CONNECTING REASONING AND SPATIAL ABILITIES TO ACADEMIC PERFORMANCE IN CONSTRUCTION SURVEYING COURSEWORK

A Thesis

by

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ABSTRACT

Cognitive tests measuring reasoning ability have been well established as a means of predicting academic success in STEM (Science, Technology, Engineering, and Math) coursework. Cognitive tests measuring spatial ability have garnered recent attention and have also been established as predictors of academic success in the "traditional sciences" (i.e., Chemistry, Biology, Physics, etc.). Instructors may use these cognitive tests as a means of predicting student achievement or adapting instruction. This study examined the relationship between scores on the Test of Logical Thinking (TOLT); a spatial test battery consisting of the Paper Folding Test (PFT), Hidden Patterns Test (HPT), Mental Rotations Test (MRT), and Purdue Visualization of Rotations Test (ROT); and multiple academic achievement measures (Lab Points, View Points, Exam Points, and Total Grade Points) in an upper-level undergraduate construction surveying course.

The TOLT and the spatial test battery were administered to 277 construction science students. The scores on the TOLT and scores on all spatial battery tests were found to be significantly correlated. Additionally, significant differences utilizing an Analysis of Variance (ANOVA) were found between the TOLT groups and exam points. Further, significant differences were discovered, using an ANOVA, between all the spatial ability test battery groups and achievement points in exams, and a significant difference was also discovered between the ROT groups and view points. Based on these findings, educators and researchers in construction science would benefit by using these

cognitive tests to assess student reasoning and spatial abilities. These tools would assist them in better understanding their students' logical thinking and spatial visualization skills, which should encourage instructors to modify instructional strategies and curriculum design to match or enhance their students' cognitive abilities.

DEDICATION

I dedicate this research to my baby girl Evelyn; may knowledge be a lifelong pursuit for you.

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NOMENCLATURE

ABET	Accreditation Board for Engineering and Technology
ACCE	American Council for Construction Education
ACT	American College Testing
ANOVA	Analysis of Variance
GPS	Global Positioning System
HPT	Hidden Patterns Test
ILS	Index of Learning Styles
IBM	International Business Machines
MRT	Mental Rotations Test
PFT	Paper Folding Test
PSVT	Purdue Spatial Visualization Test
ROT	Purdue Visualization of Rotations Test
SAT	Scholastic Assessment Test
SPSS	Statistical Package for the Social Sciences
STEM	Science Technology Engineering Math
TOLT	Test of Logical Thinking

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INTRODUCTION

Reasoning and spatial abilities are just two of the myriad of cognitive skills that are crucial to success in construction education, as well as in the construction profession. Logical reasoning is a higher order and systematic process that an individual utilizes to draw conclusions or inferences from information. It is a cognitive process of thinking about something in a logical way, in order to form a logical conclusion or judgment. Reasoning refers to the mechanisms, mental activities, and skills used to perform tasks such as learning, computation, observation, understanding, remembering, identifying, paying attention, problem solving, and generating alternatives (Powers & Dwyer, 2004). Spatial reasoning is also a higher order cognitive process involving the acquisition of knowledge and understanding of the environment through rational thought, practical experience, and visual perception. More specifically, it is the mental ability to understand, create, transform, transition, manipulate, and remember visual images and mental models (Mohler, 2008). Finally, cognitive and psychometric research has long held that the constructs of reasoning and spatial abilities overlap and are somewhat consistent over time (Wai, Lubinski & Benbow, 2009).

On a daily basis, the construction process relies on both the reasoning and spatial abilities of its practitioners when they are making logical decisions based upon their experience, interpretation, and analyses of project data within the built environment. Thus, it is imperative to gain insight into the reasoning and spatial abilities of the next generation of construction professionals; specifically, this study investigates these abilities in an undergraduate construction science surveying course. Professional performance in the construction industry and academic performance in the construction science classroom is likely affected by one's cognitive ability as measured by both reasoning and spatial ability. As previous research has linked reasoning and spatial ability (Pribyl & Bodner, 1987), this study aims to also correlate the two constructs in a construction science educational setting. As the accrediting body for construction education, the American Council for Construction Education (ACCE), recognizes both construction science and construction management degrees when evaluating baccalaureate programs for accreditation (American Council for Construction Education, 2016). Thus, this research does not make any distinction between these two similar degree programs and uses the terms interchangeably throughout this paper.

Additionally, this research will determine if reasoning and/or spatial abilities are effective predictors of success for undergraduate construction surveying students. The results of this research will allow educators and industry professionals to better understand the cognitive reasoning and spatial abilities of future construction industry professionals and the necessary cognitive skills that help predict their academic and eventual professional success.

First, a rational is provided to build the foundation of research in construction and to introduce the two cognitive abilities pertinent to this study. Additionally, an in-depth literature review is conducted to further delve into construction surveying education and to show how reasoning and spatial abilities have predicted academic success in multiple fields, both in those fields which are closely aligned with construction science as well as those in other disciplines. Then, the methodology used in this study will be explained, and the different instruments used to measure construction surveying student's cognitive abilities will be described along with the academic performance measures of success used in the data analysis. Lastly, the presentation of data collected and findings will be discussed. Both reasoning and spatial abilities are important in the construction industry (Egbu, 1999; Ahmed, Yaris, Farooqui, & Saqib, 2014); this study hopes to identify a correlation between these abilities and their effect upon a construction science student's academic success.

Rationale

In today's complex project environment, multifaceted skillsets are desired of construction managers. Egbu (1999) identified 75 types of management skills most important to the construction industry, and the work describes decision making as one of the six most important construction management skills. Ahmed et al. (2014) also identified *attention to detail* as being the most desirable trait, out of ninety-three different traits of construction students entering the workforce. The construction industry requires individuals to have a diverse set of skills; Ahmed et al. (2014) surveyed 46 construction companies to discover what positions construction management students were hired for, as well as the desired traits of those students. Most new construction management students were hired as project managers, schedulers, and estimators. These authors also found the most important attributes and ranked them in order of importance; those attributes that draw on reasoning and spatial abilities *(with its corresponding rank* *order of importance)* are: comprehension ability *(8)*, planning and goal setting *(15)*, problem solving/ analytical skills *(17)*, decision- making skills *(20)*, plan interpretation/ blueprint reading/ understand construction & shop drawings *(25)*, scheduling *(30)*, estimating *(32)*, and understanding procedural issues *(62)*. Each of these listed traits draw heavily upon a student's reasoning and spatial ability, and the authors call upon academia to focus their curricular strategies upon preparing their graduates to succeed in these skill areas. However, are these desired traits adequately reflected in the current construction management curriculum and instructional design method to better prepare construction management students for the workforce? Felder and Silverman (1988) propose that the learning styles of engineering students and the teaching styles of the instructor often times do not mesh. Most engineering students have visual, sensing, inductive, and active learning styles while traditional teaching styles in this field are auditory and abstract. In more current research, Holt, Chasek, Shaurette, and Cox (2017) also used the Index of Learning Styles (ILS) to assess the learning styles of undergraduate construction management students and found that 79% (N = 1,069) were visual, active, sensing, and sequential learners. The authors also provide necessary course curriculum design changes, assessment changes, and instructional strategies associated with each of these learning style dimensions. Additionally, Farrow, Liu, and Tatum (2011) held focus groups and found construction management students desired learning that was experiential with less textbook use and more interaction with the instructor. Much of the current literature in construction relates to the teaching and learning styles of construction students; however, little research has been done to assess the cognitive abilities of those students. This study provides an extensive review of literature concerning students' cognitive abilities and how those abilities may affect their learning and academic performance.

Inhelder and Piaget (1958) provide the foundational work on cognitive development. They propose 4 stages of cognitive development throughout childhood that are well accepted within the scientific community; these stages include sensorimotor from birth to about 2 years of age, through the preoperational and concrete operational stages, and to the final stage of formal operational thought prevalent in children over 11 years old as discovered in their study population. Arlin (1975) expands on the work of Inhelder and Piaget to propose an additional fifth stage that has received much scrutiny in the scientific community, but is worth noting. Arlin (1975) suggests cognition goes beyond just formal operational thought to an expanded fifth, two-part stage: the problem-solving stage and the problem-finding stage of formal operational thought. In more recent work, Demick and Andreoletti (2003) define four postformal operational hierarchical stages as first identified by Commons, Richards, and Armon (1984) as: (a) systematic order, (b) metasystematic order, (c) paradigmatic order, and (d) crossparadigmatic order. Most recently, Kallio (2011) critiques the various verbiage used to define postformal operational thought and contends that integrative thinking should be used as the standard nomenclature for the final stage of cognitive development. There is a vast array of cognitive abilities prevalent in adults; however, this research will focus on reasoning and spatial abilities as described in the subsequent paragraphs.

Tobin and Capie (1981) developed the Test of Logical Thinking (TOLT) as a reliable means of assessing a student's formal reasoning ability. In "Cognitive Psychology and Cognitive Neuroscience/Reasoning and Decision Making," (Wikibooks, 2017) the author stated that, "It is important to keep in mind that reasoning and decision making are closely connected to each other: Decision making in many cases happens with a previous process of reasoning." The TOLT has been used in multiple disciplines closely aligned with construction science and was found to be a strong predictor of academic success. However, existing literature in construction science does not compare reasoning, as assessed by the TOLT, to other cognitive abilities. As previous research in other disciplines has confirmed a correlation between reasoning and spatial abilities, one of the primary objectives of this research is to correlate these two cognitive abilities for construction science students. Just as this paragraph has introduced and defined reasoning ability, the following paragraph will also discuss spatial ability.

