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Spatial Ability and Academic Performance Correlations in Construction Surveying

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This study examined the relationship between scores on a spatial test battery and multiple academic achievement measures in an upper-level undergraduate construction surveying course. The test battery was administered to 277 construction science students. The scores on all spatial battery tests and assessment measures were found to be significantly correlated. Further, significant correlations were discovered between all the spatial ability test battery scores and achievement points in exams. A significant negative correlation was discovered between the Mental Rotations Test (MRT) scores and laboratory points. Additionally, significant correlations were found between total grade points and the Hidden Patterns Test (HPT) scores, the Purdue visualization of Rotations Test (ROT) scores, and the Spatial Ability Battery z-Scores. Based on these findings, educators and researchers in construction education would benefit by using these cognitive tests to assess student spatial abilities and to assist them in better understanding their students' spatial visualization skills, which should encourage instructors to modify instructional strategies and curriculum design to match or enhance their students' cognitive abilities.

Key Words: Construction Education Research, Construction Surveying, Assessment, Spatial Ability, Achievement

Introduction

Spatial abilities are just one of the myriad of cognitive skills that are crucial to success in construction education, as well as in the construction profession. Spatial reasoning is 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 construct of spatial abilities is somewhat consistent over time, but can be improved through instruction and practical spatial experiences (Wai, Lubinski & Benbow, 2009). On a daily basis, the construction process relies on the 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 spatial abilities of the next generation of construction professionals. Professional performance in the construction industry and academic performance in the construction science classroom is likely affected by one's cognition as measured by spatial ability. This research will determine if 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 spatial abilities of future construction industry professionals and the necessary cognitive skills that help predict their academic and eventual professional success.

In today's complex project environment, multifaceted skillsets are desired of construction managers. Ahmed et al. (2014) identified attention to detail as being the most desirable trait, out of ninety-three different traits of construction students entering the workforce. The most important attributes and ranked them in order of importance; those attributes that draw on spatial abilities (*with its corresponding rank order of importance*) are: comprehension ability (8), problem solving/ analytical skills (17), plan interpretation/ blueprint reading/ understand construction & shop drawings (25), scheduling (30), and estimating (32). They call upon academia to focus their curricular strategies upon preparing their graduates to succeed in these skill areas. 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. Additionally, Farrow, Liu, and Tatum (2011) held focus groups and found construction management students desired learning that was experiential with less textbook use. 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.

There is a gap in the existing body of knowledge on whether or not spatial abilities, as measured by a spatial ability test battery, can also be used as an effective assessment tool to predict the success of construction science students. Additionally, to date, no research has been conducted assessing spatial abilities and academic performance of construction science students. To further advance spatial ability performance assessment in the pedagogical practice of construction management in an attempt to fill the gaps, the major objective of this study was to investigate the effect both reasoning and spatial abilities have on academic performance of construction science students taking a construction surveying course. The subsequent literature review will outline previous research conducted in construction surveying education and identify research linking spatial abilities to academic performance across multiple fields of study. 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.

Construction Surveying

The American Council for Construction Education (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). 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. Additionally, multiple requirements for accreditation under the ACCE are directly related to spatial abilities. For example, graduates in accredited programs are required to analyze, read and interpret construction documents many of which are graphically printed or computer-generated visualizations. 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.

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 academic success in a multitude of studies. Harle and Towns (2011) links the success of STEM fields 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, 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.

Although there are many courses in the undergraduate construction science programs, this research is limited to students taking the upper-level, undergraduate surveying course. A multitude of spatial ability tests exist; but, this study does not assess all possible spatial abilities. 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. To produce

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foundational research on the spatial abilities of construction science students, this research examines how spatial abilities are correlated with a student's academic performance. It is hypothesized that students with high spatial ability would academically perform better than students with low spatial ability in a construction surveying course.

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. 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 were not evaluated as part of the data set.

