondents, provided the information needed to adequately answer the survey questions. The survey instrument was designed to answer the research questions by means of a short questionnaire and the PSVT:R; a 20 item, timed mental rotations test. The demographic questions consist of: the industry in which the respondent was currently employed (question 1), current position (question 2), age (question 3), and gender (question 4).

Following the initial four questions, respondents were asked to complete the PSVT:R within 10 minutes (listed as question 5 on the survey). Following the administration of the PSVT:R, respondents were asked four additional questions encompassing their level of training (question 6), events or educational experiences they believed had enhanced their abilities to visualize items in 2-D or 3-D (question 7), if they were able to mentally rotate the 3-D test objects, and if they were, to list three events or experiences that helped them perform that task (question 8). Finally, they were asked how often (percentage of time) they make use of spatial skills within their current position (question 9).

**Validity**

Two types of validity need to be addressed in any study: external and internal. External validity has to do with the ability to generalize to a population (Creswell, 2009). Internal validity is affected by errors in the study design or issues with the research interment (survey) (Creswell, 2009). External validly is not an issue as this study is not trying to generalize to a population. Internal validity is addressed in the limitations and delimitation sections.

Prior to the distribution of the industry survey, a panel of PhD candidates from multiple educational disciplines reviewed the survey questions. Questions regarding age, gender, current profession and position, educational levels and experience were critiqued to ensure their ability to answer specific research questions and provide general demographic information regarding respondents.

**The Purdue Spatial Visualization Test: Rotations**

To measure mental rotation abilities, respondents were asked to complete the revised (20 question) PSVT:R. The PSVT:R was developed by Roland Guay of Purdue University in 1976 and is one of the tests least likely to be complicated by analytical processing (Guay, 1976). Research supports the use of mental rotations tests like the PSVT:R as effective in measuring both intrinsic and static spatial skills, such as mental visualization and transformation (Uttal et al., 2013).

The original PSVT:R consisted of 30 unfamiliar isometric objects a respondent was required to mentally rotate within a 20 minute time period (Branoff, 1998). The revised PSVT:R created by Bodner and Guay (1997) has been refined and modified over time by the authors and now consists of 20 items to be answered in 10 minutes. Consistent with the earlier versions of the test, mental interpretation of the objects increase in level of difficulty as items progress. The first objects presented require mental rotation of 90°, while later objects require mental rotation of 180°. Concluding objects require a 90° rotation about one axis and an additional rotation of 180° about a second axis (See Figure 1 for a 90° rotation example). Because the PSVT:R is designed to become progressively more challenging as the respondent advances, distinction among respondents' PSVT:R scores show an accurate difference in mental rotation ability. (See

Appendix C for a complete list of survey questions and the PSVT:R. See Appendix D for test answers).

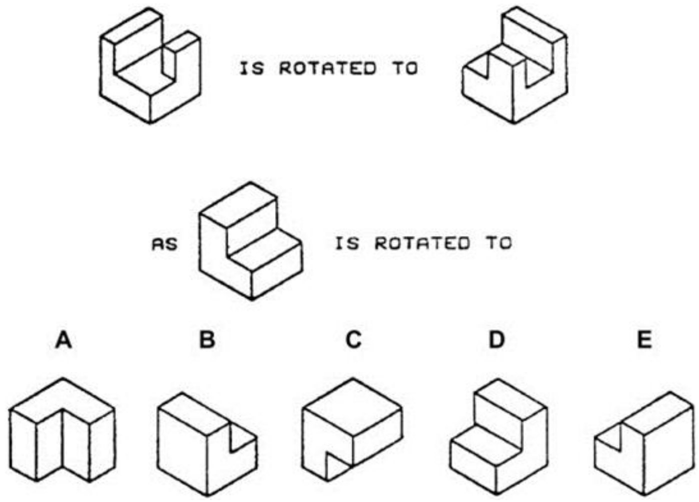


Figure 1: Purdue Spatial Visualization Test: Rotations, Example Question.

Several studies in various technical disciplines have used the PSVT:R to measure individuals' mental rotation abilities. The data were analyzed using the Kuder-Richardson Formula 20 (KR-20) to measure internal consistency. Meaning…a high degree on internal consistency makes the test more reliable as shown in Table 1 (Branoff, 1998). A more recent study by Maeda, Yoon, Kim-Kang, and Imbrie (2013a) reassessed and confirmed the validity of the revised PSVT:R instrument. Although they did not utilize the KR-20, they used a variety of statistical methods including exploratory and confirmatory factor analysis and item analysis.

*Table 1: Internal Consistency of PSVT:R Reporting the KR-20 from Studies in Varied Disciplines*

| Author(s) | Year Reported | Samples (N) | KR-20 |
|---|---|---|---|
| Guay | 1980 | 217 university students | .87 |
| | | 51 skilled machinists | .89 |
| | | 101 university students | .92 |
| Battista, Wheatley, and Talsma | 1982 | 82 preservice elementary teachers | .80 |
| Sorby and Baartmans | 1996 | 492 freshman engineering students | .82 |
| Branoff | 1998 | 249 undergraduate students | .82 |

**Pilot Study: Initial Student Survey**

As previously mentioned a pilot study was developed to explore the potential relationship between student time in the field and mental rotation ability.. The purpose being that experiences such as time spent performing a particular activity may provide insight into activities most beneficial for the improvement of mental rotation test scores. This was done to insure that the questions posed provided information necessary to answer the research questions.

The pilot study was conducted using a convenience sample of construction management students ($n = 43$) enrolled in a construction scheduling class at a single university. To investigate the relationship between the time students spent working construction and student scores from the PSVT:R, Pearson's product-moment correlation was used. A low, negative correlation between these two variables was observed: $r(41) = -.378$, $p < .05$.

According to Fryer, Fryer, Egbu, Ellis, & Gorse, (2004) construction related decisions range from routine and short-term to unstructured and long-term. They suggest there are definite steps to effective problem solving, yet for simple problems this process is often overlooked. For routine construction tasks, workers will follow a standardized or time proven processes with minimal analysis required. In other words, for simple or repetitive construction tasks there are no true problems to solve; no visualization of a task or project need occur.

The premise based upon pertinent literature was that technical experience is a key contributor in the development of spatial skills (Höffler & Leutner, 2011; Mayer & Sims, 1994). From the student sample, 3% had no experience, 19% had less than 1 year of experience, and 30% had 1 to 2 years of experience. Another 30% had 3 to 4 years of experience, and 6% reported 5 or more years of construction experience. The average duration of work experience for the students was 2.26 years. The amount of time the students spent in the construction field likely limited mastery of any one trade, limiting advancement into a position requiring a higher level of problem solving.

Measuring the spatial abilities of a sample of more experienced participants was needed to explore the development of spatial abilities. Both an individual's profession and position were needed to classify potential CoPs and identify shared experiences that may promote spatial abilities.

**Data Collection**

Initial survey distribution began on April 23, 2014 when 4,988 surveys were electronically mailed. An introductory letter was sent to the potential respondents explaining the purpose of the questionnaire and mental rotations test (Appendix E). Those interested were able to choose to take the survey by clicking a button at the bottom of the page. Two weeks after the initial email was sent, reminder emails were sent to those who had not opened the survey. This follow up process provided minimal additional respondents (Appendix F).

**Response Rate**

A limitation of sending out the survey using Qualtrics was the distribution constraint of 5,000 emails per mailing, and an additional limitation of one mailing allowed per 5 day -week. During a nine week period, 41,247 surveys were sent in 9 mailings.

Among these surveys, 9,779 were opened (24%), 408 respondents began the survey (4%) and 238 completed the survey (2%). The respondents who began the survey divided by those who completed the survey provide a completion rate of 57%. The response rate for those who opened and completed the survey is 2%.

While acknowledging that researchers should do all that is possible to reduce nonresponse, adequate or acceptable survey response rates vary depending upon the discussion in the literature and opinions on acceptability for generalization. Both the literature in journal articles and textbooks provide a wide range for response rates from 25% to 75%, in order to generalize to the entire population suggesting significant variation on this subject (Groves, 2006). Groves (2006) argues that late responders will introduce response bias into a study because of additional time allowed to reflect on the survey questions.

Evaluation of the low response rate was done by splitting the sample between early and late respondents. Late respondents were defined as those who completed the survey at 35 days or later (two standard deviations above the mean). The mean PSVT:R scores were then compared between the early (n=173) and late responders (n=65) using a t-test to address a potential internal validity problem of allowing greater time for late respondents to consider their answers. There was a statistically significant difference in the scores for early responders (M = 11.31 SD = 4.45) and late responders (M =13.45 SD = 4.15); $t(236) = -2.07$, $p = 0.04$. Utilizing a Cohen's d the effect size was 0.497, which according to Gliner et al. (2009), is a medium effect size (p.25). This indicates that late responders may have a statistically significant higher average score than those responding early.

Due to the wide range of acceptable survey response rates needed to generalize to the population as previously discussed, a sample size calculator provided by Survey Monkey was used. Since this study is not trying to generalize the results, the use of this calculator is acceptable since we are more concerned with margin of errors and confidence levels than generalizing the sample to the population. As such, a sample size of 262 was needed for a margin of error of 5% and for a confidence level of 90% (Survey Monkey, 2015).

**Data Analysis Plan**

As presented in the review of the literature, spatial ability can be improved through experience as well as specific training (Clevenger et al., 2012; Field, 2007; Sacks & Barak, 2009; Sorby, 2007). The ability to visualize and comprehend components, designs, and patterns are shared attributes of Construction and Construction Related Professionals, STEM Professionals, as well as Non-STEM Professionals (Bodner & Guay, 1997; Contero et al., 2005; Hegarty et al., 2009; Workman, 1999). Specific shared attributes, activities, and experiences among these professionals who might improve mental rotation abilities are unknown. Identification of shared mental rotation attributes, activities, or experiences among these different groups of professionals will help identify potential teaching pedagogies for construction education students.

RQ1) Is there a difference in PSVT:R scores (mental rotation abilities) among the four defined groups of professionals?

$H_0$1) There will be no differences in PSVT:R scores among the four defined groups of professionals.

RQ2) Among respondents, which experiential activities are common to those with higher or lower than average PSVT:R scores?

RQ3) Is there a difference between PSVT:R scores and the regular use of spatial skills among all respondents?

The specific research questions, variables, and appropriate statistics, as discussed below, are shown in Table 2. Survey items 3 (age), 4 (gender), and 6 (training level) are used to profile the respondents.

*Table 2: Research Questions, Variables, and Statistics for Analysis*

| Research Question | Survey Item(s) | Independent Variable | Measurement / Dependent Variable | Analysis |
|---|---|---|---|---|
| RQ1 | Questions 1,2, | Professional Groups | PSVT:R (Survey question 5) Score (possible range 0 to 20) | One-Way ANOVA, Tukey Post-hoc Test |
| RQ2 | Questions 7,8 | Experiential Activities | PSVT:R Score | Response % by Category |
| RQ3 | Question 9 | Daily Use of Spatial Skills (% of day) | PSVT:R Score | One-Way ANOVA |
| | Question 3-6 | Profiled Sample | | |

**Data Analysis**

Descriptive statistics were used for a summary of the data as well as an indicator of how each group performed on the PSVT:R. The four groups of survey respondents served as the attribute independent variable, and scores from the PSVT:R as the dependent variable (Gliner et al., 2009). The four professional groups were coded by number and segregated by both industry and employment position for entry into SPSS. Construction Professionals were coded as group one, Construction Related Professionals group two, STEM Professionals group three, and Non-STEM Professionals are group four (Appendix G).