Trindade, Fiolhais, and Almeida (2002) provide that spatial understanding stems from the ability to construct mental images from verbal or written directions and linked spatial abilities with comprehension. These authors tied conceptual understanding and comprehension capability to a student's spatial ability in chemistry and physics. They also reference multiple previous works citing that spatial aptitude can be tied to academic success in the fields of science, physics, and chemistry. However, an exhaustive review of literature does not yield any results relating academic success in construction science to a student's spatial ability.

There is a gap in the existing body of knowledge on whether or not reasoning or spatial abilities, as measured by the TOLT and spatial ability test battery respectively, can also be used as an effective assessment tool to predict the success of construction science students. As decision making has been regarded as a key component of construction management, this research analyzes the success of construction management undergraduate students based on their cognitive abilities. In general, cognitive reasoning abilities, as measured by the TOLT, have long been regarded as an acceptable predictor of student success in academia. However, in spite of its importance in assessing students' success and their learning outcomes, very little is known about the impact that cognitive reasoning abilities have on student performance, specifically for construction science higher education. After an exhaustive review of literature, only three studies linking cognitive reasoning ability to academic performance for construction science was found. Additionally, to date, no research has been conducted assessing spatial abilities and performance of construction science students. To further advance reasoning and spatial ability performance assessment in the pedagogical practice of construction management in an attempt to fill the gaps, the major objective of this study will investigate the effect both reasoning and spatial abilities have on academic performance of construction science students taking a construction surveying course. Further, this study will explore whether the effect of spatial abilities is moderated by a student's reasoning ability. This study will be the first of its kind to assess both reasoning and spatial abilities of construction surveying students and investigate any affects these may have on performance.

Further assessment of academic performance for construction science students regarding their reasoning and spatial abilities will significantly contribute to curriculum development and assessment of construction management students. The subsequent literature review will outline previous research conducted in construction surveying education and identify research linking both reasoning abilities and spatial abilities to academic performance across multiple fields of study. Additional explanation of reasoning abilities and spatial abilities will be provided in the methodology where each test measuring the aforementioned abilities to be used in this study will be explained. The general research design of this study will include three semesters of undergraduate construction surveying students with an approximate population of 320 total participants. These three semesters of students will be administered standard tests of reasoning and spatial abilities; measures of academic success and additional demographic data will also be collected on these students to be used in the data analysis. The results of this study may allow researchers and instructors to predict success or identify potential needs for curriculum adaptation in construction science undergraduate coursework.

LITERATURE REVIEW

Construction Surveying

The construction surveying practice has evolved over the past few decades as a result of technological advancement and innovation (Greenfeld & Potts, 2008). Greenfeld and Potts (2008) identify 15 body-of-knowledge outcomes in surveying education, 11 of which were taken from the Accreditation Board for Engineering and Technology (ABET) criteria 2000 model. They grouped these body-of-knowledge outcomes into three categories: technical, professional, and practice; they describe the technical outcomes as the “keystone of professional practice.” Further, the ACCE stresses the need for surveying in undergraduate degree programs by requiring graduates to, “Apply basic surveying techniques for construction layout and control” (ACCE, 2016). Additionally, multiple requirements for accreditation under the ACCE are directly related to reasoning and spatial abilities. For example, regarding both measures of cognitive ability, graduates in accredited programs are required to analyze both professional decisions and to read and interpret construction documents. However, although the word professional is used throughout this paragraph describing surveying practice, it is important to note that surveying in itself does not require any professional licensing like that of the engineering profession.

Construction surveying is defined by Williamson and Anderson (2017) as, “the spatial science and technology of determining the location and three-dimensional characteristics of the natural and built environment on the surface of the earth.”

Surveying utilizes both measurement and computation to determine areas, volumes, distances, angles, grades, and elevations in the construction sector. It is important to note the difference between construction surveying and land surveying in the context of this research; land surveying typically requires professional licensing and is often used for legal purposes to establish boundaries, easements, and mapping (Dib & Adamo-Villani, 2014). Two modes of surveying exist: plane and geodetic; plane surveying is the method predominately used in construction surveying and assumes the curvature of the earth is negligible. However, both of these modes share similar tools and technology to create survey data. In taking accurate distances and angles in both the horizontal and vertical slope, levels, theodolites, and total stations are used. Total stations are the most advanced technological tool used in surveying and incorporate computer programming, global positioning systems (GPS), lasers, and often cloud-based communication capabilities. Other forms of low-technology tools are also present in the industry and are heavily used in the classroom to form a baseline understanding of the trade; these tools include: tapes, chains, string line, plumb bobs, gammon reels, grade rods, and sight/bubble levels (Williamson & Anderson, 2017).

Wong, Wong, and Hui (2007) found that the fluctuating market and changing needs for the construction sector requires that education in surveying to be more focused on the accentuation and reinforcement of practical skills. El-Mowafy, Kuhn, and Snow (2013) call for a blended approach in surveying education to not only learn theoretical principles but also apply technical skills. The Employment Development Department for the State of California (2003) highlights the need for both reasoning ability and spatial ability in construction surveying by stating, “Surveyors use mathematical reasoning ability to visualize objects, measure distances, size, and other abstract forms.” Surveyor’s in the 21st century not only have foundational knowledge in math, physics, engineering, and law, but also have proficiency in collecting, processing, analyzing, and presenting spatial data (El-Mowafy, Kuhn, & Snow, 2013). As a subject matter expert in surveying, Enemark (2002) calls for a focus of surveying education on spatial information management. An extensive review of literature by Dib, Adamo-Villani, and Garver (2014) identified conflicting viewpoints on whether schematic or realistic visualizations are better suited for learning surveying. Their own research found no significant statistical difference in the two methods, but reported that students rated the effectiveness of realistic simulations higher in their understanding of surveying instrument set-up. However, although extensive research has been conducted on the use of visualizations and importance of spatial data in construction surveying, no research has been published on the actual spatial abilities of construction surveying students.

Reasoning Ability

Reasoning ability is a logical and systematic process used to draw conclusions or make inferences from information that may not be readily available (Markman & Gentner, 2001). It is a cognitive process of thinking through something in a logical way to reach a decision or conclusion (Northrop, 1977). Lohman and Hagen (2001) maintain that cognitive processes are essential to effective reasoning and classifies these processes as selective encoding, selective comparison, and strategic combination. The authors also assert that reasoning is the most essential and most general of all cognitive abilities with regards to academic learning. Reasoning ability allows an individual to perform tasks and processes such as: forming arguments, perceive relevance, see commonalities and differences, evaluate, and abstract (Powers & Dryer, 2003).

Kirk and Mulligan (1996) contend that many construction programs focus on subject matter that is solely left-brain to process verbal, mathematical, and science information. However, the authors propose that in order to be more effective problem solvers and critical thinkers, educators should also provide right-brain exercises that promote imagination, holistic awareness, and spatial recognition. Further, Hartman, Dorée, and Martin (2010) propose a constructivist teaching approach with role-play based scenarios to successfully develop critical thinking skills in a research methods construction management course.

TOLT

A clinical interview process used by Inhelder and Piaget (1955) to determine the formal reasoning abilities of students serves as the foundational knowledge for much of the cognitive work conducted today. However, a typical classroom setting and time constraints often prohibit the use of one-on-one interviews. Thus, Tobin and Capie (1981) developed the Test of Logical Thinking (TOLT) in response to these research limitations. The TOLT measures five modes of formal reasoning and is able to be administered to a large population of students concurrently. Cognitive reasoning abilities have long been linked to student performance across multidisciplinary pedagogical practices through the use of the TOLT, but is mainly supported by research in the traditional sciences. Table 1 shows pertinent literature used to validate reasoning ability as measured by the TOLT as a reliable means of predicting student performance and the corresponding field of study. Bhat (2016) discovered that the main predictor of success for high school students was their reasoning ability. It was also concluded that academic success of undergraduate chemistry students was determined by both the initial TOLT score and entrance SAT scores, with neither being significantly more of a statistical predictor of performance (Lewis & Lewis, 2007). Vazquez and Difabio de Anglat (2009) found a significant relationship between first year engineering student’s academic performance and reasoning ability using the TOLT. Additionally, in determining at-risk pharmacy students, Etzler and Madden (2014) found the TOLT to be a strong predictor of success in first-year pharmacy students. Overall, performance of a construction management student’s cognitive reasoning abilities remains mostly unmeasured. However, research by Lee, Lee, and Koval (2016) has shown that instructional method most significantly impacted the success of academically weak students and that there was no significant impact of instructional method on academically strong students in construction management coursework.

Table 1. Summary of Literature Review Pertaining to the TOLT as a Predictor of Success.

