A Comparative Analysis of Gender and the Impact of Mathematics Achievement on Spatial Visualization Ability in Engineering Technology Students

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Abstract

The purpose of this study is to determine if there is a relationship between spatial visualization ability and mathematics performance based on gender for 300 freshmen students in an introductory engineering design graphics course. SAT and ACT mathematics scores will be analyzed versus an initial pre-test using the Purdue Spatial Visualization Test: Rotation (PSVT:R). Based on previous studies, evidence supports a strong correlation between higher mathematics achievement and spatial visualization ability. In addition, prior research has indicated that gender has been a factor in performance with males outperforming their female counterparts in spatial ability. It is expected that male students continue to possess a higher level of spatial ability correlated with math performance compared to their female peers.

Introduction

This study will be conducted beginning August, 2018. Preliminary results will be presented at the EDGD mid-year in January.

Spatial Ability: Research suggests that spatial ability is the “gatekeeper” to admission and achievement in STEM (Science, Technology, Engineering, Mathematics) education (Uttal, Meadow, Tipton, Hand, Alden, Warren & Newcombe, 2013; Newcombe, 2010; Kell, Lubinski, Benbow & Steiger, 2013; Miller & Bertoline, 1991; Sorby & Baartmans, 2000). Cultivating spatial abilities has been shown to support development and achievement in mathematics and science (Keller, Washburn-Moses & Hart, 2002; Olkun, 2003; Robichaux, 2003; Shea, Lubinski & Benbow, 1992).

Spatial ability is the capacity to formulate and retain mental representations of given stimuli allowing learners to relate within a given environment (Carroll, 1993; Höffler, 2010, Hegarty & Waller, 2004). This ability is a critical component for success in many STEM fields including engineering and technical fields such as mathematics and even the medical field. Developed spatial reasoning is recognized as “the most fundamental and rewarding part of engineering graphics instruction" (Contero, Company, Saorín & Naya, 2006, p. 472). Spatial ability skills are considered to be an important predictor for achievement in controlling objects and interacting with computer-aided design (Norman, 1994). Research has suggested that there are positive correlations between spatial ability and retention of technology and engineering students' ability to complete degree requirements (Brus, Zhoa & Jessop, 2004; Sorby, 2009; Mayer & Sims, 1994; Mayer, Mautone & Prothero, 2002).

Spatial Visualization: Spatial visualization is often synonymous with "spatial ability" and "visualization" (Braukmann, 1991) involving the mental alteration of an object through a sequence of modifications and is suggested to be a key element for success in engineering coursework (Ferguson, Ball, McDaniel, & Anderson, 2008). McGee (1979) defined spatial visualization as the "ability to mentally manipulate, rotate, twist or invert a pictorially presented stimulus object" (p. 893). Strong & Smith (2001) went on to define it as "the ability to manipulate an object in an imaginary 3-D space and create a representation of the object from a new viewpoint" (p. 2). There are many factors suggested through research that may have an impact on spatial ability. These factors include, but are not limited to environmental influences such as culture, social, gender and stereotype, developmental and educational factors (Mohler, 2008; Mann, Sasanuma, Sakuma, & Masaki, 1990; Belz & Geary, 1984; Tracy, 1990; Harris, 1978). Educational factors such as problem solving skills specifically used in mathematics influence spatial ability performance (Clements & Battista, 1992; Mislevy, Winersky, Irvine, & Dann, 1990; Michaelides, 2002; Wheatley, Brown, & Solano, 1994; Heitland, 2000; Robichaux & Guarino, 2000). Descriptive geometry, orthographic views, and three-dimensional modeling have been used as a means to improve the spatial abilities of learners (Martín-Gutiérrez, Gil, Contero & Saorín, 2013).

Spatial Visualization and Engineering Education: Spatial visualization is perhaps one of the most critical skills lending itself to success in engineering coursework and ultimately in the workforce. Spatial thinking, specifically spatial visualization is perhaps one of the most distinctive characteristics for engineers to possess. It is used as a means for documenting concepts and design modeling, and communicating these concepts and models to others (Condoor, 1999). More generally spatial visualization encompasses the mental alteration of an object through a sequence of adjustments, and considered a key factor in the success of engineering students (Ferguson, et. al, 2008).