Data were then evaluated among the four groups. To maintain test validity, it is recognized that the groups within the sample needed to be similar in size to maintain a balanced design. A one-way ANOVA assumes homogeneity of variance, meaning that variances within the separate groups are equal while the variance among groups were tested. A Levene test was used to test for homogeneity of variance.

A one-way ANOVA was used to examine any statistically significant difference in PSVT:R scores among the four groups (Table 2). One-way ANOVA are standard for determining if there are differences between the mean scores of two or more groups (Lund & Lund, 2013a). The p value for this study is .05, which is commonly used in social science research. The p value is a calculated probability for finding the observed results when the null hypothesis is true.

A Tukey Honest Significant Difference (HSD) post-hoc test was utilized to test all possible group comparisons when a statistically significant difference was found in the one-way ANOVA. According to Morgan, Leech, Gloeckner, and Barrett (2007), a moderate post-hoc test such as the Tukey HSD can identify which groups' mean scores differ from the others.

Respondents were asked in questions 7 and 8 to list their perceptions of what experiences helped augment their mental rotation skill ability. Examples of these experiences by coded category and related respondent comments are shown in table 3

*Table 3: Respondents Listed Experiences Augmenting Mental Rotation*

| Coded Categories | Examples of Experience Comments in Category |
|---|---|
| Genetics/ Intrinsic | *Innate skill* |
| Technical Drawing / Design/ CAD | *Engineering education, CAD drafting* |
| Education/ Mathematics | *Descriptive geometry, design school* |
| Construction Experience / Plan Reading | *Job plans, working on a construction site* |
| Tactile Mechanics and Hobbies | *Model building, wood working* |
| Toys / Games /Puzzles | *Legos* |
| Aviation/Sailing | *Military helicopter pilot* |
| Video Games | *Tetris* |
| None | *None- I was a business major* |

Factors reported to affect mental rotation abilities include levels of training, and education (Uttal et al., 2013). These factors acquired from the survey were used as control variables and offer explanations for differences in PSVT:R scores.

As previously stated, the goal of this research sought to understand practitioners' perceptions of attributes that helped develop their mental rotation abilities. To accomplish this task, the research questions focused on mental rotation ability, experience, and profession. Using a survey methodology the data were analyzed using comparative and descriptive statistics.

# CHAPTER 4: ANALYSIS AND FINDINGS

Chapter 4 presents the data analysis and findings of the survey. Findings comprise the instrument validity, descriptive analysis and results from quantitative analysis utilizing a one-way ANOVA, and a summary of the findings. The purpose of this study is to discover specific activities, experiences, or education perceived to improve mental rotation abilities.

Research question one focused on differences in PSVT:R scores among Construction Professionals, Construction Related Professionals, STEM Professionals, and Non-STEM Professionals. Survey items one and two provided respondents with open-ended questions regarding their industry and current employment positions. Their responses allowed the researcher to code respondents into one of the four professional groups.

Research question two sought to discover experiential activities common to respondents with either higher or lower than average PSVT:R scores.  Survey item seven asked respondents to list three experiences that helped them visualize objects in both 2-D and 3-D. Survey item eight asked respondents to list educational experiences that help them perform the task of 3-D mental rotation. Respondents either answered these questions similarly, or left question eight blank. This may suggest that respondents saw no difference in the questions and did not take the time to provide similar answers. Combined answers were reviewed and organized into nine categories as displayed in chapter 3 (Table 3). Experiential responses were compared by percentage with respondents who either scored within the range of one standard deviation above the mean PSVT:R score (high) or one standard deviation below (low).

Research question three sought to compare the regular use of spatial skills with respondents' PSVT:R scores. Survey item nine asked respondents to choose from five "time duration" categories measured by percentage of the day in which they made use of mental rotation skills.

**Descriptive Analysis**

The data for this study were collected using Qualtrics software and transferred to SPSS for analysis. Respondents who failed to list profession or position could not be properly placed in one of the four professional groups based upon SIC codes and were excluded from the study. Likewise those who failed to complete the PSVT:R were excluded. Of the four groups of professionals completing the PSVT:R, the highest average score was reached by Construction Professionals (12.84). The highest overall score (perfect score of 20) was achieved by an individual in the Non-STEM Professional group. The lowest minimum score (2) was found in two groups, Construction Related Professionals and Non-STEM Professionals (see table 4).

*Table 4: PSVT:R Scores and Descriptives of the Four Professional Groups*

| Group | N | M | SD | Min. | Max. |
|---|---|---|---|---|---|
| Construction Professional. | 56 | 12.84 | 4.053 | 4 | 19 |
| Construction Related Professional | 22 | 10.91 | 4.839 | 2 | 19 |
| STEM Professional | 37 | 12.32 | 4.460 | 5 | 18 |
| Non-STEM Professional | 123 | 10.72 | 4.417 | 2 | 20 |
| Total | 238 | 11.49 | 4.453 | 2 | 20 |

**Sample Demographics**

The respondents (N = 238) for all groups who participated in the survey were predominately male (68%). Of the four defined groups of professionals, those coded as Non-STEM Professionals made up the largest group (52%); Construction Related Professionals were the smallest of the four groups (9%). The profile of the four defined groups of professionals is presented in Table 5.

*Table 5: Professional Group Demographics Totals and Percentages*

| Professional Groups | Female | Male | Total | Group |
|---|---|---|---|---|
| | | Frequencies | | % |
| Construction | 8 | 48 | 56 | 24 |
| Construction Related | 6 | 16 | 22 | 9 |
| STEM | 11 | 26 | 37 | 16 |
| Non-STEM | 52 | 71 | 123 | 52 |
| Total | 77 | 161 | 238 | 100 |
| Gender % | 32 | 68 | | |

Of the 238 respondents, 224 answered the survey question regarding their level of training and 33% reported having earned a college degree, and 63% reported having earned a graduate degree. The frequencies of respondents by training level and professional group are outlined in Table 6.

*Table 6: Frequency of Training Level by Professional Groups*

| Training Level | Construction | Construction Related | STEM | Non-STEM |
|---|---|---|---|---|
| n = | 55 | 18 | 36 | 115 |
| High School | 1.82 | 0.00 | 0.00 | 0.00 |
| Some College | 0.00 | 0.00 | 0.00 | 1.74 |
| Associates Degree | 3.64 | 0.00 | 0.00 | 0.00 |
| College Degree | 49.09 | 61.11 | 0.00 | 20.87 |
| Graduate Degree | 43.64 | 38.89 | 33.33 | 74.78 |
| Technical School | 1.82 | 0.00 | 66.67 | 0.00 |

### Instrument Validity

Participants were coded as Construction Professional, Construction Related Professional, STEM Professional, or the Non-STEM Professional. To ensure consistency in coding, a definition of each of the four professionals groups was provided to each of the three coders. A Cohen's κ was run to determine if there was agreement among the three observers' judgments on whether the 238 professionals were coded into the same categories. There was a moderate agreement among the three observers' judgments, $\kappa = .593$, $p < .0005$ (Landis & Koch, 1997).

#### Self-Reporting

Questions naturally arise concerning the value of self-reporting and personal observations of events or experiences. The survey utilized several specific questions that required respondents to report their perceptions and list events they regarded as influential to their abilities to mentally visualize and rotate 3-D objects. According to Podsakoff and Organ (1986), there are three challenges to the validity of self-reporting that must be addressed. These challenges include *artificial covariance* between self-reported measures, the *consistency motif*, and the *social desirability* problem.

The challenge of *artificial covariance* occurs when two reported measures come from the same source, thereby potentially contaminating both measures in the same manner and in the same direction (Podsakoff & Organ, 1986). This study avoids this by comparing differences between one objective and one subjective variable (PSVT:R score and profession).

Issues with the *consistency motif* occur when respondents submit to the urge to maintain a consistent line through a series of answers. People have a tendency to interrelate organizations and outcomes (e.g., educational level and ability) when asked for summary judgments (Podsakoff & Organ, 1986). This is supposedly less of a problem when reporting discrete events such as the PSVT:R. The test was a discrete event because survey respondents were not aware of their score and not able to compare answers with their measured ability.

The challenge of *social desirability* ensues when respondents answer questions in such a way as to portray themselves in a favorable light (Podsakoff & Organ, 1986). The dependent variable was the PSVT:R, which is neither an opinion nor event. The independent variable is likewise unaffected because the instrument design required respondents to list both their industry and position. Self-promotion within an organization would not change how respondents were coded into professional groups.  An example would be if a desk librarian falsely listed themselves as a director. Coding for both positons would still place the respondent with the Non-STEM Professionals group.

The challenge of artificial covariance within this study was mitigated due to the PSVT:R score being an objective variable. The *consistency motif* is likewise mitigated because participants were unaware of their test scores. Finally, *social desirability* would be a problem only if participants falsely claimed position within a different industry causing their scores to be analyzed within the wrong group. This hypothetical event seems unlikely.

Challenges associated with self-reported activities provided by respondents are acknowledged, yet due to the survey instrument design and use, the three common threats to instrument validity were mitigated.

**Research Question One**: Is there a difference in PSVT:R scores (mental rotation abilities) among the four defined groups of professionals?

To test whether these groups vary in PSVT:R scores, a one-way ANOVA was used; the null hypothesis being that there will be no difference in scores among groups. This section reviews the assumptions and procedures considered in conducting the one-way ANOVA.

There are six assumptions to assure a valid one-way ANOVA (Lund & Lund, 2013a). The first assumption is that there is a continuous dependent variable, and the PSVT:R score meets this assumption. Assumption two is that the independent variable has two or more independent groups. As there are four defined groups of professionals, this assumption is also met. The third assumption is the independence of observations. The members of the groups are distinct. The four groups are not nested in organizations or subject to repeated measures. Assumption four is that there are no outliers. Due to the constrained dependent variable (PSVT:R score) and common range variation of scores, the possibility of outliers were substantially reduced.

The fifth assumption is the normal distribution of dependent variable. The Shapiro-Wilk was utilized because of its design for groups of less than 50. Its null hypothesis is that the dependent variable is normally distributed within each group. Thus, the significance test rejects this null hypothesis in the Construction Professional Group, Construction Related Professional Group, STEM Professional Group, and the Non-STEM Professionals Group. Results are shown in Table 7. This finding was confirmed by the histograms shown in Figure 2.