Author (year)	Subject Discipline	Results
Bousquet (1982)	Agriculture	The TOLT was second only to prior knowledge in predicting success on a post-test in an introductory undergraduate natural resources course.
Szabo, Atkinson, & Spooner (1985)	Sociology	The TOLT was used to identify weak formal thinkers and tailor instruction to meet the students' need.
Trifone (1987)	Biology	The TOLT score of students is tied to their academic growth.
Wilson (1988)	Geology	Those scoring higher on the TOLT performed better academically.
Schoenfeld-Tacher, Persichitte, & Jones (2000)	Biochemistry	The TOLT was a significant predictor of success in a goal-based scenario lesson on DNA in biochemistry.
Oliva (2003)	Science Education	Those with higher formal thought, as measured by the TOLT, were able to better grasp concepts in a high school science course.
BouJaoude, Salloum, & Abd-El-Khalick (2004)	Chemistry	The TOLT was a significant predictor of success for conceptual chemistry problems but not a strong predictor of success for algorithmic problems in high school chemistry.
Lewis & Lewis (2007)	Chemistry	Both SAT scores and the TOLT were good predictors of academic success in chemistry with neither being superior.
Vázquez & de Anglat (2009)	Engineering	TOLT had good internal consistency and construct validity in predicting success across four engineering related courses.
Doymus, Simsek, & Karacop (2009)	Chemistry	The TOLT was a strong predictor of success on a micro-level States of Matter Test in undergraduate chemistry students.
Sadi & Çakiroglu (2014)	Medicine	Reasoning ability, as measured by the TOLT was nearly three times more successful at predicting success for high school students on the Human Circulatory System Achievement Test than any other measure.
Kılıç & Sağlam (2014)	Biological Education	Reasoning ability, as measured by the TOLT was the most significant predictor of understanding fundamental genetic concepts in eleventh graders.
Etzler & Madden (2014)	Pharmacy	There was a correlation between a student's TOLT score and their academic performance in courses requiring quantitative reasoning ability.

Spatial Ability

Dennis and Tapsfield (2013) define spatial ability as "the ability to generate, retain, retrieve, and transform well-structured visual images." They highlight two contrasting modes of thinking regarding spatial abilities; (1) that spatial abilities are correlated with creativity and higher levels of thinking, and (2) that spatial abilities are implicated with lower level concrete thinking. Regardless the mode of thinking, spatial abilities have been tied to success in a multitude of studies. Harle and Towns (2011) links the success of STEM fields, and in particular chemistry, to spatial abilities. Also, they found that through the development of spatial abilities, retention rates and success of students in science can be increased. Specifically, Harle and Towns (2011) suggest direct instruction on the transformation of 2-D and 3-D molecular formulas and also suggest students use a visualization tutorial to better practice and understand 3-D molecular structures. Wu and Shah (2004) cited multiple studies correlating academic achievement and spatial abilities and provided curriculum design principles to assist spatial understanding. These curriculum design principles include: multiple descriptions, visible links, dynamic and interactive presentations, 2-D to 3-D transformation, and integrated information. However, Hinze et al. (2013) discovered that spatial abilities can be used in both effective and ineffective ways towards solving chemistry problems. When subjects were presented with pre-study tasks that focused on limited subsets of information, the students used spatial skills ineffectively. Conversely, the author also reports, “Pre-study tasks often help individuals more effectively comprehend information, particularly when the tasks elicit knowledge or strategies that align with the processes or activities necessary for successful performance.”

A multitude of spatial ability tests exist. Ekstrom, French, and Harmon (1976) compiled 72 cognitive tests assessing 23 cognitive factors. All of these tests have been validated through multi-factor analysis and tested across multiple studies. Additionally, all of the tests used in this study have been determined to have a high reliability; the corresponding reliability coefficients found in previous studies are displayed in Table 2. Carroll (1993) lists three spatial ability factors as identified by Lohman: spatial relations, spatial orientation, and spatial visualization. In the identification of these factors, the subsequent spatial ability tests were selected for use in this study.

Table 2. Internal Consistency of Testing Instruments.

Author (year)	Testing Instrument	Reliability Statistic (Cronbach's Alpha)
Bodner & Guay (1997)	Purdue Visualization of Rotations Test (ROT)	$\alpha = 0.80$
Stumpf (1993)	Paper Folding Test (PFT)	$\alpha = 0.82$
Stumpf (1993)	Mental Rotation Test (MRT)	$\alpha = 0.88$
Stumpf (1993)	Hidden Pattern Test (HPT)	$\alpha = 0.80$

ROT

The ROT, also referred to as the Purdue spatial visualization of rotations test, was created by Bodner and Guay (1977) as an expansion of the rotations category from the Purdue Spatial Visualization Test (PSVT; Guay, 1976). The original PSVT consisted of 36 questions equally divided into three categories of spatial ability testing: developments, rotations, and isometric views (Yue, 2009). As an assessment of one's spatial visualization ability, the ROT requires visualization of rotation of 3-D isometric shapes in both the horizontal and vertical planes. The ROT has been tested and validated as a reliable means of predicting academic success across multiple disciplines, many of which are closely aligned to construction science. Guidera (2010) administered the ROT to 68 students in a first-year undergraduate design foundations course, 22 of which were construction management students and the rest were either architecture or interior design majors. The ROT was determined to be a reliable predictor of academic success in their research. Further, Guidera (2010) did not find any statistically significant difference in spatial ability between the students in different academic majors that were participating in the course. Branoff and Dobelis (2012) investigated whether spatial ability, as measured by the ROT, had any relation to an engineering student's ability to read and interpret engineering drawings as measured by a modeling test. Their analysis discovered a significant correlation between spatial ability and scores on the modeling test. Visualization, as defined by Lohman (1993) is the "ability in manipulating visual patterns." Visualization has been attributed to the interpretation and creation of design drawings, a crucial task that is assessed in a construction surveying course. Thus, spatial visualization, as measured by the ROT, is one critical factor in understanding a construction surveying students' overall spatial ability.

PFT

Spatial ability visualization is also assessed by the Paper Folding Test (PFT) as created by Ekstrom et al. (1976). They highlight the research of Carroll (1974) that claims spatial visualization, as assessed by the PFT, requires performing serial operations while mentally manipulating a folded object; an additional step beyond just spatial orientation. Visualization, as measured by the PFT, is less researched than the previous visualization test; however, it has been correlated with academic success, but some conflicting results arise throughout different academic disciplines. Turgut and Yilmaz (2012) utilized the PFT and another visualization test, the surface development test, to correlate spatial ability to academic success in high school mathematics students. However, another study conducted with high school students by Liner (2012) did not find a correlation between academic success and this spatial ability in physics students. Further, Liner (2012) conducted a pre-test and post-test PFT with the high school students and found no significant increase in this spatial ability; the author attributed these results to a lack of spatial visualization required in the high-school physics course. Lastly, Baker and Talley (2012) linked spatial visualization to academic ability, as measured by the American College Testing (ACT) scores; but they found less of a correlation between spatial visualization and academic success in freshman level undergraduate chemistry students. Conflicting results from the PFT, as administered in previous research, highlights how the importance of spatial visualization differs across academic discipline and poses the question of whether spatial visualization is a key spatial ability component for construction science undergraduate students.

MRT

To assess Lohman's (Carroll, 1993) spatial ability component of spatial relation, the Mental Rotation Test (MRT) was created by Vandenberg and Kuse (1978). The

MRT requires visualization of rotations of 3-D shapes about the horizontal axis. Spatial relation has been linked to academic success across multiple disciplines; Rohde and Thompson (2007) identified such a link in undergraduate psychology students. Additionally, Furnham and Chamorro-Premuzic (2004) correlated spatial relation, as measured by a rotations test similar to the MRT, with exam scores in an undergraduate statistics course. In an undergraduate functional anatomy course, Guillot, Champely, Batier, Thiriet, and Collet (2007) identified a strong correlation between the MRT and the group embedded figures test to academic success. The group embedded figures test is similar to that of the Hidden Patterns Test (HPT); the HPT is discussed in the following section. Peters et al. (1995) researched the influence academic major had on a student's spatial ability using the MRT; they found that Bachelor of Science majors significantly outperformed their Bachelor of Arts counterparts. Further, Peters, Lehmann, Takahira, Takeuchi, and Jordan (2006) found similar results when comparing those in traditional science majors versus social science majors using data from four universities across diverse cultural areas. Lastly, Chamorro-Premuzic, Furnham, and Ackerman (2006) recognized confounding results relating academic performance with spatial relation ability; significant correlations were found between spatial relation and academic performance for exams and essays, but not for the final project or continuous assessment of undergraduate psychology students. Will these confounding results be present when assessing the different academic performance measures and spatial abilities with undergraduate construction science students?

HPT

The final spatial ability assessment test in the spatial battery, the HPT, measures spatial orientation as described by Carroll (1993). The HPT requires spatial object recognition and visual detection of embedded features. Prior research conducted utilizing the HPT is mainly focused on gender differences; however, some research has linked the HPT to both academic performance and practical life skills. Liben, Myers, and Christensen (2010) found a link between the practical life skill of mapping performance and three spatial ability tests (HPT, MRT, and PFT) with undergraduate psychology students. Additionally, Lin (2016) found a significant difference in spatial ability performance, specifically for spatial visualization and spatial orientation of undergraduate students majoring in design disciplines compared to those in non-design majors. Further, no significant difference was found between the two groups in terms of spatial relations performance as measured by the HPT. Williamson, Williamson, and Hinze (2016) found a significant difference in scores between undergraduate chemistry students taking an online version of the HPT versus a paper-and-pencil version, whereas there was no significant difference found in the other five cognitive tests researched. However, the authors attributed this finding to an error in translating the paper-and-pencil version to an online format. Thus, this study must carefully examine the multiple cognitive ability tests used and ensure the instrument translation mirrors the paper-and-pencil versions to the greatest extent possible.

