Mental Rotation Skills and Academic Success

A Case Study at an HBCU

Mohammad Javed Khan and **Chadia Affane Aji**
Tuskegee University

Abstract

This paper reports findings on how performance on a mental rotation test is related to academic performance, specifically to performance on mathematics. Limited empirical studies are available for students from underrepresented groups. The participant population of this study is traditionally underrepresented in Science, Technology, Engineering and Mathematics (STEM) disciplines. The comparison between male and female participants and the impact of an engineering graphics course on performance on the mental rotation test is also discussed.

Keywords

Mental rotation, academic performance, engineering graphics course, mathematics, aerospace engineering

Introduction

Spatial ability is one of the three significant cognitive abilities identified as important for learning, the other two being quantitative and verbal abilities[1]. There are many definitions for spatial ability[2], e.g. '*Spatial ability is the capacity to understand and remember the spatial relations among objects* (JHU 2010), *'...a collective term for a wide range of acquired skills, all of which make use of basic memory for shape and position*'[3]. Spatial ability or spatial skills are broadly divided into two categories: spatial visualization and spatial orientation[4]. Spatial visualization can be further divided into mental rotation (of a complete object) and mental transformation (for example, rotating parts of an object to form the object). The recognition of spatial ability as one of the important cognitive abilities is attributed to Edward Thorndike who called it 'mechanical intelligence'[5]. More recently the correlational and predictive aspects of spatial abilities and academic success have been the focus of research. A number of studies have reported the crucial role that spatial abilities play in academic success[6]. Conner and Serbin reported several studies included in *Spatial Abilities: Its Educational and Social Significance*[7] that indicated the importance of spatial abilities and success in math. The influence of mental imagery on the scientific thinking of 64 eminent scholars has been reported[8]. The correlation between performance on certain physics assessment questions and spatial abilities were discussed by Pallrand et al.[9] Students with higher spatial visualization abilities were observed to perform better in certain organic chemistry concepts[10,11].

There is a large body of research literature on gender and spatial skills and various reasons for the difference in abilities have been proposed[12-16]. The effect of unequal social status of genders on performance on the mental rotation test has been reported in a study of 53 countries by Tsui et

al.[17] with females performing at a lower level than males. They also noted that while narrowing of gender gap has been reported by several investigators, the gap has not narrow on mental rotation as observed by Voyer et al.[12] and Masters etal.[18] In a study by Casey et al.[19], it was noted that males performed better on both a spatial abilities test as well SAT (math) as compared to females for the higher spatial ability group, but there was no difference in performance for the lower ability group. The lower performance on a mental rotation test by students from underrepresented groups has also been reported in literature[20,21].

The questions that are being researched are (a) when is the onset of gender associated difference in spatial abilities? (b) can spatial abilities be improved with appropriate interventions? and (c) does the improvement in spatial abilities impact academic performance? Cheng et al.[22] studied the effect of spatial training and performance on math of 6-8 years old elementary school children and observed that they were correlated. Sorby et al.[23] observed significant improvement in the spatial abilities of non-engineering students when exposed to a special workbook and software originally developed for engineering students. The effect of spatial visualization training on retention of female students has also been reported by Metz et al.[24] who noted retention of 77% of female first year students who enrolled in a spatial skills course as compared to 44% retention of females who did not enroll in the course. They also noted statistically significant differences in average grades in Introductory Engineering, Calculus-I, Physics-I, and Chemistry-I. However, the meta-analysis by Uttar et al.[25] cautions that while some studies indicated that spatial training could improve performance in STEM disciplines, further research was needed.

Objective

The results reported in this paper are a continuation of the work by the authors. The objective of the present study is to determine if performance on the mental rotation test is correlated to academic success in general and specifically on performance in Pre-Calculus and Trigonometry. The study also was aimed at providing additional empirical data for students from underrepresented groups at an HBCU.

Method and Materials

The Purdue Visualization Test for mental rotation (PVST-R) that had 30 questions was administered to freshmen students at an HBCU. An example of the PVST-R questions is given in Fig. 1. The test was uploaded to the learning management system and students could take the test at their convenience. The test was not timed. This was to alleviate the possible effects of test anxiety and stereo-type threat[26]. The participating students took the test voluntarily.

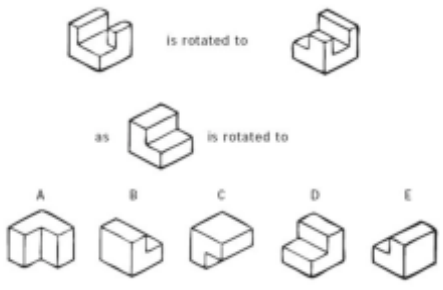

Figure 1: A Typical PVST-R Question

A subset of the participants who were aerospace science engineering majors took a 1-credit course the next semester. During students this course the met with

the instructor once a week for three hours. This course was primarily an engineering graphics course that emphasized sketching orthographic views and isometric drawings. Later part of the course was dedicated to computer-aided drafting. This subset of participants took the 12-item PVST-R pretest and then a posttest at end of the course. The scores on the PVST-R were compared for various groupings to determine the effect of gender, prior CAD-experience and the engineering graphics course. The correlation between the PVSR-R scores and performance Pre-Calculus and Trigonometry course taken in the first semester was also studied.

Demographic data on the participants was collected which included gender, prior experience with CAD, and major. A total of N = 175 students (74 males, 101 females) responded to the PVST-R. There were 34 participants who had CAD experience and 141 participants did not have CAD experience. All these students were African-American and first semester freshmen at a historically black university.