*Table 7: Shapiro-Wilk Test of Normality for the PSVT:R Scores by Professional Group*

| Professional Groups | Statistic | df | Sig. |
|---|---|---|---|
| Construction | .945 | 56 | .013 |
| Construction Related | .965 | 22 | .597 |
| STEM | .889 | 37 | .001 |
| Non-STEM | .961 | 123 | .001 |

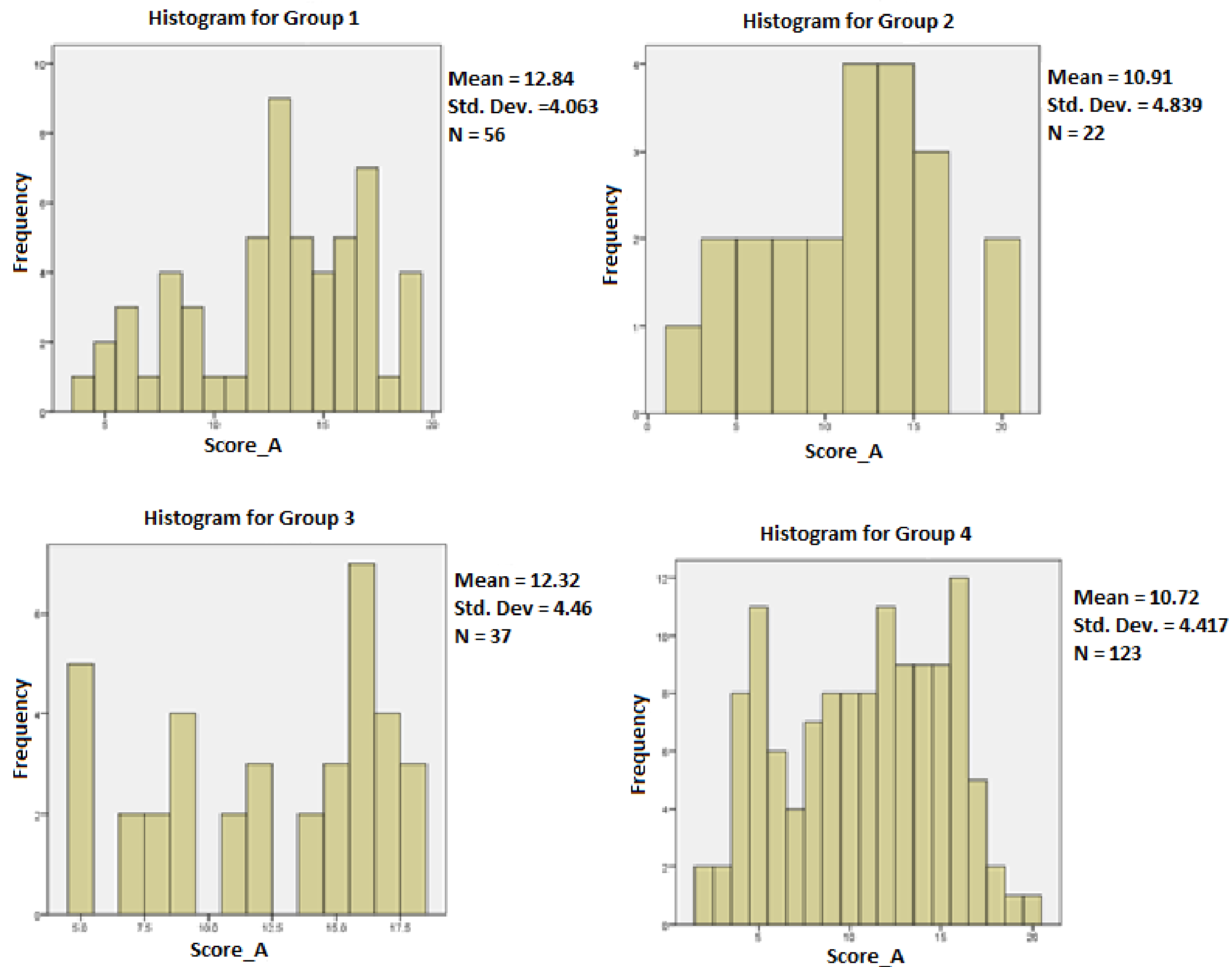

Figure 2: Dependent Variable Distributions for each Professional Group

One approach in dealing with the lack of normalcy in the dependent variable is mathematically transforming the dependent variable (e.g. logarithm, square root) and creating histograms of the dependent variable for each group. This process of checking normalcy was completed using Stata software. This action made a slight improvement to Non-STEM Professionals.  The other three professional groups saw no change as shown in the comparative histograms (see Appendix H). Because the non-normality assumption has been shown not to substantially affect the Type 1 error rate (the rejection of a true null hypothesis), a one-way ANOVA was used. Violations of this assumption will be noted as needed.

The sixth assumption is the homogeneity of variances. A Levene's tests the homogeneity of variances; the null hypotheses being that the variances are homogeneous. The Levene Statistic of this test was .916 and was not statistically significant (*p* = .434). Therefore, the hypothesis is retained and the assumption of homogeneity of variance holds.

The research hypothesis states that there exists a difference in the PSVT: R scores among groups. The null hypothesis being that there will be no difference in scores among the groups. Table 8 shows the results of the one-way ANOVA and rejects the null hypothesis.

*Table 8: One-Way Analysis of Variance Summary Table for PSVT-R Scores by Groups*

| PSVT:R Score | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 207.381 | 3 | 69.127 | 3.601 | .014 |
| Within Groups | 4492.081 | 234 | 19.197 | | |
| Total | 4699.462 | 237 | | | |

While the one-way ANOVA indicates a statistically significant difference (p = .014) in mean scores among groups, it does not indicate which scores are different. Therefore, a post-hoc test is necessary. A Tukey post-hoc test is used for pair-wise comparison among groups assuming there is homogeneity of variance, previously shown with the Levene's test, and shown in Table 9 indicating the Construction Professional group's mean score was significantly different (12.84) from the Non-STEM group (10.72), but not significantly different from the Construction Related Professional (10.91) group or the STEM Professional's group (10.32).

*Table 9: Tukey Post-hoc Mean Score Comparison*

| Dependent Variable | | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| Construction | Construction. Related | 1.930 | 1.102 | .300 | -.92 | 4.78 |
| | STEM | .515 | .928 | .945 | -1.89 | 2.92 |
| | Non-STEM | 2.116* | .706 | .016 | .29 | 3.94 |
| Construction. Related | Construction | -1.930 | 1.102 | .300 | -4.78 | .92 |
| | STEM | -1.415 | 1.180 | .628 | -4.47 | 1.64 |
| | Non-STEM | .186 | 1.014 | .998 | -2.44 | 2.81 |
| STEM | Construction | -.515 | .928 | .945 | -2.92 | 1.89 |
| | Construction Related | 1.415 | 1.180 | .628 | -1.64 | 4.47 |
| | Non-STEM | 1.601 | .822 | .211 | -.53 | 3.73 |
| Non-STEM | Construction | -2.116* | .706 | .016 | -3.94 | -.29 |
| | Construction Related | -.186 | 1.014 | .998 | -2.81 | 2.44 |
| | STEM | -1.601 | .822 | .211 | -3.73 | .53 |

*. The mean difference is significant at the 0.05 level.

**Research Question One Summary**

A one-way ANOVA was conducted to determine if mental rotation abilities were different for professional groups classified: Construction Professionals (n = 56), Construction Related Professionals (n = 22), STEM Professionals (n = 37), and Non-STEM Professionals (n = 123). PSVT:R scores were statistically different among different professional groups, $F(3, 233) = 3.601$, $p = .014$. PSVT:R scores are different for Non-STEM Professionals ($M$ =10.72, $SD$ = 4.417) compared to the Construction Related Professionals ($M$ = 10.91, $SD$ = 4.839), other STEM Professionals ($M$ = 12.32, $SD$ = 4.460), and Construction Professionals ($M$ = 12.84, $SD$ =

4.053) groups. Tukey post hoc analysis revealed that the mean difference of Non-STEM Professionals to Construction Professionals (2.116, 95% CI [-0.92, 4.78]) was statistically significant ($p$ = .016), but no other group differences were statistically significant. The group means were statistically significantly different ($p < .05$) and, therefore, we can reject the null hypothesis.

**Effect Size**

Omega squared ($\omega^2$) is a measure of effect size, or degree of association for a population. Omega squared is considered to be less biased than eta-squared and is appropriate for this analysis due to small sample sizes. The Omega squared was .031, which indicates the effect size of the mean score difference is medium or typical (Gliner et al., 2009).

$$\omega^2 = \frac{SS_b - (df_b)MS_w}{SS_t + MS_w} \qquad \omega^2 = \frac{207.381 - (3)19.197}{4699.462 + 19.197} = .031$$

**Research Question Two**: Among respondents, which common experiential activities are related to higher or lower PSVT:R scores?

Open ended response to experiential activities were coded into eight categories that respondents attributed to their personal spatial rotational abilities, shown in Table 10. These categories were coded from the open-ended responses from survey question seven. The drawing category includes sketching, drafting, plan reading and CAD. Crafts include mechanics, woodworking, light construction, and art related craft projects. 3-D modeling includes the creation of both computer and physical models. The games category includes response for board games, computer games, 3-D games and puzzles. The math category includes both educational math classes and the regular use of mathematical systems and methods. The toy category includes Lego blocks, puzzles, and models. Innate ability was coded as genetics. The category of none was included because several people in the low score rank surmised that they had limited spatial abilities and expected a low score. Of the 238 respondents, 56 (24%) were categorized as high, receiving a PSVT:R score one standard deviation or more above the mean (15.94). In contrast 53 (22%) were categorized as low, receiving a PSVT:R score of one standard deviation below the mean (7.03) or lower.

*Table 10: Self-Attributed Experiential Activities*

| Activities | High Score (n=56) | Low Score (n=53) |
|---|---|---|
| | Number of activities selected | |
| Drawing | 52 | 15 |
| Crafts | 23 | 2 |
| Games | 21 | 9 |
| 3-D Modeling | 18 | 9 |
| Math | 18 | 20 |
| Toys | 7 | 0 |
| Innate Ability | 5 | 0 |
| None | 0 | 16 |

**Research Question Two Summary**

Comparison of respondents' self-attributed experiences to personal spatial abilities (shown as number of activities selected) display the greatest contrast in the drawing category. 3-D modeling, games, and crafts had greater frequency among those scoring in the higher category. Mathematics held a near equal response frequency between both groups.

**Research Question Three**: Is there a difference between PSVT:R scores and the regular use of spatial skills among all respondents?

Initially there were five categories of percentage of time per day spent using rotational skills on the job were compared with difference in mean scores on the PSVT:R. However, due to the size of group 4 (n = 3) and group 5 (n = 2), these groups were collapsed and combined with group 3 to create more equal sized groups. Participants were classified into three groups: those who reported using mental rotations skills for less than 10% of the day (group 1, n = 138), those using mental rotation skills 11- 25% of the day (group 2, n = 29), and those who reported using mental rotation skills greater than 26% of the day (group 3, n = 31).

The research hypothesis is there exists a difference in the PSVT: R scores among the groups depending on the amount of time spent regularly making use of spatial skills. The null hypothesis being that there will be no difference in scores among the groups. Table 11 shows the one-way ANOVA and retains the null hypothesis; there is no difference.

*Table 11: One-Way Analysis of Variance Summary for Time Spent Using Spatial Skills*

| PSVT:R Score | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 55.973 | 2 | 27.987 | 1.630 | .199 |
| Within Groups | 3348.537 | 195 | 17.172 | | |
| Total | 3404.510 | 197 | | | |

### Research Question Three Summary

A one-way ANOVA was conducted to determine if mental rotation abilities were different for three groups categorized by, percentage of time per day utilizing mental rotation skills. PSVT:R scores were not statistically different among the three groups, (2, 194) = 1.630, *p* = .199.: As such descriptives are not shown in table format.