Spatial Battery z-Score

As described above in the rationale and literature review, both industry and academia require a multitude of spatial skills. Ahmed et al. (2014) identified 93 different traits that were important to industry regarding construction students. As one of those skills, plan interpretation/ blueprint reading/ understanding construction and shop drawings utilizes a multitude of spatial skills. Academia also recognizes the importance of reading and interpreting shop drawings by employing multiple spatial skills as the ACCE (2016) lists this as one of the core competencies of accreditation. Since the skills required of a construction student often go beyond just a single measure of spatial ability, a composite spatial ability score will be coalesced from the previous four spatial ability tests. This composite spatial battery z-score provides a more holistic view of a student's overall spatial ability and be an additional measure of spatial ability to be used in statistical analysis. A mathematical z-score is computed by taking the difference between a sample value and the mean and dividing it by the standard deviation. Thus, this study will utilize a summation of each student's z-score on the PFT, HPT, MRT, and ROT to calculate a composite spatial battery z-score which will be used for analysis of a student's overall spatial ability.

Semester Length

Shortened semesters and intensive modes of delivery in the educational setting are more common now than ever before as Universities aim to meet the needs of their students in a changing world; however, this change is not founded on good pedagogy and is rather a mode of convenience for students (Davies, 2006). Yet, this does not mean that compressed courses cannot provide an adequate learning experience, and Davies (2006) states, “In short, there is nothing in the research to indicate that intensive teaching need not be a successful and effective mode of delivery. Intensive modes of delivery may result in considerable advantages for students when used by effective teachers in appropriate subjects.” Two modes of compression are present in the educational setting: 1) reduction of total contact hours and 2) no reduction in total contact hours. Williamson (2017) researched the former type of compression in his study on the achievement of construction management students. Due to the similarities of this study, the research by Williamson (2017) is of particular interest to this study. Williamson (2017) discovered that students taking a shortened (mini) semester scored better on lab activities, reading quizzes, and total course points. However, exam grades were found to be significantly better in the mini-mester course than the full-semester offering. On the contrary, further analysis by Williamson (in-press) discovered no significant differences in academic achievement between the min-mester course and the full-semester offering. Investigation into this discrepancy reveals that the original publication by Williamson (2017) utilized random selection of students from the full-semester offering to yield equal sample sizes. However, when the full data set was used by Williamson (in-press) and unequal cell sizes were considered for, no significant findings were yielded. This contradictory research is just one instance of the many contradictory findings that are present in the abundant research on this topic.

Although the literature varies on its definition of a compressed semester, research regarding compression generally provides that classes offered during a four-week period or less to be compressed and that 15 or 16-week courses are described as traditional. In fact, Austin and Gustafson (2006) found that "intensive courses do result in higher grades than traditional 16-week semester length courses and that this benefit peaks at about 4 weeks." Additionally, the authors attributed these higher grades to actual knowledge gain and not resultant of "lowering the bar" for the compressed course format. Daniel (2000) also supports this claim, and research from a comprehensive literature review discovered that any course, regardless of discipline, can effectively implement compressed courses without sacrificing a student's learning experience. Some advantages of compressed courses listed by Daniel (2000) include: convenience, higher scores, stimulated discussion, and creative teaching techniques; some of the disadvantages include: fatigue, stress, lack of preparation time, and lack of time to study.

An abundance of literature on compressed course formats are tied to spacing effect theory and how variations in the frequency and timing of instruction affect a student's learning. A meta-analysis of 63 studies was conducted by Donovan and Radosevich (1999) and compared massed practice conditions to spaced practice conditions. Donovan and Radosevich (1999) defined each of these conditions as follows: "Massed practice conditions are those in which individuals practice a task continuously without rest, while spaced practice conditions are those in which individuals are given rest intervals within the practice session." The authors found a significant performance increase in spaced practice conditions; however, the authors also claim the appropriate interval spacing between instruction varies by task difficulty. In support of these findings, research by Petrowsky (1996) found that the compressed course students performed better on the first test requiring simple recall of information while the traditional course performed better on the second test involving comprehension, application, and analysis. While some research supports an increase in performance for students taking compressed courses versus the traditional format (Austin & Gustafson, 2006; Bentley, 2006; Gallo & Odu, 2009; Logan & Geltner, 2000; Van Scyoc & Gleason, 1993), other research show an increase in failure rates with decreased performance (Doggrell & Schaffer, 2016; Donovan & Radosevich, 1999), and some research discovered no significant difference in performance between the two groups (Anastasi, 2007; Carrington, 2010; Ewer, Greer, Bridges, & Lewis, 2002).

Overall success of compressed courses requires certain attributes as described by Scott (2003): instructor characteristics, teaching methods, classroom environment, and evaluation methods. Workload requirements of compressed courses were investigated by Lutes and Davies (2013) and found a significant difference between compressed and traditional courses using surveys of over 29,000 undergraduate students; their research concluded that traditional course students spent an average of 17 minutes more per credit per week than their compressed counterparts. This means that a student in a traditional three credit course would spend an average of 51 more minutes per week on their coursework than a student in a compressed semester format.

Research Questions and Limitations

Although there are many courses in the undergraduate construction science degree program, this research is limited to students taking the upper-level, undergraduate surveying course. A multitude of cognitive reasoning and spatial ability tests exist; but, this study does not assess all possible cognitive reasoning and spatial abilities. Additionally, overall student performance is measured by combined points in major graded areas, not on an item-by-item basis. Finally, a construction surveying student's laboratory grade points are a result of group-graded events; the effect of this group scoring was not investigated in this study and would be a viable topic for further research.

To produce foundational research on the spatial abilities of construction science students as mentioned in the previously stated objectives, this research first examines how cognitive reasoning and spatial abilities are correlated with a student's academic performance. It is hypothesized that students with high reasoning ability will academically perform better than students with low reasoning ability in a construction surveying course. Additionally, students with high spatial ability will academically perform better than students with low spatial ability in a construction surveying course. Further, it is hypothesized that students with both high reasoning and high spatial abilities perform better academically than those students with both low reasoning and low spatial abilities in a construction surveying course. In an attempt to fill gaps in the current construction science body of knowledge, the research in this study will attempt to answer the following research questions:

- Are the reasoning abilities and spatial abilities of construction surveying students correlated as it has been found in other disciplines?
- Is there a correlation between a student's academic performance in a construction surveying course and their reasoning or spatial abilities?
- Is reasoning ability alone or spatial ability alone sufficient as a predictor of a student's academic performance in the construction surveying course, or are both cognitive abilities required?

METHOD

Population

Three semesters (Fall 2016, Spring 2017, and Summer 2017) of construction surveying courses taught by the same instructor at a large, south-central university in the United States were used for this study. Four sections limited to 30 students each are offered each semester; approximately 360 students were invited to take part in this study. Construction surveying is a 300-level undergraduate course with most students registering during their senior year; however, some sophomore and junior students also take this course and were included in the study. As approved by the institutional review board, students gave written permission prior to their data being used in this research. Additionally, those students voluntarily declining to participate in either the reasoning ability instrument or spatial ability instruments were not evaluated as part of the data set. Furthermore, any students taking an unusually high or low time on the TOLT, are considered outliers and removed from the study. Outliers were identified as those performing greater than two standard deviations from the mean, relating to their timing on the TOLT, as calculated during data analysis. Lastly, any students electing to drop or withdraw from the course were excluded from this study.

Testing Instruments

Reasoning Ability Instrument- TOLT

The TOLT was developed by Tobin and Capie (1981) to assess cognitive reasoning ability based on the foundational work of Inhelder and Piaget (1955, 1958). Through the use of this assessment, Tobin and Capie were able to measure, with high consistency, the formal thinking ability of students in grade levels six through college. Trifone (1987) dissected the test into each of its measured formal reasoning abilities including: proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning. Proportional reasoning was described as crucial in the comprehension of the quantitative aspects of science. Controlling variables is an important reasoning ability used in experimental situations and allows a student an understanding of manipulating both independent and dependent variables. Experimental understanding is an important factor related to probabilistic reasoning, and one of the TOLT's aims is to determine if a student has the ability to think in terms of probability and the need for repetition in research trials. The relationship between variables within a data set is described by a student's correlational reasoning ability. Lastly, the combinatorial reasoning ability questions on the TOLT determine a whether a student can list all possible outcomes of a solution set. Each of these abilities is tested equally among the TOLT and broken down by a subset of two questions each.

The TOLT consists of eight multiple choice and two exhaustive solution listing questions, which prior research has found the test to take approximately 40 minutes.

Two questions are asked for each of the first four measures of formal reasoning. These eight questions require the student to select the correct answer along with the correct justification for selecting that answer. Correct responses require both the correct answer and reasoning to receive a score for that question. The last measure of formal reasoning, combinatorial reasoning, is measured by two questions requiring the student to list all possible combinations from a set of items. A response on these last two questions require every possible combination, without replication, to be scored as correct. For all 10 questions, a correct response receives a score of one, and an incorrect response is scored as a zero; the maximum score on the TOLT is 10 points. In their foundational research, Tobin and Capie (1981) measured the reliability of the TOLT to be α=0.85. The following is a sample question from the TOLT as created by Tobin and Capie (1981): "Four large oranges are squeezed to make six glasses of juice. How much juice can be made from six oranges?" This question assesses proportional reasoning where the correct answer would be 9 oranges; the correct corresponding reasoning answer would be, "The number of glasses compared to the number of oranges will always be in the ratio 3 to 2."