Results and Discussion

The mean score on the PVST-R was 15.2. The females had an average score of 13.3 while the males had an average score of 17.9. The difference in the performance was statistically significant at $p < 0.0001$ (two-tailed t-test). A comparison of performance between self-reports of No-CAD and CAD experience indicated a statistically significant difference on performance at $p < 0.0001$(CAD, 20.44; No-CAD, 13.96). The performance of females with no CAD experience was lower than the males with CAD experience, the difference being statistically significant at $p < 0.0001$ (F, N=89, mean = 12.38; M, N = 52, mean = 16.67). The difference in the performance on the PVST-R test of females with CAD experience and males with CAD experience was not statistically significant at $p < 0.05$ (F, N =12, mean = 19.67; M, N = 22, mean = 20.86). A summary of this data and results is given in Table-I.

The performance of a subset of participants on PSVT-R was compared with their grades on the college math course that they took during the first semester were available. The analysis indicated that for male participants (N=44) with no CAD experience, a statistically significant ($p < 0.05$) correlation ($r = 0.28$) between performance on the PSVT-R and math grades existed. However, no statistically significant correlation between performance on PSVT-R and math grades was observed for females with (N=12) and males with CAD experience (N=12). This could be attributed to the low sample size. The performance of females (N = 70) with no CAD experience was also not correlated with their grade in the math course.

The performance of a total of 69 participants (aerospace majors) with 18 females and 51 females who took an engineering graphics course were given the PVST-R test at the end of the course. The females' performance on the pretest was lower (mean = 6.17) than the males (mean = 8.06) at $p < 0.005$. There was statistically significant difference in performance between pretest and posttest at $p < 0.0001$ (two-tail t-test) for this group. The pretest mean for the group (N = 69) was 7.57 while the posttest mean was 9.33. The female participants (N = 18) exhibited an improved performance that was statistically significant at $p < 0.05$, with a pretest mean of 6.17 and posttest mean of 7.88.

Group	N	Mean Score	Statistical Significance
All	175	15.22	
Females (F)	101	13.24	Yes, p<0.0001
Males (M)	74	17.92	
CAD Experience - All			
Yes	34	20.44	Yes, p<0.0001
No	141	13.96	
CAD Experience - F			
Yes	12	19.67	Yes, p<0.0001
No	89	12.38	
CAD Experience - M			
Yes	22	20.86	Yes, p<0.01
No	52	16.67	
Gender-No CAD Experience			
Female (F)	89	12.38	Yes, p<0.0001
Male (M)	52	16.67	
Gender – CAD Experience			
Female	12	19.67	No
Male	22	20.86	

Table I: Performance on PVST-R

Group	N	Mean Score	Statistical Significance
All	69		Yes, p < 0.0001
Pretest		7.57	
Posttest		9.33	
Females	18		Yes, p < 0.05
Pretest		6.17	
Posttest		7.18	
Males	51		Yes, p < 0.0001
Pretest		8.06	
Posttest		9.82	
Posttest			
Females	18	7.88	Yes, p < 0.001
Males	51	9.82	
Pre-Post			
Females (Post)	18	7.88	No
Males (Pre)	51	8.06	

Table II: Effect of Intervention

Statically significant improvement at $p < 0.0001$ was recorded for male participants ($N = 51$) as well, with pretest mean of 8.05 and a posttest mean of 9.82. However, there still existed a statistically significant difference ($p < 0.001$) in performance between males and females after the course. No statistically significant difference was observed in the gains of the female and male participants on the PVST-R test as a result of the intervention. It was also noted that there was no statistically significant difference in performance of the female participants on the PVSTR posttest in comparison to the pretest performance of the male participants. This data is summarized in Table-II.

Conclusions

The mental rotation skills of freshmen students from underrepresented groups were investigated. It was observed that:

(a) Males performed better on the mental rotation test as compared to females. This observation is consistent with the research literature.
(b) Both males and females improved their mental rotation skills after undergoing a 3-hr per week, one semester long engineering graphics course. However, the difference in performance between males and females persisted with males performing better than females. This can be attributed to the comparatively lower performance by the females on the pretest.
(c) Difference in gains in mental rotation ability between males and females after the engineering course was statistically insignificant.
(d) Difference in mental rotation ability of females after the engineering course and of males prior to the course was statistically insignificant.

(e) Performance on the math course was correlated with performance on the mental rotation test for males with no prior CAD experience.
(f) No correlation was observed between math grades and performance on the mental rotation test for females.
(g) No correlation was observed between math grades and performance on the mental rotation test for males or females with prior CAD experience. This could be attributed to the small sample size.

Additional studies need to be conducted to understand the absence of correlation between performance in math and the mental rotation test for females and for all participants with prior CAD experience.

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Mohammad Javed Khan

M. Javed Khan is Professor and Head of the Aerospace Science Engineering Department at Tuskegee University. He received his Ph.D. in Aerospace Engineering from Texas A&M, MS in Aeronautical Engineering from the US Air Force Institute of Technology and his undergraduate degree in Aerospace Engineering from Karachi University. His research interests include vortex dominated flows, and aircraft design. He is actively involved in research on engineering education and K-12 STEM education. He is a Fellow of the Royal Aeronautical Society, an Associate Fellow of the AIAA and a member of the ASEE.

Chadia Affane Aji

Chadia Affane Aji is a Professor in the Department of Mathematics at Tuskegee University. Dr. Aji received her Ph.D. and M.S. in Mathematics from Auburn University and a Bachelor in Chemical Engineering from Texas A&M University. Her research interests lie in the areas of numerical analysis, computational applied mathematics, complex analysis, and on improving students' learning in STEM disciplines. Dr. Aji is involved in retention activities at Tuskegee University. In particular, she works closely with sources on campus to design strategies to assist incoming freshmen cope with first year mathematics classes. She developed teaching modules to improve students' learning in mathematics using technology.