Mathematics Education. Mathematics is an essential subject required in the early years of education relying on psychological factors such as self-confidence, motivation, and most importantly working memory which is considered to be the most significant cognitive element (Kyttälä, Aunio, Lehto, Van Luit, & Hautamäki, 2003; Cornoldi &

Lucangeli, 2004; Middleton & Spanias, 1999; Casey, Nuttall & Pezaris, 1997). Working memory controls, regulates and processes information to conduct the cognitive tasks associated with mathematical processing (De Smedt, Janssen, Bouwens, Verschaffel, Boets & Ghesquière, 2009). Research has shown significant evidence that visuo-spatial ability is critical for the development of mathematical skills as working memory is also a key factor in the development of spatial skills (Agus, Mascia, Fastame, Melis, Pilloni & Penna, 2015; Van Garderen, 2006; Heathcote, 1994; Van Garderen & Montague, 2003).

Spatial Ability and Mathematics: The correlation observed between spatial and mathematical ability suggest the importance of spatial ability in problem solving specifically as a significant factor in the success of many STEM fields (Bogue & Marra 2003; Contero, et. al., 2006; Mohler, 2008; Sorby, 2009; Miller & Halpern, 2013; Sorby, Casey, Veurink, & Dulaney, 2013; Grandin, Peterson & Shaw, 1998; Keller, Wasburn-Moses & Hart, 2002). Since spatial visualization is directly correlated with problem solving ability (Carter, LaRussa, & Bodner, 1987), mathematics becomes a significant factor in understanding how spatial skills are developed through achievement in mathematics. Research has suggested that there is a relationship between spatial ability and mathematics (Casey, et. al., 1995; Geary, 2011; Mix & Cheng, 2012; van der Ven, van der Maas, Straatemeier & Jansen, 2013; Tosto, Hanscombe, Haworth, Davis, Petrill, Dale, Malykh, Plomin & Kovas, 2014; Sella, Sader, Lolliot & Kadosh, 2016). Research interest has existed since the mid-1900's and has been supported by research identifying the possible concurrent development of spatial ability and mathematics performance (Casey, Nuttall, Pezaris, & Benbow, 1995; Casey, et. al., 1997; Ganley & Vasilyeva, 2011; Verdine, Golinkoff, Hirsh-Pasek, Newcombe, Filipowicz, & Chang, 2014). Rohde & Thompson (2007) found spatial ability to moderately correlate with raw SAT-M scores at the age of 18, and an important predictor of mathematics performance after controlling for working memory, general intelligence, and processing speed. However, the key question remains whether or not there is a unique and exclusive link between the two (Rutherford, Karamarkovich & Lee, 2018). There are several reasons for exploring the relationship between mathematics achievement and spatial visualization ability. Spatial ability and high achievement in mathematics are critical factors for student success in STEM fields including mathematics and engineering education. A link between these two disciplines further substantiates the importance of problem-solving as a key skill for success in both areas as well as STEM-related fields. However, as observed by Uttal, et al. (2013), there may be a "Catch 22" regarding spatial ability in early STEM education. Students lacking achievement in mathematics as well as spatial ability face significant challenges affecting performance in STEM-related majors.

Spatial Ability and female students: A significant body of research has been conducted on the performance of females enrolled in STEM-related majors. Much of the research conducted over the past several decades indicates that females lack adequate spatial ability and thus perform at a lower level than their male counterparts (Linn & Petersen, 1986; Masters & Sanders, 1993; Sorby, 2009; Voyer, Voyer & Bryden, 1995;). However, more recent research is finding that female students are more skilled than in the past due to perhaps changing technologies and the digital age (Sorby & Veurink, 2010).

Research Question and Hypothesis

To complement the body of knowledge related to female students in mathematics and spatial ability, the following study was conducted.

The following was the primary research question:

Is there a difference between freshmen engineering technology male and female subjects' mathematics performance and its effect on spatial visualization ability?

The following hypotheses will be analyzed to determine the solution to the research question:

H_0: There is no correlation between mathematics performance and spatial visualization ability between male and female students as measured through the PSVT:R and freshmen SAT and ACT mathematics scores.

H_1: There is a significant correlation between mathematics performance and spatial visualization ability between male and female students as measured through the PSVT:R and freshmen SAT and ACT mathematics scores.