Reasoning Ability

Tobin and Capie (1981) developed the Test of Logical Thinking (TOLT) to measures five modes of formal reasoning and is able to be administered to a large population of students concurrently. These modes include proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning. They measured the reliability of the TOLT to be a Cronbach's α=0.85. Cognitive reasoning abilities have long been linked to student performance across multidisciplinary pedagogical practices. Williamson & Anderson (2017) reported that the TOLT could be used as a valid means of assessing cognitive reasoning ability within construction education. The TOLT was used in this study to assess a construction surveying student's reasoning ability and to ensure the different class sections have similar cognitive functions and therefore can be treated as a single population for data analysis.

Spatial Ability Battery

All of the Spatial Ability Battery (SAB) 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 1. Carroll (1993) lists three spatial ability factors, 1) spatial relations (*transformation*), 2) spatial orientation (*rotation*), and 3) spatial visualization (*identification*), as being essential to the quality of one's spatial reasoning ability and performance. In the identification of these factors, the subsequent spatial ability tests were selected for use in this study.

Table 1

Internal Consistency of the Spatial Ability Battery Testing Instruments.

Author (year)	Testing Instrument	Factor	Cronbach's Alpha
Bodner & Guay (1997)	Rotations Test (ROT)	3-D Rotation	α = 0.80
Ekstrom et al. (1976)	Paper Folding Test (PFT)	Image Transformation	α = 0.82
Vandenberg and Kuse (1978)	Mental Rotation Test (MRT)	3-D Rotation	α = 0.88
Ekstrom et al. (1976)	Hidden Pattern Test (HPT)	Pattern Identification	α = 0.80

ROT

The ROT, also referred to as the Purdue spatial visualization of rotations test, was created by Bodner and Guay (1977). The ROT requires visualization of rotation of 3-D isometric shapes in both the horizontal and vertical planes and measures complex object rotation. The ROT 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. 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. 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.

PFT

The Paper Folding Test (PFT) as created by Ekstrom et al. (1976). The PFT requires performing serial operations while mentally manipulating a folded object and measures one's visuospatial transformation ability; an additional step beyond just spatial orientation. This test is less researched than the previous visualization test; however, it has been correlated with academic success (Turgut & Yilmaz, 2012). 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 test, students were 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 had to select the unfolded square piece of paper with the appropriately positioned holes.

MRT

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 and measures the speed of mental rotation. Spatial relation has been linked to academic success across multiple disciplines. 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. Consisting of 20 questions, the test was divided into two parts, each constrained to a time limit of three minutes. Each question identified a subject figure and four alternative rotations to select from. Two of these alternatives were correct rotations while the other two were either mirrored rotations of the subject image or altogether different subject images that were rotated; these incorrect rotated figures were referred to as "distractors". The MRT required the selection of both correct answers for a correct response to prevent unreliable results from simply guessing the answer. Correct responses were scored as one point while incorrect or no response was scored as zero points. Total scores on the MRT ranged from zero to 40 points.

HPT

The final spatial ability assessment test is the Hidden Patterns Test (HPT), which measures the ability to identify patterns in the midst of distracting stimuli (Ekstrom et al. 1976). The HPT requires spatial object recognition and visual detection of embedded features. 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. This test consists of 400 total patterns divided into two parts; each 200-pattern question set was constrained to 3 minutes. For each part of the test, students were given a subject geometric pattern and 200 possible geometric figures. The student had to determine whether the subject pattern, in its original configuration, existed in each of the 200 possible figures. For each figure, if the subject pattern is embedded the student would select the option of "X," and if it is not embedded in that figure they had to select the option of "O." Correct responses received a score of one, incorrect responses received a score of negative one, and unanswered figures received zero points.