As a validated means of assessing cognitive reasoning ability, the TOLT will be used in this study to assess a construction surveying student's reasoning ability. To this end, the TOLT will ensure the different class sections have similar cognitive functions and can be treated as a single population for data analysis.

Spatial Battery

As a robust measure of spatial ability, four tests of spatial aptitude will be used in this study. Two of the tests will assess spatial orientation abilities and the other two will assess spatial visualization abilities. The Mental Rotation Test (MRT), created by Vandenberg and Kuse (1978), measures spatial orientation of rotated three-dimensional objects. Additionally, a spatial orientation test that measures more complex rotations and hidden parts will be used, the Purdue Visualization of Rotations Test (ROT). The first of the two visualization tests is the Paper Folding Test (PFT) created by Ekstrom et al. (1976); this test measures the ability to mentally restructure a folded two-dimensional piece of paper. Lastly, Ekstrom et al. (1976) created the Hidden Patterns Test (HPT) to measure spatial visualization and flexibility by requiring the identification of a given figure within a "distracting perceptual field."

MRT

The MRT requires students to spatially orient mentally rotated images. Consisting of 20 questions, the test is divided into two parts, each constrained to a time limit of three minutes. Each question identifies a subject figure and four alternative rotations to select from. Two of these alternatives will be correct rotations while the other two are either mirrored rotations of the subject image or altogether different subject images that are rotated; these incorrect rotated figures are referred to as "distractors" by Vandenberg and Kuse (1978). Vandenberg and Kuse (1978) required the selection of both correct answers for a correct response to prevent unreliable results from simply guessing the answer. Figure 1 shows a sample question from the MRT in which the first image is the subject figure and both the second and fourth images are correct responses. Correct responses are scored as one point while incorrect or no response is scored as zero points. Total scores on the MRT range from zero to 40 points.

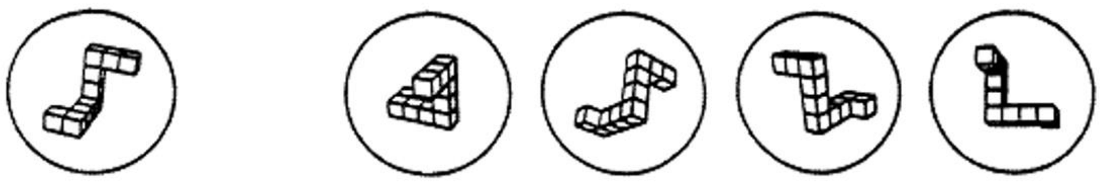

Figure 1. Sample Question from the MRT

ROT

Purdue created the visualization of rotations test (ROT) as another spatial ability instrument to measure spatial orientation. Similar to the MRT, the ROT requires mentally manipulating an object but Bodner and Guay (1997) claim there are multiple differences. The ROT, unlike the MRT, uses the natural axis of the object, contains questions where parts of the subject object are hidden, and allows rotation of the object about more than one axis. The ROT is a 20-item test restricted to 10 minutes. For each question, three rows of images are provided. The top row consists of two images; one displays a sample image and the other shows the desired rotation. On the second row, students are given the subject image and then required to select the proper image of desired rotation from five possible images in the third row. A correct response receives a score of one and an incorrect response receives a score of zero; the maximum score on the ROT is 20 points. Figure 2 shows an example question from the ROT where image D is the correct answer.

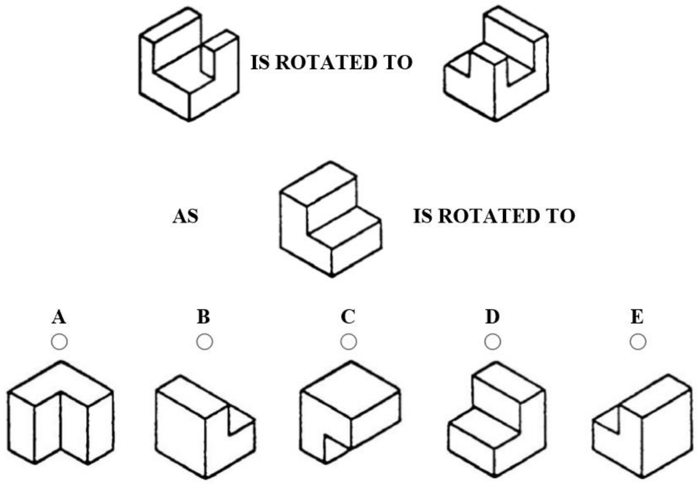

Figure 2. Sample Question from the ROT

PFT

The PFT is the first of two visualization tests that require mental manipulation of a folded object. Two sets of ten questions each are provided in this test; each set has a time limit of three minutes. Unlike the scoring in the previous tests, students will be given one point for each correct answer, zero points for an unanswered question, and a negative score of 0.2 for each incorrect answer. However, the minimum score for the test is set at zero and the maximum possible points is 20 points. Each question provides a square piece of paper sequentially folded up to three times with a hole punched through it. The student is required to mentally reconstruct the paper to determine the position of the holes when unfolded. Five images of square paper with holes are provided with each sequentially folded question set; the student must select the unfolded square piece of paper with the appropriately positioned holes. In the Figure 3 sample question from the PFT, just a single fold is conducted and the correct response is C.

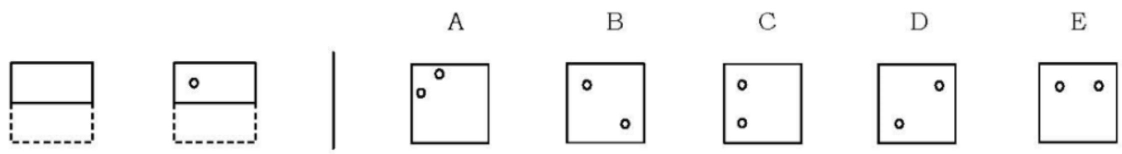

Figure 3. Sample Question from the PFT

HPT

The last test of spatial ability is the HPT. This test consists of 400 total patterns divided into two parts; each 200-pattern question set is constrained to 3 minutes. For each part of the test, students are given a subject geometric pattern and 200 possible geometric figures. The student must determine whether the subject pattern, in its original configuration, exists in each of the 200 possible figures. For each figure, if the subject pattern is embedded the student selects the option of “X,” and if it is not embedded in that figure they must select the option of “O.” Correct responses receive a score of one, incorrect responses receive a score of negative one, and unanswered figures receive zero points. Scoring on this test is bound from -400 to 400. Figure 4 displays an example problem where the correct response in selecting the “X” would be: 1, 3, 4, 8, and 10.

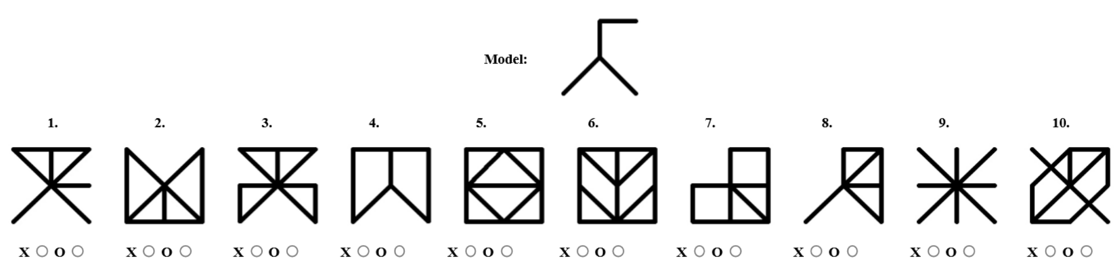

Figure 4. Sample Question from the HPT

Procedure

Construction surveying is an online hybrid course offering web-based materials, in-class recitation, and surveying laboratory fieldwork. The web-based materials include videos explaining and illustrating surveying fieldwork and additional pdf documents to supplement student learning outcomes. Specified viewing times are required to receive points for accessing the web-based materials; a total of 100 points are possible for accessing the web-based materials. A one-hour per week voluntary recitation period is offered in the evening to discuss weekly activities, demonstrate equipment usage, and answer student questions related to course material; the recitation period is not scored, and students do not receive any grade points for attendance. Surveying laboratory fieldwork comprises the majority of course points and consists of a dedicated four-hour laboratory activity each week. Laboratory scoring includes nine fieldwork activities with associated data analysis worth 70 points each; 630 total points are available for this graded course objective. Lastly, two equally weighted exams worth a total of 270 points are provided during the semester to assess student learning outcomes. 1,000 total grade points are available in the construction surveying course. An additional 20 grade points will be provided to students participating in this study but will not be considered in the data analysis of student academic performance. The TOLT will be assigned during the second recitation period and will be taken online in an unproctored environment. Spatial ability tests will be assigned later in the semester and will also be taken online in an unproctored environment. To be included in this study, students must, as approved by the Institutional Review Board:

- Voluntarily take the reasoning ability instrument, the TOLT; and spatial ability instruments, the MRT, ROT, PFT, and HPT;
- and give, in writing, permission to use their background information and academic performance data.

Students were provided consent forms at the beginning of the study; these forms were collected and stored until the semester was completed and grades were tabulated. Once final grades were posted, the consent forms were reviewed to identify those students that have or have not given permission to participate in the study. As approved by the Institutional Review Board, only those students giving permission were included in the data analysis for this study.