## Chapter 4 Summary

Findings from this study indicate the PSVT:R scores from Construction Professionals were statistically significantly different than the scores from the Non-STEM Professionals, with Construction Professionals scoring higher. Mean scores among Construction Professionals, Construction Related Professionals, and STEM Professionals were not statistically significantly different. Mean PSVT:R scores among Non-STEM Professionals, Construction Related Professionals, and STEM Professionals were not statistically significantly different. Based upon the percentages of responses, 48% (52/109) of the respondents scoring one standard deviation above the PSVT:R mean listed drawing as an experience augmenting their mental rotation ability. Conversely, of those respondents scoring one standard deviation below the mean, 14% (15/109) listed drawing. The responses of this lower scoring group 15% (16/109) indicated that no experiences helped them with mental rotation. The high and low scores for math selection were nearly equal. Time spent daily making use of mental rotation skills did not result in a statistically significantly difference among the four professional groups taking the PSVT:R. .

# CHAPTER 5: DISCUSSION

This study sought to discover the specific activities, experiences, or education that are perceived to improve mental rotation abilities in four professional groups utilizing the PSVT:R and a survey instrument. Differences were measured among the four professional groups and when significant differences occurred, the Tukey HSD identified the professional groups with statistically significant differences.

**Research Question One: Difference**

Analysis revealed a statistically significant difference in the mean test scores from the PSVT:R between Construction Professionals and Non-STEM Professionals. The effect size of the difference between Construction Professionals and Non-STEM Professionals was small. Mean scores among Construction Professionals, Construction Related Professionals, and STEM Professionals were not statistically significantly different. Likewise mean scores among Non-STEM Professionals, Construction Related Professionals, and STEM Professionals were not statistically significantly different.

When compared with findings of Wai et al.'s (2009) in their 11+ year longitudinal study that adolescents with higher spatial abilities gravitated toward occupational (and academic) outcomes aligned with STEM. Interestingly, this was not the case with Construction Related Professionals and STEM-Professionals. While both of these groups may be considered STEM practitioners, they did not score significantly higher on the PSVT:R test than those in the Non-STEM group. One possible explanation for this occurrence was the large diversity of professions included within both Construction Related Professionals (9) and STEM-Professionals (33).

Participants in the Construction Professional group consisted primarily of architects, designers, civil and electrical engineers, and construction related managers. The initial observation presented a diverse group of individuals with varied educational backgrounds and distinctive responsibilities regarding successful construction project completion. Among construction professionals, the common need is to look at the same data and visualize the same finished product. Each individual is required to view, understand, and explain projects utilizing similar technology and terminology. An example would be the interpretations of an electronic or paper set of construction plans utilizing the uniform drawing code (UDC), specifying organization and utilizing a specific group of symbols. The enabling factor of this requirement is a higher level of spatial intelligence.

As stated in the literature (Wenger, 2009), engineering is a prime example of a CoP. Logically electrical engineers will understand one another, possibly age group dependent, even when communicating complex mathematical formulas that would be as mystifying as a foreign language to an outsider. Yet the shared knowledge, vision, and practices are part of the intellectual mortar that binds a CoP together. Similarly, Construction Professionals, while more diverse than one particular area of engineering, still share a common understanding to instigate effective collaboration. This study provides evidence that spatial intelligence, or the ability to interpret drawn lines, symbols, and figures as a solid object, provides a virtual Rosetta Stone for unique understanding within the community of Construction Professionals.

Adding to the argument that Construction Professionals constitute a knowledge dependent CoP, research conducted by Bilderbeek and den Hertog (1998) list specific building services (e.g. architecture, surveying, and construction engineering) as a Knowledge-Intensive Business Service or KIBS. The authors define KIBS as private companies or organizations that rely heavily on professional knowledge and supply intermediate products and services that are knowledge-based (Bilderbeek, & den Hertog, 1998). This study's findings of higher spatial abilities among Construction Professionals may provide a potential bridge between KIBS and CoPs. This concept suggests specific knowledge or intelligence as an important factor in defining specific professional communities and provides a working hypothesis for future research.

Findings from this research can benefit the construction industry. In addition to the dependence of talent searches upon experienced and education based resumes, spatial ability tests can be implemented to inform employers of a potential candidate's probability of success. Comparable to the research completed by Uttal et al. (2013), finding that higher spatial ability was a predictor of success within the STEM domains; this research adds the additional finding that those in particular CoPs may score higher than others within STEM.

**Research Question Two: Relationships**

To determine which experiential activities were common to those respondents with similar spatial abilities, respondents answered an open-ended survey question regarding experiences they believed helped them visualize the required mental rotations on the PSVT:R. Respondents were allowed to list multiple experiences. Forty-eight percent (52/109) of those respondents who scored one standard deviation above the mean score listed the experience of drawing as an enabling factor. No other experience received this frequency of response regardless of the respondent's score. In contrast, of those respondents scoring one standard deviation below the mean, 14% listed drawing as an enabling factor.

The experiential importance of drawing to mentally manipulate 3-D drawings adds to the research (and conclusions) of Olkun (2003) and Sorby (2007). Both of whom advocate freehand drawing as a significant experience to improve spatial ability. Sorby (2007) also lists other spatial ability improvement factors that surfaced in this study's findings. These include playing with construction related toys such as Legos, games, and mathematics. In this study, those identified with higher spatial skills, 7% listed toys, 21% listed games, and 18% listed mathematics as contributing factors in their spatial ability. Those identified with lower spatial skills generally responded in lower percentages concerning the same factors: None of the respondents listed Toys and 9% listed games. A slightly higher number of respondents (20%) listed mathematics.

These finding have implications concerning construction education and are comparable to the findings of Sorby (2007), suggesting spatial skills and the related ability to visualize objects can be improved by drawing (sketching). Therefore, if greater spatial ability allows for better visualization of construction plans, renderings, and models, logic would dictate a greater emphasis on drawing related course content may improve overall learning.

Construction management education would likely benefit from similar studies as those conducted by Sorby (2007) for engineering students. Measurement over time of change in students' spatial ability following training in hand sketching and engineering graphics could help identify effective pedagogy for improving students' spatial skills. Results from this study's perceived experiential advantages suggests that future research along this path could be informative.

**Research Question Three: Difference**

The third research question within this study asks if the daily use of spatial skills helped respondents complete the mental rotation tasks of the PSVT:R. Analysis revealed that there was no significant difference in mean test scores among the groups for the amount of time spent using spatial skills.

These findings appear to be in contrast to the meta-analysis conducted by Uttal et al. (2013), which found spatial skills to be highly malleable in that training not only improved spatial skills, but that spatial ability gained through training for a specific task was transferrable to other spatial tasks. One possible explanation is that specific spatial training and the daily use of spatial skills may take on different forms and therefore are not equal. Implications for construction education suggests that participation in activities requiring spatial skills may not be as effective as actual spatial training. No additional information on spatial training was solicited from participants.

**Limitations**

This section will focus on two dimensions of this study's limitations, those being study design and execution. This study's sample frame was random, since it was purchased from a third party that sells email lists. However, based upon low response rates from the survey and test, this study is not generalizable. While the literature provides a theoretical definition of a COP, this construct was not analyzed for this study as respondents were coded and categorized into four professional groups based on a conservative definition of STEM.

Survey instrument execution was hindered by recipients who opened but did not complete the survey and test. Two possible reasons for this action could be time required for survey completion and lack of motivation. Lack of motivation to complete the test may potentially have been overcome by an offered incentive such as a gift card to those who completed the survey and test. Survey item self-response is an additional limiting factor, as respondent's retrospection was required to recall self-attributed activities that may have improved their spatial abilities, rather than obtaining responses from specifically recorded events. Finally, responses regarding drawing as a self-attributed activity that enhanced spatial ability show exploratory evidence rather than causation.

## Significance of the Study

As previously stated, a challenge within construction management education is creating practical curriculum aligned with the needs of the industry. Even with the advancement in 3-D modeling software, the industry still places a high priority on the ability to correctly read and interpret construction plans in a 2-D format, requiring a higher level of spatial ability. This study found the group designated as Construction Professionals scored higher in mental rotation skills than Non-STEM Professionals.

Experiential activities common to those with higher spatial skills identified drawing as the most common activity. While other activities recognized in the literature as possible initiators of higher spatial ability were identified by respondents, none approached the level of drawing. As the construction industry adds new layers of technology, by necessity construction education may need to update curriculum to meet the needs of industry. However findings from this study suggest that drawing is a core skill that needs to remain in any updated pedagogy.

What this study did not find was a statistical difference in the time spent using spatial skills daily and mean scores on the PSVT:R. This finding combined with the previous finding suggest time spent performing one’s job and focused training may not be perceived to be equally beneficial.

## Future Studies

As stated previously, identifying Construction Professionals as a CoP could benefit the industry recruitment process. In addition to spatial ability testing, a more detailed investigation of shared practices, stories, concerns, and passions could solidify definitions and potentially create a standardized CoP identification process for the construction industry.

Findings from this study suggest the practice of drawing can improve spatial ability, however the findings are not definitive. A longitudinal study design implementing a pre/post-test with an intervention utilizing multiple drawing exercises is warranted to discover specifically which types of practice are most beneficial and efficient. Best practice identification could then be implemented to improve early construction education course design.

As previously discussed the PSVT:R accurately measured the difference in mental rotation abilities for this study. However, to improve research, construction education, and industry recruitment, the ability to accurately rank individuals by spatial ability level deserves further research. To this end, a blending of tests measuring multistep manipulations, object matching and comparisons, and physical force perceptions and mental rotations producing a single score is recommended. This is comparable to Piaget's three levels of spatial ability (Bishop, 1978). Ranking in this manner could help inform educators concerning missing components in an individual's spatial ability and allow for tailored instruction and course design.

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## APPENDIX A: HUMAN SUBJECTS APPROVAL

Colorado State University

**Research Integrity & Compliance Review Office**
Office of Vice President for Research
Fort Collins, CO 80523-2011
(970) 491-1553
FAX (970) 491-2293

Date: April 11, 2014

To: Carole Makela, Ph.D., Professor, School of Education
Scott Glick, Ph.D., Assistant Professor, Construction Management
Dale Porter, Doctoral Student, School of Education

From: Evelyn Swiss, CIP, IRB Coordinator Evelyn Swiss

Re: The Importance of Spatial Ability Among Intuitive Problem Solvers

**IRB ID:** 063 -15 **Review Date:** April 10, 2014
**This project is valid for three years from the review date.**

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The Institutional Review Board (IRB) Coordinator has reviewed this project and has declared the study exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b)(2): Research involving the use of educational tests,….survey procedures, interview procedures or observation of public behavior, unless: a) **information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects.**

The IRB determination of exemption means that:

- **This project is valid for three years from the initial review.** After the three years, the file will be closed and no further research should be conducted. If the research needs to continue, please let the IRB Coordinator know before the end of the three years. You do not need to submit an application for annual continuing review.
- You must carry out the research as proposed in the Exempt application, including obtaining and documenting (signed) informed consent if stated in your application or if required by the IRB.
- Any modification of this research should be submitted to the IRB through an email to the IRB Coordinator, prior to implementing any changes, to determine if the project still meets the Federal criteria for exemption.
- Please notify the IRB Coordinator if any problems or complaints of the research occur.