Procedure

Construction surveying is an online hybrid laboratory course offering web-based materials, in-class recitation, fieldwork, and application of the measured data. A one-hour voluntary recitation period is offered in the evening to discuss activities, demonstrate equipment usage, and answer student questions related to course materials, equipment, and field activities. The web-based materials included videos explaining and illustrating surveying fieldwork, and additional pdf documents to supplement student learning outcomes. Specified viewing times were required to receive points for accessing the web-based materials; a total of 100 points were possible for accessing the web-based materials. Surveying fieldwork comprises the majority of course points and consisted of a dedicated four-hour laboratory activity each week. Laboratory scoring included nine fieldwork activities with associated data analysis worth 70 points each; with 630 total available points. Lastly, two equally weighted exams, worth a total of 270 points, were provided during the semester to assess learning outcomes. 1,000 total grade points were available. An additional 20 grade points were provided to students participating in this study but were not be considered in the data analysis of student academic performance. The TOLT was assigned to be taken during the second recitation period and was taken online in an unproctored environment. Spatial ability tests were assigned later in the semester and were also taken online in an unproctored environment. Williamson, Williamson, and Hinze (2016) conducted a comparative administration of the SAB tests, between in-class (proctored paper and pencil) and on-line (unproctored Internet) (N = 457). The findings suggested no significant differences across administration formats, and that on-line administration had similar properties of predicting student performance as the in-class version. Therefore, on-line administration is a viable option for instructors to consider especially when dealing with large classes. To be included in this study, students must have, as approved by the Institutional Review Board: voluntarily taken the reasoning ability and spatial ability instruments; and give, in writing, permission to use their background information and academic performance data.

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.

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 to 44 ($M = 22.80$, $SD = 2.44$). 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. To determine if any differences existed between the semester groups, a one-way analysis of variance (ANOVA) was conducted on the TOLT. No significant differences were identified between the students' reasoning ability between semesters, 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.

The next analysis conducted was into how well correlated were the assessment and the spatial ability scores. A correlation is a statistical measure that quantifies the degree of relationship between variables. The data were analyzed for bivariate correlations between each assessment measure (Table 2) and spatial ability scores (Table 3). 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, all spatial ability scores and the cumulative spatial ability z-score were significantly correlated at the $p = .01$ level with Pearson's correlation values ranging from .376 to .803.

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Table 2

Pearson's Correlation between Assessment Measures. (*N* = 277)

		1	2	3	4
1	Lab Points	1			
2	Viewing Points	.232**	1		
3	Exam Points	.186**	.134*	1	
4	Total Grade Points	.830**	.443**	.662**	1

** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed).

Table 3

Pearson's Correlation between Spatial Ability Measures. (*N* = 277)

	1	2	3	4	5	6
1	PFT Score	1				
2	HPT Score	.476**	1			
3	MRT Score	.540**	.442**	1		
4	ROT Score	.449**	.376**	.425**	1	
5	Spatial Battery z-Score	.803**	.748**	.784**	.733**	1

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

The primary objective of this study was to determine whether any of the spatial abilities measured were linked to academic performance. A bivariate correlation using Pearson's correlation was conducted to determine the correlations between each achievement measure and each spatial ability test score (Table 8). Significant positive correlations at the p = .01 level were found between exam points and all of the spatial ability scores 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 4

Pearson's Correlation between Assessment and Spatial Ability Measures. (*N* = 277)

	PFT Score	HPT Score	MRT Score	ROT Score	Spatial Battery z-Score
Lab Points	-.024	.008	-.126*	-.006	-.048
Viewing Points	-.066	.018	-.012	.017	-.014
Exam Points	.201**	.224**	.256**	.300**	.320**
Total Grade Points	.071	123*	.041	.151*	.126*

** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed).

Conclusions

Although not unexpected, all assessment measures were found to be significantly positively correlated. Additionally, all the spatial scores had significant positive correlations. Since this specific battery of spatial tests is well recognized in the academic community, these results were somewhat 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. As spatial ability is a function of a student's intelligence and was found to be positively correlated in this study, it is concluded that students with a high spatial ability tend to have high achievement measures.

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Additionally, a significant negative correlation was discovered with the MRT and lab points. 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. 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.

In conclusion, exam points, an individual effort, were the only true measure of academic achievement that was consistently significant in relation to spatial abilities. 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 assessment measures and spatial abilities will assist educators in adapting curriculum to adequately educate, and ultimately assess their students.

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