Prior to conducting statistical analysis, the data was analyzed for any potential outliers as defined in the methodology. Outliers in this study were determined by any student performing two standard deviations from the population mean on the reasoning ability instrument (the TOLT) with regards to time elapsed. Once the outliers were removed from the data, appropriate descriptive and statistical analysis was conducted with the three semester groups of students in regards to both the reasoning ability and spatial ability instruments. Initial data analysis, as defined in the methodology, was done to establish whether all three groups have statistically similar levels of cognitive maturation and can be combined into a single data set population. Each academic performance measure was analyzed independently in correlation with each spatial ability instrument. Further exploratory data analysis was conducted to identify any correlations in academic performance and cognitive abilities. The following assumptions were considered valid when analyzing the data after all outliers have been removed from the study:

- It is assumed that all students taking the reasoning ability test and spatial ability tests in an unproctored online environment are doing so with integrity.
- It is assumed that all students taking the reasoning ability test and spatial ability tests put forth their best effort in that their scores are representative of their actual cognitive abilities.
- It is assumed that the order in which a student takes the cognitive test battery will not significantly affect any of their test scores.
- It is assumed that a student's progression through the undergraduate Construction Science program will not significantly affect their cognitive or spatial ability scores.

RESULTS

Of the initial 329 participants, 39 students were excluded due to either not finishing the course and/or not taking the all of the reasoning and spatial tests. Additionally, 13 students were excluded as outliers. An outlier for this study was identified when a student's TOLT duration was shorter or longer than two standard deviations from the population mean (*M* = 20.77, *SD* = 7.66). Upon excluding these students, the final sample size was 277 subjects; fall 2016 (*n* = 101), spring 2017 (*n* = 86), and summer 2017 (*n* = 90). The participants consisted of 33 female and 244 male students with ages ranging from 19.71 to 44.65 (*M* = 22.80, *SD* = 2.44). The high ratio of males to females in this study is representative of the entire construction science student population at this university as well as in the construction industry's workforce. One student was a freshman, one was a sophomore, 42 were juniors, and 233 were seniors. For this analysis, all possible grade points were considered. The average grade points in the course was a low "B" (*M* = 807.85, *SD* = 54.69). The distribution of letter grades were: A = 9, B = 162, C = 98, and D = 8. Descriptive statistics for the variables of interest are provided in Table 3.

Table 3. Descriptive Statistics

Assessment (*possible points*)	*N*	Minimum	Maximum	Mean	Std. Deviation
All Lab Points (*630 pts*)	277	408.34	584.12	520.82	37.53
All Lab View Points (*100 pts*)	277	10	100	88.09	11.82
All Exam Points (*270 pts*)	277	113.91	262.85	198.94	27.64
Total Grade Points (*1000 pts*)	277	656.45	922.02	807.85	54.69

To determine if any differences existed between the semester groups, a one-way analysis of variance (ANOVA) was conducted on the TOLT scores using SPSS for Windows (IBM, 2017). No significant differences were identified between the students' reasoning ability for the three semesters, as measured by the TOLT, thus indicating the three semester groups could be pooled into a single sample set for analysis. Descriptive variables were also analyzed using an ANOVA to identify any differences present in the assessment measures by age, gender, grade level, and semester. No significant differences were identified for age and grade level between the assessment measures. Males performed significantly better on the exams ($F(3,028) = 4.01$, $p = .046$) than their female counterparts but no other assessment measures yielded significant differences for gender. Significant differences in all assessment measures were present between semester groups as shown in Table 4.

Table 4. Assessment Measures ANOVA by Semester Group

Assessment	*F*	*Sig.*	*Post hoc (Games-Howell)*
Lab Points	*F*(55,258) = 22.70	*p* = .000	Summer > Fall** & Spring**
View Points	*F*(1,142) = 4.18	*p* = .016	Summer > Spring*
Exam Points	*F*(13,556) = 9.41	*p* = .000	Spring > Fall*; Summer > Fall**
Total Grade Points	*F*(110,156) = 21.10	*p* = .000	Summer > Fall** & Spring**

** Post hoc p-value is significant at the 0.01 level (2-tailed).

* Post hoc p-value is significant at the 0.05 level (2-tailed).

A Post Hoc analysis utilizing Games-Howell to account for unequal cell sizes regarding semester groups and lab points revealed that the Summer 2017 (*M* = 540.79, *SD* = 25.64) group was significantly better than the Fall 2016 (*M* = 514.30, *SD* = 33.83) at the *p* = .000 level. Additionally, the Summer 2017 (*M* = 540.79, *SD* = 25.64) group performed significantly better than the Spring 2017 (*M* = 507.58, *SD* = 43.46) group in lab points at the *p* = .000 level. The Summer 2017 (*M* = 90.00, *SD* = 7.20) group performed significantly better than the Spring 2017 (*M* = 85.14, *SD* = 15.22) group in view points at the *p* = .022 level. Regarding exam points, the Spring 2017 (*M* = 202.43, *SD* = 25.81) group significantly outperformed the Fall 2016 (*M* = 189.88, *SD* = 27.95) group at the *p* = .005 level. Further, the Summer 2017 (*M* = 205.78, *SD* = 26.51) group performed significantly better than the Fall 2016 (*M* = 189.88, *SD* = 27.95) group for exam points at the *p* = .000. Finally, in total grade points, the Summer 2017 (*M* = 836.57, *SD* = 43.57) group performed significantly better than the Fall 2016 (*M* =

793.07, *SD* = 49.81) group and the Spring 2017 (*M* = 795.15, *SD* = 59.24) group at the *p* = .000 level for both. These point differences are unresolved; no differences in course content or administration differed between the three semester offerings.

The next analysis conducted was into how well correlated the assessment measures, reasoning ability test, and spatial ability tests were. A correlation is a statistical measure that quantifies the degree of relationship between variables. The data were analyzed for bivariate correlations between each asessment measure (Table 5) and each spatial ability measure (Table 6). As one would expect, there was a significant correlation between each of the assessment measures with Pearson's correlation values ranging from .134 to .830. Additionally, as expected, all spatial ability measures and the cummulative spatial ability z-score were significantly correlated at the *p* = .01 level with Pearson's correlation values ranging from .376 to .798.

Table 5. Pearson's Correlation Between Assessment Measures with Associated *p*-values ($N = 277$)

	1	2	3	4
1 Lab Points	1			
2 View Points	.232**	1		
p-value	.000			
3 Exam Points	.186**	.134*	1	
p-values	.002	.025		
4 Total Grade Points	.830**	.443**	.662**	1
p-values	.000	.000	.000	

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

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

Table 6. Pearson's Correlation Between Spatial Ability Measures with Associated *p*-values (*N* = 277)

	1	2	3	4	5
1 PFT Score	1				
2 HPT Score	.476**	1			
p-value	.000				
3 MRT Score	.540**	.442**	1		
p-values	.000	.000			
4 ROT Score	.449**	.376**	.425**	1	
p-values	.000	.000	.000		
5 Spatial Battery z-Score	.803**	.748**	.784**	.733**	1
p-values	.000	.000	.000	.000	

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

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

The first objective of this study was to determine whether, like in other disciplines found in the literature review, spatial abilities and reasoning abilities of construction surveying students were correlated. To do this, a bivariate correlation analyzing the relevant relationship between the TOLT and each spatial ability measure was conducted (Table 7). Similar to the findings in other fields of study, the TOLT was found to have a significant positive relationship at the $p = .01$ level with each of the spatial ability measures with Pearson's correlation values ranging from .287 with the MRT to .452 with the Spatial Battery z-Score.

Table 7. Pearson's Correlation Between TOLT and Spatial Ability Scores with Associated *p*-values (*N* = 277)

	PFT Score	HPT Score	MRT Score	ROT Score	Spatial Battery z-Score
TOLT Score	.383**	.357**	.287**	.359**	.452**
p-values	.000	.000	.000	.000	.000

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

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

The primary objective of this study was to determine whether any of the spatial ability measured were linked to academic performance as determined by the four assessment measures. First, a bivariate correlation using Pearson's correlation was conducted to determine the correlations between each achievement measure and each spatial ability score (Table 8). Significant positive correlations at the $p = .01$ level were found between exam points and all of the spatial ability measures with Pearson's correlation values ranging from .201 to .320. Additionally, significant positive correlations at the $p = .05$ level were found between total grade point and the HPT score ($r = .123$, $p = .041$), ROT Score ($r = .151$, $p = .012$), and Spatial Battery z-Score ($r = .126$, $p = .037$). Lastly, there was a significant negative correlation between lab points and MRT score ($r = -.126$, $p = .037$).

Table 8. Pearson's Correlation Between Assessment and Spatial Ability Measures with Associated *p*-values (N = 277)

	PFT Score	HPT Score	MRT Score	ROT Score	Spatial Battery z-Score
Lab Points	-.024	.008	-.126*	-.006	-.048
p-values	.695	.899	.037	.914	.424
View Points	-.066	.018	-.012	.017	-.014
p-values	.276	.761	.841	.783	.817
Exam Points	.201**	.224**	.256**	.300**	.320**
p-values	.001	.000	.000	.000	.000
Total Grade Points	.071	.123*	.041	.151*	.126*
p-values	.238	.041	.500	.012	.037

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

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

To analyze the hypothesis of whether students with a high reasoning ability will academically perform better than students with low reasoning ability, the TOLT scores first had to be categorized into ordinal groups. To do this, the TOLT scores were sorted in ascending order and placed into three ordinal groups: low, medium, and high. Traditionally, TOLT scores have a mean of seven with a standard deviation of two (Williamson & Anderson, 2017); thus, low scores were grouped as those scoring less than five, medium scores were grouped as those scoring five through eight, and high scores were grouped as those scoring a nine or ten. This led to the creation of three ordinal groups of low (N = 50), medium (N = 161), and high (N = 66) to be used as the independent variable in this analysis. Another sort was fit to the data to accommodate four ordinal groups in which very low was defined as scores four and below; moderate low was scores of five or six; moderate high consisted of scores seven, eight, and nine; and very high was defined by a score of ten. There were differing rationales for each of these splits, but each yielded analysis with the same significant findings. Therefore, the traditional split of low, medium, and high for the TOLT groups will be reported here in this research. An ANOVA was conducted between the assessment measures and the three TOLT groups (Table 10). A significance level of .05 was used for all analyses. The *Levene* test for equality of variances was found to be not significant for view points, exam points, or total grade points, indicating the assumption underlying the application of ANOVA was met for these tests. However, the *Levene* test for equality of variances was violated for lab points. Thus, the *Welch* value for significance was used to account for inequality of variances and is denoted below Table 9 appropriately.