Please note that you must submit all research involving human participants for review by the IRB. **Only the IRB or designee may make the determination of exemption**, even if you conduct a similar study in the future.

C. Division C: Construction
- Major Group 15: Building Construction General Contractors And Operative Builders
- Major Group 16: Heavy Construction Other Than Building Construction Contractors
- Major Group 17: Construction Special Trade Contractors

# Major Group 15: Building Construction General Contractors and Operative Builders

This major group includes general contractors and operative builders primarily engaged in the construction of residential, farm, industrial, commercial, or other buildings. General building contractors who combine a special trade with the contracting are included in this major group.

**Industry Group 152: General Building Contractors-residential**
- 1521 General Contractors-Single-Family Houses
- 1522 General Contractors-Residential Buildings, Other Than Single-Family

**Industry Group 153: Operative Builders**
- 1531 Operative Builders

**Industry Group 154: General Building Contractors-nonresidential**
- 1541 General Contractors-Industrial Buildings and Warehouses
- 1542 General Contractors-Nonresidential Buildings, Other than Industrial Buildings and Warehouses

# Description for 1541: General Contractors-Industrial Buildings and Warehouses

Division C: Construction | Major Group 15: Building Construction General Contractors and Operative Builders

Industry Group 154: General Building Contractors-nonresidential
1541 General Contractors-Industrial Buildings and Warehouses

General contractors primarily engaged in the construction (including new work, additions, alterations, remodeling, and repair) of industrial buildings and warehouses, such as aluminum plants, automobile assembly plants, pharmaceutical manufacturing plants, and commercial warehouses.
- Aluminum plant construction-general contractors
- Building alterations, industrial and warehouse-general contractors
- Building components manufacturing plant construction-general
- Building construction, industrial and warehouse-general contractors
- Clean room construction-general contractors
- Cold storage plant construction-general contractors
- Commercial warehouse construction-general contractors
- Custom builders, industrial and warehouse-general contractors

- Designing and erecting, combined: industrial-general contractors
- Dry cleaning plant construction-general contractors
- Factory construction-general contractors
- Food products manufacturing or packing plant construction-general
- Grain elevator construction-general contractors
- Industrial building construction-general contractors
- Industrial plant construction-general contractors
- Paper pulp mill construction-general contractors
- Pharmaceutical manufacturing plant construction-general contractors
- Prefabricated building erection, industrial-general contractors
- Remodeling buildings, industrial and warehouse-general contractors
- Renovating buildings, industrial and warehouse-general contractors
- Repairing buildings, industrial and warehouse-general contractors
- Truck and automobile assembly plant construction-general contractors
- Warehouse construction-general contractors

## APPENDIX C: SURVEY AND PSVT:R TEST

Q1. Please list the Industry in which you are currently employed:

______________________________________________________________________________.

Q2. Please list your current position:

______________________________________________________________________________.

Q3. Please indicate your age group:

___ Under 20

___ 20-30

___ 31-40

___ 41-50

___ 51-60

___ 61 and Older

Q4. Please indicate your gender:

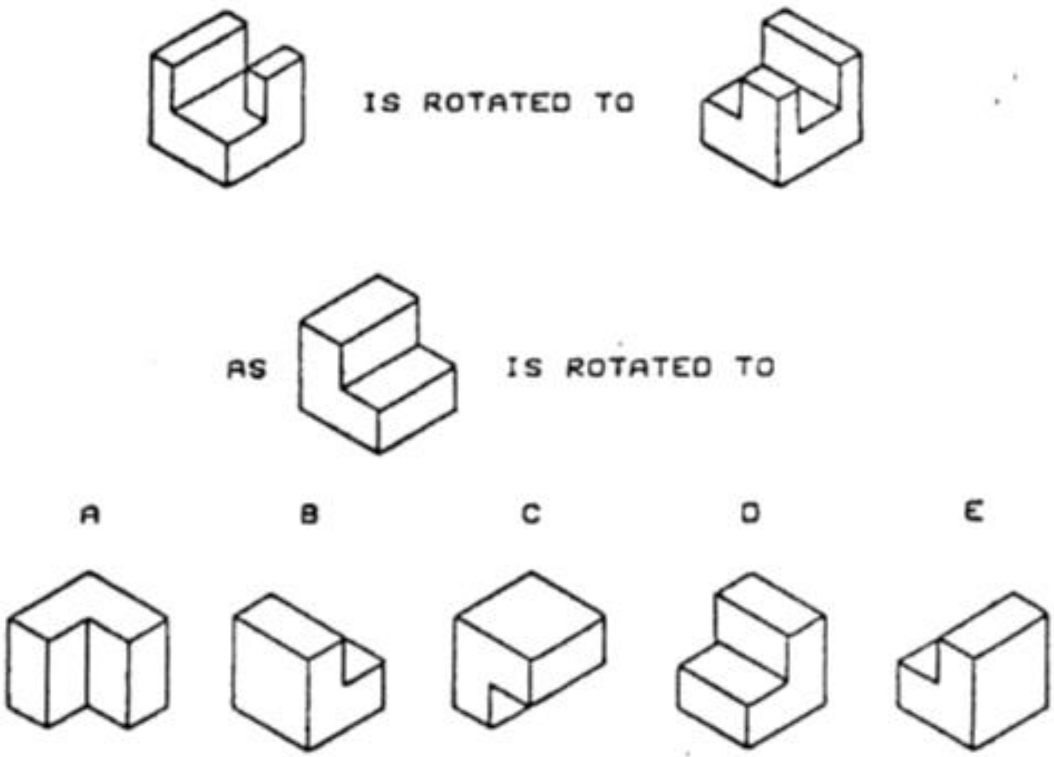
___ Male

___ Female

The following portion of the survey contains a timed, mental rotations test. This test is designed to measure your spatial ability. Participants will be allowed 10 minutes to complete the test. Your participation is greatly appreciated.

## DIRECTIONS

This test consists of 20 questions designed to see how well you can visualize the rotation of three-dimensional objects. An example of the type of question included in this test is shown below.




For each question, you should:

I. Study how the object in the top line of the question is rotated.

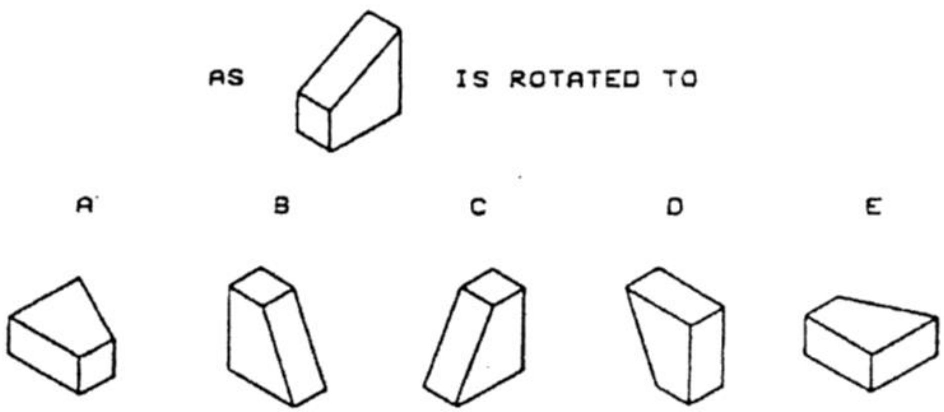
II. Picture in your mind what the object shown in the middle line of the question looks like when rotated in exactly the same manner.

III. Select from among the five drawings (A, B, C, D, or E) given in the bottom line of the question the one that looks like the object rotated in the correct position.

What is the correct answer to the example shown above?

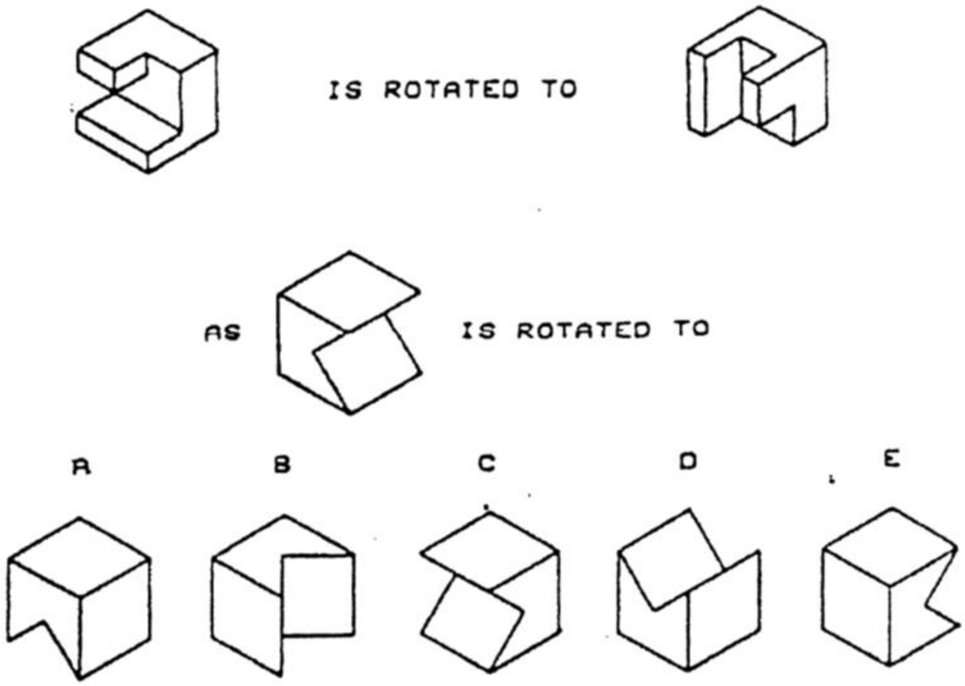
Answers A. B. C. and E are wrong. Only drawing D looks like the object after it hsa been rotated. Remember that each question has only one correct answer.