Methodology

To perform the comparative analysis, a quasi-experimental study was performed during the fall of 2018. Subjects for the study were enrolled in an engineering design graphics course as part of the course requirements for the Engineering Technology program. This course focuses on basic principles in engineering design including drawing/hand sketching, dimensions, and tolerance. The engineering design graphics course also emphasizes practice through a hands-on environment using 3D AutoCAD software, as well as editing, manipulation, visualization, and presentation of technical drawings.

A population of 300 freshman students was used as a convenience sample. Using the Purdue Spatial Visualization Test (PSVT:R), students were asked to complete a pre-test the first week of classes to measure their initial spatial ability. Upon completion of the pre-test, students SAT and ACT mathematics scores were assessed to determine if mathematics scores correlated with performance in spatial visualization ability and if the study's population revealed a difference between male and female subjects. Data for SAT and ACT mathematics scores were provided by the university's assessment administrators.

Results

A Pearson's correlation was used to determine the association between PSVT:R pre-test scores and SAT and ACT scores between male (N= 230) and female (N=70) subjects. The maximum score on the PSVT:R was 36, 800 for the SAT and 36 for the ACT. Scores for male subjects reveal a mean of 17.72 for the PSVT:R, 651.63 for the SAT, and 29.10 for the ACT (Table 1). No correlation was found between the PSVT:R pre-test and the SAT, p = .079, p > .05 (Table 2), or the ACT, p = .262, p > 0.5 (Table 2).

Scores for female subjects reveal a mean score of 17.91 on the PSVT:R, 648.26 for the SAT, and 30.04 on the ACT (Table 3). A statistically significant correlation was identified for the female population for the PSVT:R and SAT, p = .000, p < .05, however no correlation was found between the PSVT:R and the ACT, p = .941, p > .05 (Table 4).

Table 1
Male Descriptive Results

	N	*Mean*	*SD*
PSVTPre	230	17.72	3.360
SAT	230	651.63	67.095
ACT	230	29.10	3.262

Table 2
Male Pearson Correlation

		PSVTPre	SAT	ACT
PSVTPre	Pearson Correlation	1	.116	.074
	Sig. (2-tailed)		.079	.262
	N	230	230	230
SAT	Pearson Correlation	.116	1	.293
	Sig. (2-tailed)	.079		.000
	N	230	230	230
ACT	Pearson Correlation	.074	.293	1

	Sig. (2-tailed)	.262	.000	
	N	230	230	230

Table 3
Female Descriptive Results

	N	*Mean*	*SD*
PSVTPre	70	17.91	4.187
SAT	70	648.26	71.334
ACT	70.	30.04	2.590

Table 4
Female Pearson Correlation

		PSVTPre	SAT	ACT
PSVTPre	Pearson Correlation	1	.412	-.009
	Sig. (2-tailed)		.000	.941
	N	70	70	70
SAT	Pearson Correlation	.412	1	.274
	Sig. (2-tailed)	.000		.022
	N	70	70	70
ACT	Pearson Correlation	-.009	.274	1
	Sig. (2-tailed)	.941	.022	
	N	70	70	70

To find if a statistically significant difference existed between male and females, the $Z_{OBSERVED}$ test was used. The $Z_{OBSERVED}$ for the SAT was .529, since $-1.96 < .529 < 1.96$ there is no statistically significant difference between male and female subjects. The $Z_{OBSERVED}$ for the ACT was .471, since $-1.96 < .471 < 1.96$, there is no statistically significant difference between male and female subjects.

Conclusion

This study was conducted to determine a relationship based on gender between spatial ability in freshmen engineering students in an introductory engineering design graphics course. Past studies in the field have historically revealed that male subjects typically outperform their female counterparts in spatial ability and mathematics. This study compared the PSVT:R pre-test with SAT and ACT scores for male and female subjects finding no statistically significant difference between the two genders. Furthermore, it should be noted that a statistically significant correlation was identified for the female population for the PSVT:R and SAT. These findings suggest that female subjects may in fact be improving in spatial ability and mathematics performance where historically they have been less successful than their male counterparts. The findings also support Sorby & Vuerink, 2010 where female students are more skilled than in the past due to the changing technology landscape and the digital age.

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