Table 9. ANOVA of Assessment Scores by TOLT Groups

Assessment	*SS*	*df*	*MS*	*F*	*Sig.*
Lab Points	7490.48	2	3745.24	2.69	.136[1]
View Points	115.81	2	57.91	.41	.662
Exam Points	8444.89	2	4222.44	5.72	.004**
Total Grade Points	917.36	2	458.68	.15	.859

** The mean difference is significant at the 0.01 level (2-tailed)

[1] Robust Test for Equality of Means Welch statistic used.

A significant difference at the $p = .01$ level was found between the exam points and the TOLT ($F(8,445) = 5.72$, $p = .004$). A post hoc test to examine where these differences existed was conducted and provided in Table 10. This analysis only examined where the ANOVA showed significant differences within the in-group means. A Games-Howell post hoc test was used because it accomodates unequal cell sizes as well as unequal variances that were present in lab points of the prior analysis. Only results relating to exam points were investigated with the Games-Howell, as they were the only assessment measure that yielded significant ANOVA findings. A significant difference at the $p = .01$ level indicated that the high TOLT group significantly outperformed the low TOLT group in exam points.

Table 10. Post Hoc Test Between TOLT Groups and Exam Points

(I) TOLT	(J) TOLT	Mean Difference (I-J)	Std. Error	*Sig.*
Low	High	-17.23	5.22	.004**

** The mean difference is significant at the 0.01 level (2-tailed)

Next, prior to conducting an ANOVA between the assessment measures and spatial ability measures, each of the spatial ability scores had to be sorted into ascending order and categorized into four ordinal groups: very low, moderate low, moderate high, very high. Very low scores were defined as those below one standard deviation from the mean, moderate low scores were defined as those within one standard deviation below the mean, moderate high scores were defined as those within one standard deviation above the mean, and very high scores were defined as those more than one standard deviation from the mean. Since scoring on these spatial ability tests traditionally yield an integer value or a value with one single decimal point, none of the values fell directly on a standard deviation or the mean. Descriptive characteristics for each of the spatial ability scores are provided in Table 11 and frequencies for the ordinal groups of interest are provided in Tables 12.

Table 11. Descriptive Statistics for Spatial Ability Scores (*N* = 277)

Spatial Test (*possible scoring*)	*M*	*SD*
PFT Score (*0 to 20 pts*)	9.96	4.08
HPT Score (-*400 to 400 pts*)	70.82	34.32
MRT Score (*0 to 40 pts*)	16.30	8.93
ROT Score (*0 to 20 pts*)	11.52	4.35
Spatial Battery z-Score	0.0016	3.07

Table 12. Frequency Distribution of Ordinal Groups for Spatial Abilities (*N* = 277)

	Very Low	Moderate Low	Moderate High	Very High
PFT Score	51	76	110	40
HPT Score	52	56	135	34
MRT Score	47	107	70	53
ROT Score	50	82	89	56
Spatial Battery z-Score	46	85	102	44

Then, an ANOVA was conducted on the assessment measures by spatial ability test groups (Tables 13-17). An alpha of .05 was used for all analyses. The *Levene* test for equality of variances was found not to be significant in the PFT (Table 13), HPT (Table 14), and MRT (Table 15), indicating the assumption underlying the application of ANOVA was met for these tests. However, the *Levene* test for equality of variances was violated for both view points and exam points in the ROT (Table 16) and Spatial Battery z-Score test (Table 17). Thus, in both these instances, the *Welch* value for significance was used to account for inequality of variances and is denoted below the Tables 14 and 15 appropriately.

Table 13. ANOVA of Assessment Scores by PFT Groups

Assessment	*SS*	*df*	*MS*	*F*	*Sig.*
Lab Points	2502.51	3	834.17	.59	.622
View Points	328.43	3	109.48	.78	.505
Exam Points	6427.24	3	2142.41	2.86	.037*
Total Grade Points	6484.82	3	2161.61	.72	.540

* The mean difference is significant at the 0.05 level (2-tailed)

Table 14. ANOVA of Assessment Scores by HPT Groups

Assessment	*SS*	*df*	*MS*	*F*	*Sig.*
Lab Points	2230.20	3	743.40	.53	.665
View Points	175.83	3	58.61	.42	.741
Exam Points	8227.96	3	2742.65	3.70	.012*
Total Grade Points	9666.17	3	3222.06	1.08	.359

* The mean difference is significant at the 0.05 level (2-tailed)

Table 15. ANOVA of Assessment Scores by MRT Groups

Assessment	*SS*	*df*	*MS*	*F*	*Sig.*
Lab Points	9117.76	3	3039.25	2.19	.090
View Points	459.74	3	153.25	1.10	.350
Exam Points	13816.63	3	4605.54	6.38	.000**
Total Grade Points	2002.53	3	667.51	.22	.882

** The mean difference is significant at the 0.01 level (2-tailed)

Table 16. ANOVA of Assessment Scores by ROT Groups

Assessment	*SS*	*df*	*MS*	*F*	*Sig.*
Lab Points	1086.49	3	362.17	.26	.858
View Points	1321.28	3	440.43	3.23	.045[1]*
Exam Points	20332.74	3	6777.58	9.71	.000[1]**
Total Grade Points	18333.18	3	6111.06	2.07	.105

** The mean difference is significant at the 0.01 level (2-tailed)

* The mean difference is significant at the 0.05 level (2-tailed)

[1] Robust Test for Equality of Means Welch statistic used.

Table 17. ANOVA of Assessment Scores by Spatial Battery z-Score Groups

Assessment	*SS*	*df*	*MS*	*F*	*Sig.*
Lab Points	3709.82	3	1236.61	.88	.454
View Points	477.88	3	159.29	1.14	.251[1]
Exam Points	17939.77	3	5979.92	8.46	.000[1]**
Total Grade Points	13171.36	3	4390.45	1.48	.222

** The mean difference is significant at the 0.01 level (2-tailed)

[1] Robust Test for Equality of Means Welch statistic used.

Significant differences were found on the exam points for all the spatial ability test groups, and a significant difference was also found on the view points for the ROT test groups. Significant differences at the $p = .01$ level were found on the exam points for the MRT groups ($F(13,817) = 6.38$, $p = .000$), the ROT ($F(20,333) = 9.71$, $p = .000$), and Spatial Battery z-Score ($F(17,940) = 8.46$, $p = .000$). Significant differences at the $p = .05$ level were present on the exam points for the PFT groups ($F(6,427) = 2.86$, $p = .037$) and HPT ($F(8,228) = 3.70$, $p = .012$) and for the view points for the ROT groups ($F(1,321) = 3.23$, $p = .045$). A post hoc test to examine where these differences existed was conducted and provided in Table 18. These analysis were only examined where the

ANOVA or *Levene* test showed significant differences within the in-group means. A Games-Howell post hoc test was used because it accomodates unequal variances that were present in four instances of the prior analysis. Only results relating to view points and exam points were investigated with the post hoc test and only where they previously yielded significant findings. No significant differences were found in the post hoc tests between the PFT score groups and exam points or the ROT score groups and view points. Significant differences at the p = .01 level indicated that the very high group performed significantly better in exam points than the very low group for the HPT, MRT, ROT, and Spatial Battery z-Score.

Table 18. Post Hoc Tests Between Spatial Groups and Exam Points

	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	*Sig.*
HPT	Very Low	Very High	-19.21	5.61	.006**
MRT	Very Low	Very High	-21.83	4.91	.000**
	Moderate Low	Very High	-15.84	3.91	.000*
ROT	Very Low	Moderate Low	-14.08	4.59	.014*
	Very Low	Moderate High	-15.90	4.78	.006**
	Very Low	Very High	-27.64	4.56	.000**
	Moderate Low	Very High	-13.56	4.04	.006**
	Moderate High	Very High	-11.73	4.26	.033*
z-Score	Very Low	Moderate High	-13.73	5.19	.046*
	Very Low	Very High	-24.74	5.08	.000**
	Moderate Low	Very High	-20.06	3.83	.000**
	Moderate High	Very High	-11.01	4.08	.039*

** The mean difference is significant at the 0.01 level (2-tailed)

* The mean difference is significant at the 0.05 level (2-tailed)

The final investigation was into whether any spatial abilities were moderated by reasoning ability. To determine whether any spatial abilities were moderated by reasoning ability, an ANOVA was conducted using the independent value of the TOLT groups on each of the spatial ability measures (Table 19). A significance level of .05 was used for all analyses. The *Levene* test for equality of variances was found not to be significant in the PFT, MRT, and Spatial Battery z-Score, indicating the assumption underlying the application of ANOVA was met for these tests. However, the *Levene* test for equality of variances was violated for both the HPT Score and ROT Score. Thus, in both these instances, the *Welch* value for significance was used to account for inequality of variances and is denoted below Table 19 appropriately. Significant differences at the $p = .01$ level were present for the TOLT groups on all spatial ability scores.