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


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

1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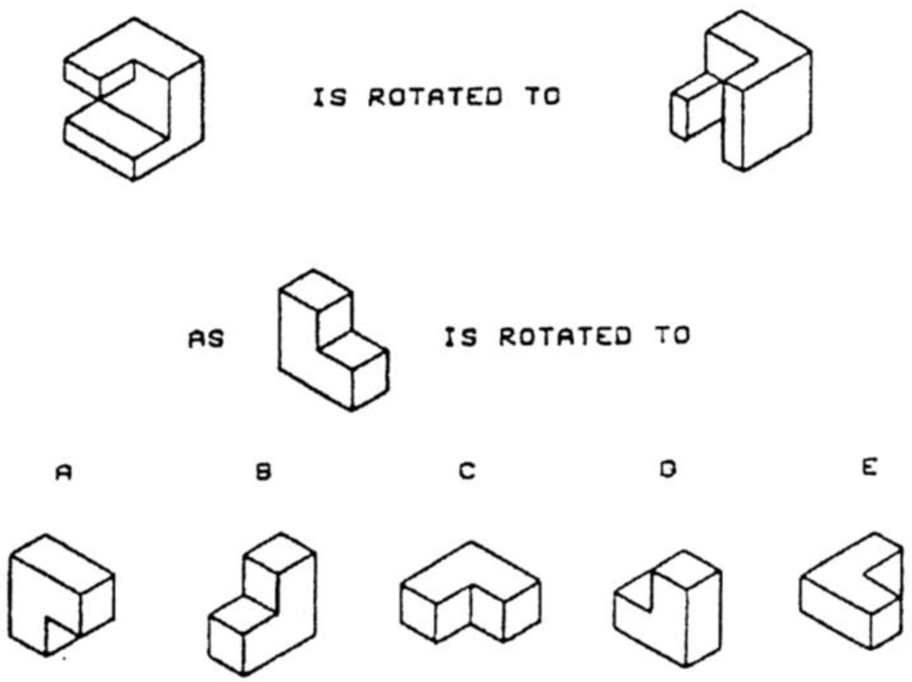
AS
IS ROTATED TO
A
B
C
D
E

2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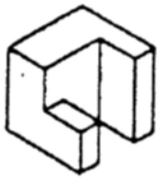
**3**  IS ROTATED TO 

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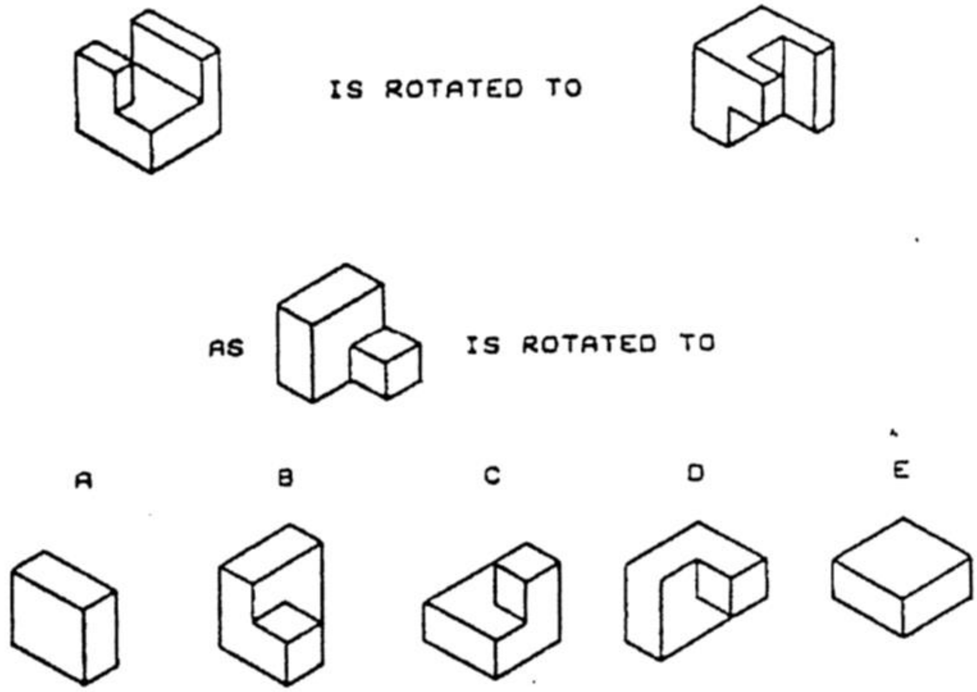
**5**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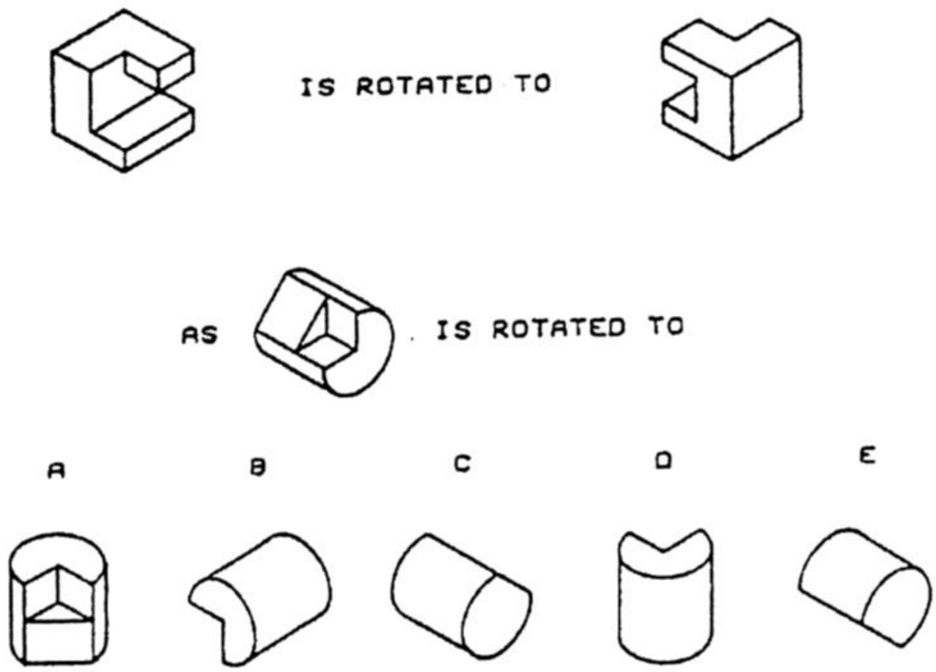
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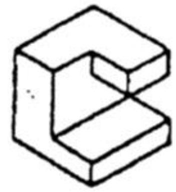
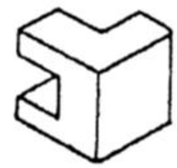
**7**  IS ROTATED TO 

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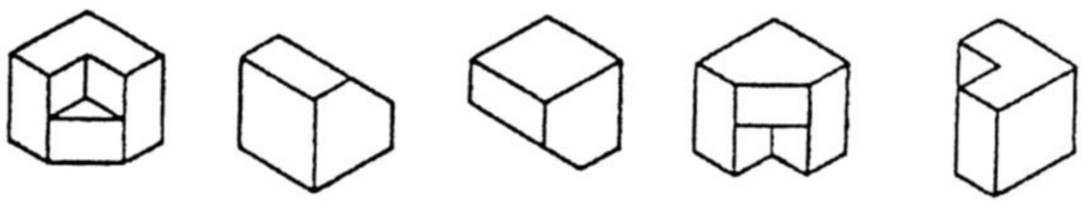
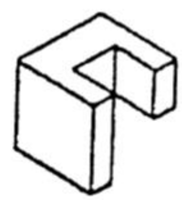
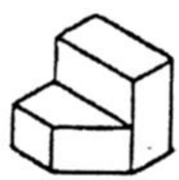


**8**  IS ROTATED TO 

AS  IS ROTATED TO

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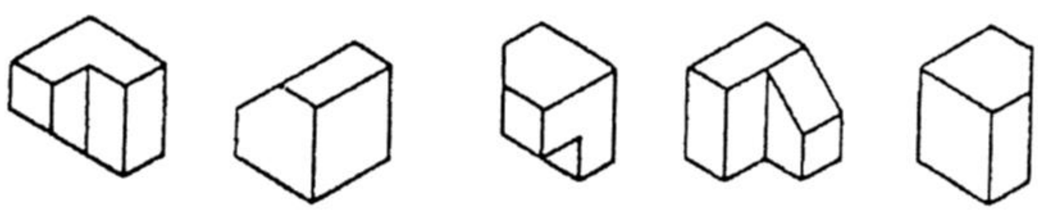

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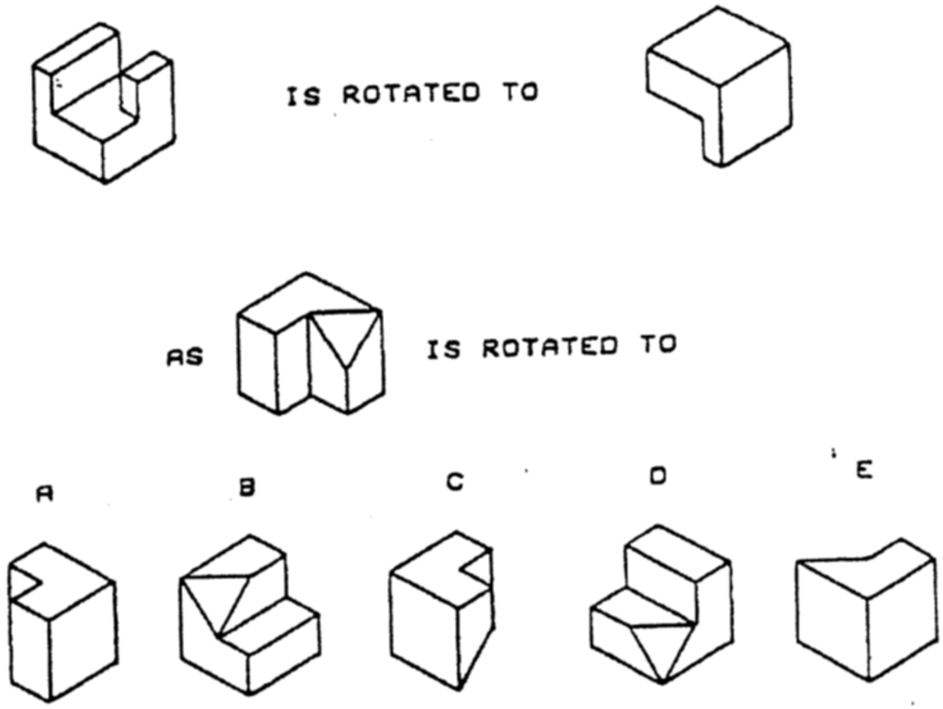

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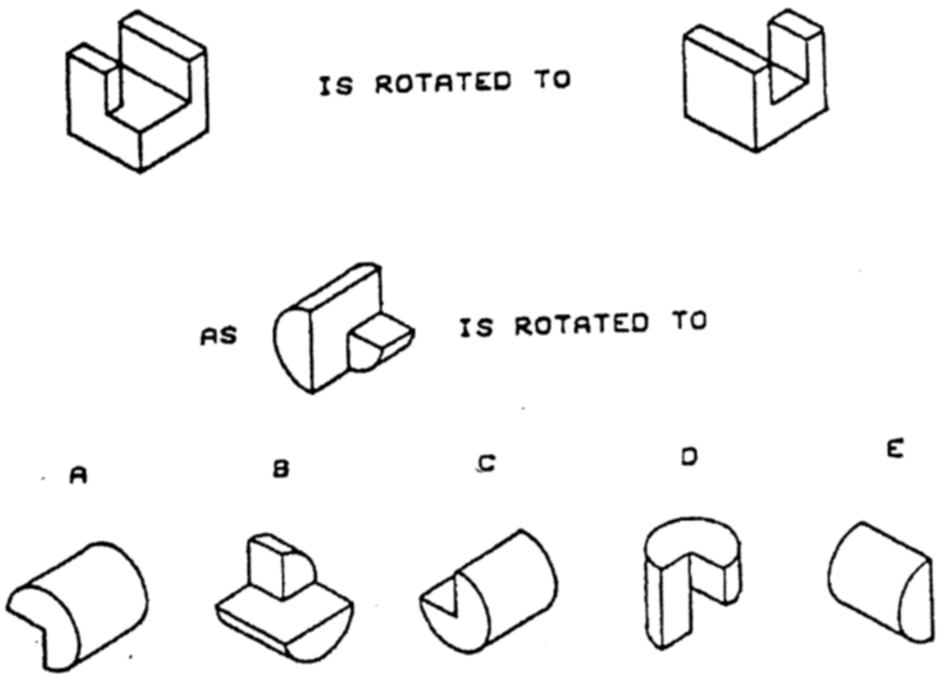

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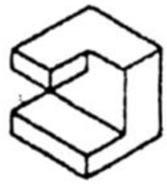
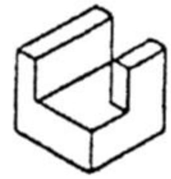
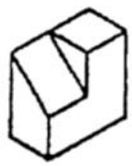
**11**  IS ROTATED TO 

AS  IS ROTATED TO

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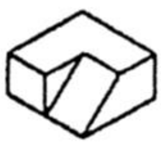
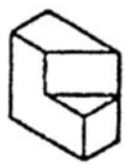
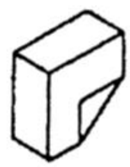
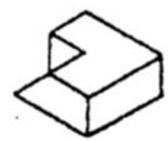
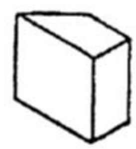
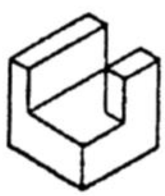
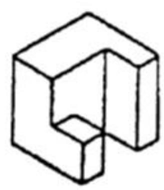
    

**12**  IS ROTATED TO 

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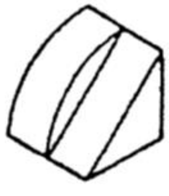 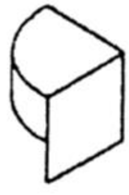 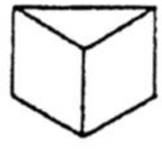 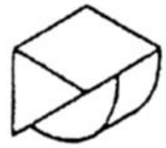 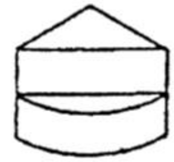

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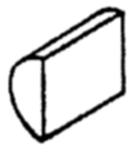
AS  IS ROTATED TO

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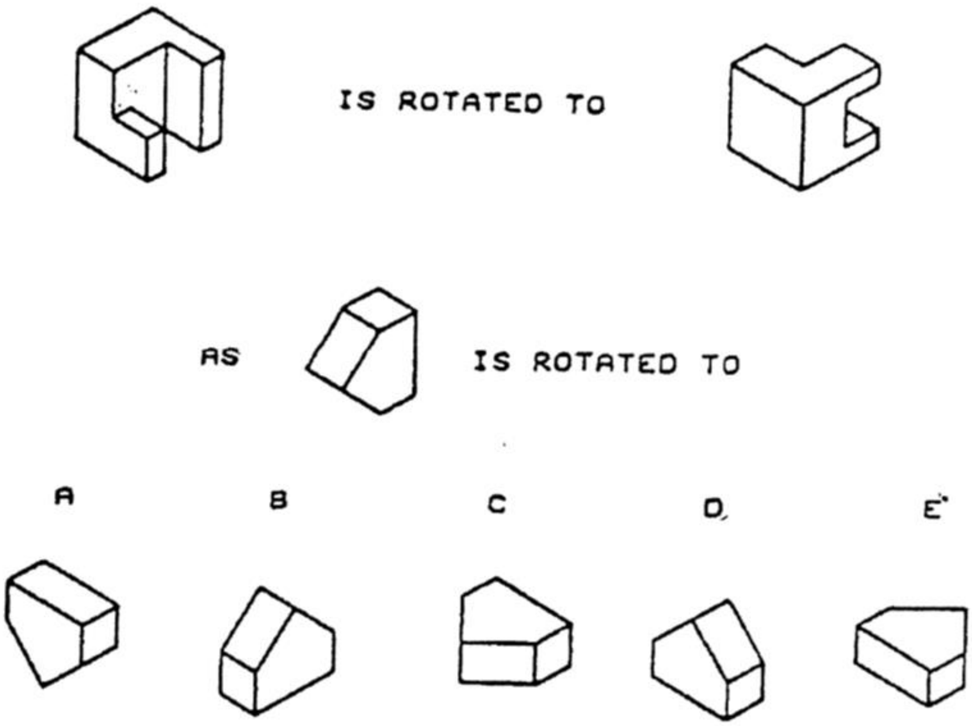
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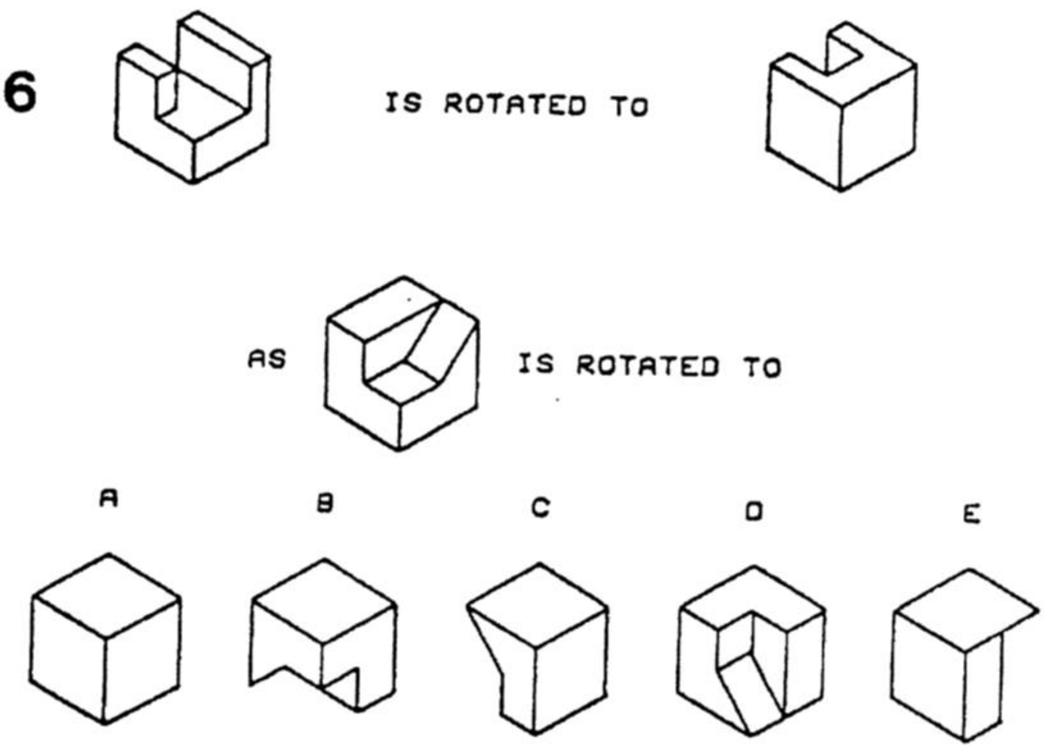
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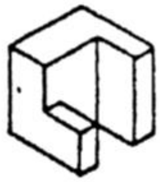
**17**  IS ROTATED TO 

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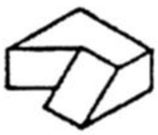
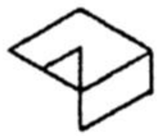
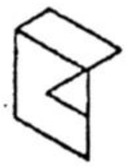
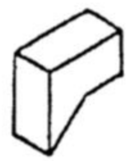
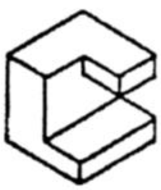
    

**18**  IS ROTATED TO 

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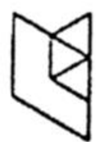
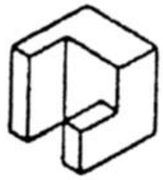
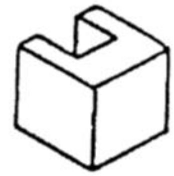
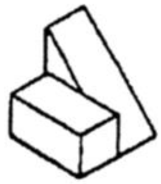
    

**19**  IS ROTATED TO 

AS  IS ROTATED TO

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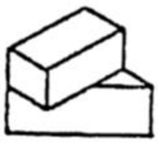
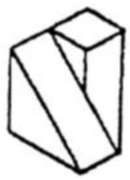
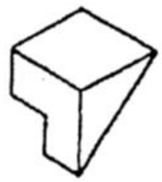
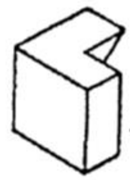
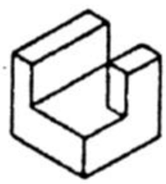
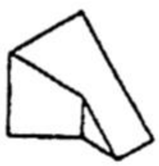
|  |  |  |  |  |

**20**  IS ROTATED TO 

AS  IS ROTATED TO

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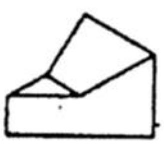
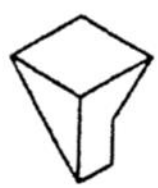
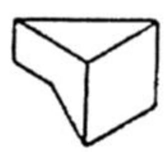
|  |  |  |  |  |

Please take the time to answer the remaining 4 questions.

Q6. Please indicate your training level:

___ High School

___ Apprenticeship

___ Some College

___ Associate Degree

___ Specialty Certification

___ College Degree

___ Graduate Degree

___ Technical School

___ Military Certification

Q7. Please list three events or educational experiences that you feel have enhanced your abilities to visualize objects in 2D or 3D (the skill used in the mental rotations test portion of this survey):
______________________________________________________________________________
_____________________________________________________________________________.

Q8. If you were able to mentally rotate the 3D test objects, please list three events or educational experiences that enabled you to perform this task:
______________________________________________________________________________
_____________________________________________________________________________.

Q9. How often do you use mental rotation skills in your job?

___ Less than 10% of the time

___ 11-25% of the time

___ 26-50% of the time

___ 51-75% of the time

___ Over 76% of the time

# APPENDIX D: PSVT:R ANSWER KEY

| PSVT:R Key | |
|---|---|
| Question | Answer |
| 1 | A |
| 2 | D |
| 3 | A |
| 4 | B |
| 5 | E |
| 6 | C |
| 7 | B |
| 8 | E |
| 9 | A |
| 10 | C |
| 11 | B |
| 12 | E |
| 13 | A |
| 14 | E |
| 15 | D |
| 16 | A |
| 17 | B |
| 18 | D |
| 19 | D |
| 20 | E |

## APPENDIX E: PARTICIPANT INTRODUCTION LETTER

Colorado State University

College of Health and Human Sciences
School of Education
209 Education Building • 1588 Campus Delivery • Fort Collins, Colorado 80523-1588
Phone: (970) 491-6317 • Fax: (970) 491-1317 • www.soe.chhs.colostate.edu

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Dear Participant,

My name is Dale Porter and I am a PhD candidate in the Education Human Resource studies program at Colorado State University. I am conducting research on the processes that enable our emerging work force to analyze data and make decisions. Your perception and abilities as a professional within your specific industry is extremely important to expand the current research. As you may be aware, it has become difficult to hire new employees with the skill sets necessary to be successful in many industries. Research has shown that spatial abilities (a form of measurable intelligence) are an effective predictor of success in fields that require high levels of intuition and problem solving skills. This information and any differences found between specific industries could help educators identify events that lead to the enhancement of this skill set. The results of this research will be submitted for publication in academic and professional journals.