Table 19. ANOVA of Spatial Ability Scores by TOLT Groups

	SS	*df*	*MS*	*F*	*Sig.*
PFT Score	523.43	2	261.71	17.74	.000**
HPT Score	29449.57	2	14724.78	13.65	.000[1]**
MRT Score	1070.86	2	535.43	7.01	.001**
ROT Score	581.22	2	290.61	17.16	.000[1]**
Spatial Battery z-Score	390.23	2	195.11	24.21	.000**

** The mean difference is significant at the 0.01 level (2-tailed)

[1] Robust Test for Equality of Means Welch statistic used.

A post hoc test to examine where these differences existed was conducted and provided in Table 20. Once again, a Games-Howell post hoc test was used because it accomodates unequal variances that were present in two instances of the prior analysis. Significant differences at the $p = .01$ level were found between the low TOLT group and both the medium and high TOLT groups for each spatial ability score in all but one instance; this one instance is the MRT score where the low TOLT group and the medium TOLT group were found to be significant at the $p = .05$ level. Additionally, siginificant differences at the $p = .05$ level were found between the medium TOLT group and high TOLT group for the PFT score and ROT score. Lastly, significant differences at the $p = .01$ level were discovered between the medium and high TOLT groups for the Spatial Battery z-Score.

Table 20. Post Hoc Tests Between TOLT Groups and Spatial Test Scores

	(I) TOLT	(J) TOLT	Mean Difference (I-J)	Std. Error	*Sig.*
PFT Score	Low	Medium	-2.91	.59	.000**
	Low	High	-4.22	.67	.000**
	Medium	High	-1.31	.55	.047*
HPT Score	Low	Medium	-22.85	6.71	.003**
	Low	High	-31.20	6.85	.000**
MRT Score	Low	Medium	-3.58	1.36	.028*
	Low	High	-6.13	1.57	.000**
ROT Score	Low	Medium	-2.88	.64	.000**
	Low	High	-4.49	.69	.000**
	Medium	High	-1.61	.56	.012*
z-Score	Low	Medium	-2.44	.48	.000**
	Low	High	-3.66	.51	.000**
	Medium	High	-1.22	.37	.004**

** The mean difference is significant at the 0.01 level (2-tailed)

* The mean difference is significant at the 0.05 level (2-tailed)

Limitations

Although construction science programs are discussed throughout this research, this study was limited to three semesters of students taking an upper-level undergraduate surveying course at Texas A&M University. Further, while a variety of reasoning and spatial abilities were measured, not all possible measures of these cognitive abilities were assessed. Additionally, academic achievement was measured by a composite score in four major graded areas but not broken down into an item-by-item basis for evaluation. Finally, although gender and semester differences in academic achievement measures were discovered, these findings remain unresolved as they were not the primary objective of this research. Additional research would be needed to further investigate these differences.

CONCLUSIONS

The spatial test battery used in this research has been well established as a reliable means of assessing students' spatial abilities across multiple disciplines; yet, this is the first study of its kind to assess spatial abilities of construction science students. This study will provide construction researchers and educators with a validated means of predicting success in construction science students. As the first of its kind in construction science research, this study provides a baseline of spatial ability scores present in a population of 277 undergraduate students in construction surveying. Additionally, this study provides additional insight on the cognitive reasoning abilities of these students and will add to the already existing body of knowledge in this area.

In analyzing the descriptive statistics, two major findings were discovered. First, males performed significantly better than females on the exams. This result is similar to findings of other research; however, since gender was not a specific focus of this study, the population was not specifically analyzed regarding this measure. Further analysis and research would be required to determine if there truly is a significant gender difference regarding exam points. The second major finding was within the semester groups; in all assessments measures, the summer performed significantly better than either the spring or fall. These findings are in agreement with the previous conference proceeding findings of Williamson (2017) but conflict with the findings of Williamson (in-press). The author of this study would conclude that the summer semester overall performs better than the traditional fall or spring semester as found in this study and by other researchers. The author proposes that the better summer performance could be resultant of student course load; students registering for the summer course of construction surveying are not allowed to enroll for any other courses for that term. This allows a student to be completely immersed in the course and have less distractions leading to better academic performance.

Although not unexpected, all assessment measures were found to be significantly positively correlated. Additionally, all the spatial measures had significant positive correlations. Since this specific battery of spatial tests is well recognized in the academic community, these results were expected. Spatial ability is one measure of intelligence, and since this battery of tests analyzes different subcomponents of a student’s overall spatial ability, it is not surprising that there were significant positive correlations between all the tests. Further, in response to the first research question, a significant positive correlation was found between the TOLT and all spatial ability test measures. As both spatial and reasoning abilities are a function of a student’s intelligence and were found to be positively correlated in this study, it is concluded that students with a high reasoning ability tend to have a high spatial ability.

As to the second research question, it was discovered that significant positive correlations existed between the all spatial test measures and the exam points and between the HPT, ROT, and Spatial Battery z-Score with total points. Additionally, a significant negative correlation was discovered with the MRT and lab points. The author offers no explanation as to why a negative correlation exists with the MRT; future research is needed to further investigate this finding. Hegarty (2017) performed two studies (N = 97) related to the strategies used to solve items on the MRT. It was discovered that utilizing a mental rotation strategy was not correlated with success on the MRT and students implemented multiple strategies to solve items including: perspective taking, counting cubes, local turns, and global shapes. Since solving the MRT does not solely rely on spatial strategies and this research has shown a significant negative correlation between the MRT and one of the assessment measures, the author suggests removing this spatial ability test from the current spatial battery for future research. Additionally, the ROT has been researched as a reliable means of assessing a student's spatial ability of 3-D object rotation and has also had significant positive correlations in this current study. Using the MRT as an additional test of 3-D rotational spatial ability is unnecessary, especially with evidence provided against its validity in assessing spatial ability.

When analyzing the data using an ANOVA on academic achievement scores for the different spatial ability groups (HTP, PFT, ROT, MRT, and Spatial Battery z-Score groups), significant differences were found for exam scores on all measures. Further investigation using the post hoc analysis determined that the very high spatial groups scored significantly better on exam scores than the very low spatial groups for all spatial ability measures except the PFT. There was also a significant finding using an ANOVA comparing view points by the ROT groups but the post hoc did not determine any significance between the groups. It must be recognized that the PFT did not have a positive correlation with total grade points and also did not uncover any significant findings in the Games Howell post hoc regarding exam score by PFT groups. The author suggests that the current course curriculum does not challenge students' serial spatial operations as much as the other spatial visualization aspects of spatial ability. Since the literature review deems serial spatial operations as an important attribute for construction, it would be suggested that the instructor revisit the assessment measures and curriculum design to potentially adapt the course design to include aspects that challenge the student in this regard.

As for reasoning ability groups, an ANOVA discovered that grouping by this cognitive ability also had significant differences in the achievement measure of exam points. A post hoc analysis determined that the high TOLT group was significantly better on exams than the low TOLT group. The author believes that the overwhelming significance and correlation between the reasoning and spatial ability tests and exam points stems from the fact that exams are purely an individual effort. In the construction surveying course analyzed in this research, lab points and total grade points are confounded by issues of group work and collaboration which may negate any individual reasoning or spatial ability differences present in students. Additionally, the view points are not a true measure of reasoning or spatial ability and are merely a result of effort on the student's part to read the assigned material. The author suggests the instructor revisits the assessment measure of view points and potentially alter the curriculum to ensure students cognitive abilities, and therefore intelligence and effort in the course are adequately assessed.

For the final investigation of this research, an ANOVA on the spatial ability test measures split by TOLT groups was conducted. It was determined that all cognitive measures were statistically significant. The post hoc analysis showed that those students with a high reasoning ability performed significantly better than students with a low reasoning ability on every spatial ability test measure. These findings confirm those found in the literature review that reasoning and spatial abilities are linked and that students with a high reasoning ability will also have a high spatial ability. Educators would benefit from taking note of these significant findings and be aware that both reasoning and spatial abilities can be effective predictors of success in construction science coursework if the course and curriculum design appropriately challenge the students.

In conclusion, exam points were the only true measure of academic achievement that was consistently significant in relation to both cognitive reasoning and spatial abilities. As discussed above, exam points are the only achievement measure provided in this construction surveying course that is purely individual effort. Additionally, due to the relatively low point value of exams (270 out of 1,000 points), exam points were not able to significantly alter a student's total grade points. It is suggested that the instructional design of this construction surveying course, as well as other construction science courses, be better constructed to truly assess a student's reasoning and spatial ability and to have a grading system that recognizes these individual differences in intelligence. This study's findings and correlations between reasoning and spatial abilities will assist educators in adapting curriculum to adequately educate, and ultimately assess their students. Further, this study will help to identify potential at-risk students in construction science according to their reasoning or spatial abilities.

However, further research will need to be conducted to assess how curriculum development or instructional strategies could assist at-risk students or provide the best learning environment for those students identified as either high or low performers with regards to their cognitive abilities.

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