Please help me by taking a confidential online survey and a short test of your spatial abilities. Participation will take approximately 10-15 minutes. Your participation in this research is voluntary. If you decide to participate in the study you may withdraw your consent and stop participation at any time without penalty.

We will not collect your name or personal identifiers. When we report and share the data we will combine the data from all participants. While there are no direct benefits to you I would be happy to share the results of this study with you when complete. Check here

There are no known risks in participating in this study. It is not possible to identify all potential risks in research procedures, but the researchers have taken reasonable safeguards to minimize any known and potential, but unknown, risks.

If you have questions about the research please contact

Dale Porter

Assistant Professor

University of Nebraska-Kearney

## APPENDIX F: EMAIL REMINDER

This is a friendly reminder that you have not yet completed your spatial awareness survey and test. Please take 10-15 minutes to help with this important research. Your time and efforts are sincerely appreciated.

Dale Porter
Doctoral Candidate & Co Principal Investigator
CSU School of Education
Assistant Professor, University of Nebraska-Kearney
308-865-8288

## APPENDIX G: CODING OF PROFESSIONALS BY GROUP

(as identified by respondent)

| Group 1: Construction Professionals | |
|---|---|
| **Industry** | **Position** |
| Architecture | Architect |
| Architecture | Landscape Architect |
| Architecture and Interior Design | Architecture & Interior Design |
| Building Construction | Acoustical Engineer |
| Building Construction | Electrical Engineering |
| Civil engineering Surveying | Civil Engineer |
| Construction | Executive |
| Construction | Geotechnical engineer/materials consultant |
| Construction | Information technology |
| Construction | Structural Engineer |
| Construction | Project Manager |
| Consulting Engineering and Architecture | Civil Engineer |
| Consulting Engineering | Managing Partner / Senior Structural Engineer |
| Demolition | Project Manager |
| Highway Construction | Quality Control Manager |
| Transportation | Structural Engineer |

| Group 2 : Construction Related Professionals | |
|---|---|
| **Industry** | **Position** |
| Architecture | Business Director |
| Construction | Vice President of Marketing and Business Development |
| Construction Equipment | Management |
| Engineering Consulting | Geospatial Manager |
| Environmental consulting | Geologist |
| Industrial Design | Product Design Consultant / Educator |
| Real Estate | President/CEO of Commercial Real Estate company |
| Retail Building Materials | VP |
| Steel | Sales Manager |

| Group 3: Other STEM Professionals | |
|---|---|
| **Industry** | **Position** |
| Aerospace | Director, Engineering Services and IT |
| Aerospace | Plant Manager |
| Aerospace | Sales Manager |
| Aerospace | Thermal Engineer |
| Aerospace and Defense Manufacturing | CEO |
| Aerospace Electronics; Medical implants | Engineer |
| Biotechnology | President and CEO |
| Chemical Manufacturing | CEO/Attorney |
| Consulting Engineering | Engineer/business owner |
| Consulting Services | Environmental Scientist |
| Design and manufacture metalworking machinery | Mechanical Engineer |
| Education | Director, Software Development |
| Education | Faculty at a medical school |
| Education | Information Technology Director |
| Electric Utility | IT Manager |
| Engineering | CEO |
| Engineering Education | Engineering Professor |
| Engineering Education | Professor of Mechanical Engineering |
| Health | Nurse Practitioner |
| Health Care | Physician |
| Higher Education | College Administrator: libraries and IT |
| Higher Education | Economist |
| HVACR Education | Program Director/Instructor |
| Manufacturing | Director of Marketing |
| Manufacturing | General Manager |
| Manufacturing | President |
| Manufacturing primary metals | Quality Assurance |
| Manufacturing (pressure sensors) | Electrical Engineer |
| Oil and Gas | Chartered Engineer working in senior mgmt. |
| Software Development | Software Developer, Manager |
| Steel | VP Purchasing |
| Technical Education | Data Director |
| Telecommunications | Engineering |

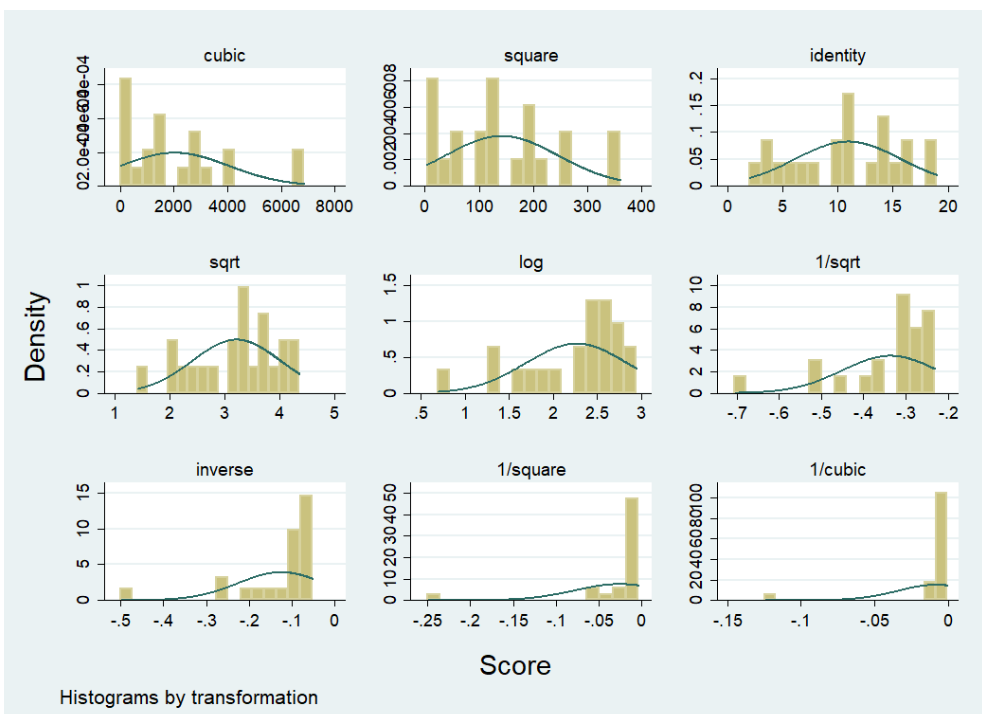
| Group 4: Non-STEM Professionals | |
|---|---|
| **Industry** | **Position** |
| Admission/Enrollment Services | Dean of Admission and Enrollment Services |
| Aerospace/Defense | Enterprise Supply Chain Operations |
| Agricultural Irrigation and Drainage Sales and Service | President |
| Agriculture | Accountant |
| Agriculture | General Manager: PCA's, Engineers and a Agronomic Laboratory |
| Arts and Entertainment | Patrons Services Director for Performing Arts Venue |
| Athletics Communications/Media Relations | Assistant Director of Athletics for Media Relations |
| Auto | VP |
| Automotive | CRO |
| AV | Associate Director - Media Services |
| Aviation | Executive Assistant/HR Recruiter |
| Aviation | Sales |
| Banking | Banker |
| Brokerage | EVP, Marketing and Bus |
| Chemical Manufacturing | CEO |
| Chemical Manufacturing | Quality Control Manager |
| Commercial Real Estate | Finance and Capital Markets |
| Construction | Human Resources Talent Acquisition |
| Construction | Accounting |
| Consumer Products Industry | Engineering Manager |
| Dining Services | Part-time Administrative Coordinator |
| Education | Teacher |
| Education | Librarian |
| Education | University Ombudsperson |
| Facilities Management | Director of Facilities |
| Finance | Chief Investment Officer |
| Finance | Accountant |
| Food Manufacturing/Distribution | IT Systems Architect |
| Foundry | Manager |
| Higher education | University Administrator |
| Higher Education | Learning Disabilities Specialist |
| Higher Education | Marketing |
| Higher Education Administration | Director of Career Services |
| Industrial Flow Meter | Marketing Manager |
| Insurance | CEO |
| Lawn Care | CIO |
| Legal Education | Law Professor |

| | |
|---|---|
| Manufacturer of Electrical Devices | Procurement manager |
| Nonprofit | Editor |
| Nonprofit Service | Chief Financial Officer |
| Pharmaceutical | Medical Writer |
| Private Equity | Private Equity Investor |
| Private Equity, Oil and Gas, Industrial Manufacturing | CFO |
| Professional Speaking and Training | Professional Speaker, Trainer and Author |
| Pump Manufacturing | Casting buyer |
| Restaurant Industry | Partner/GM |
| Retail | Human Resources Management |
| Retail | Ecommerce Director |
| Software | President/COO |
| Software as a Service | Chief Procurement Officer |
| Software consulting | Software Consultant |

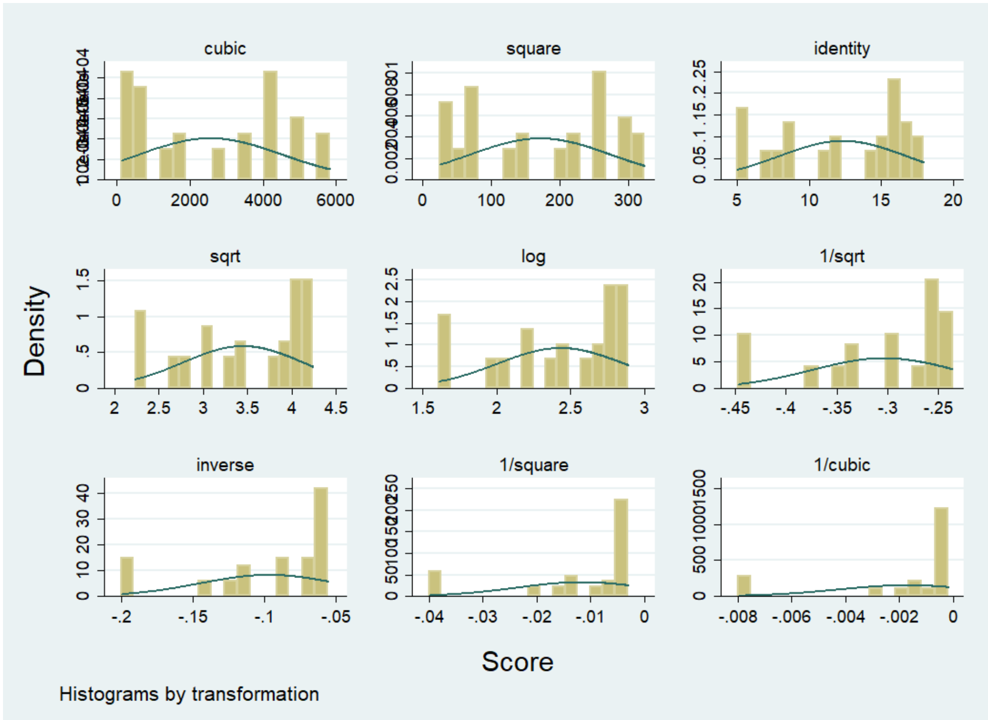
## APPENDIX H: TRANSFORMATION HISTOGRAMS

Construction Professionals


Construction Related Professionals



STEM Professionals




Non-STEM Professionals