2006-920: THE EFFECT OF SPATIAL ABILITY ON THE RETENTION OF STUDENTS IN A COLLEGE OF ENGINEERING AND PHYSICAL SCIENCE

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The Effect of Spatial Ability on the Retention of Students in a College of Engineering and Physical Science

Abstract

Spatial ability has been shown to be positively correlated with retention and achievement in science disciplines such as chemistry and physics. However, whether such a correlation exists for engineering has been disputed in the literature. To provide further data to answer this question, portions of the Purdue Spatial Visualization Test (PSVT) were administered to freshman engineering and undeclared students from a College of Engineering and Physical Science (CEPS). In addition, a self efficacy test, which was developed to assess the self confidence of students related to spatial tasks, was also administered. The data analysis showed that those students who remained in CEPS from their freshman to sophomore year (either change majors within CEPS or stayed in the same major) performed better on the PSVT than those students who changed colleges or withdrew from the university. For the self efficacy measure, a similar effect was found; however, this effect was small and not reliable. If evaluating only engineering students, the data analysis did not find such an effect for either spatial ability or self efficacy. Thus, the importance of spatial ability with respect to the retention of undeclared students in STEM disciplines, but not engineering students alone, was clearly found. Additional data analysis also showed that freshman and senior students from various engineering disciplines had equivalent spatial ability and self efficacy.

Introduction

The shortage of engineering students and fear that the United States will lose its global technological advantage are well documented[1] while enrollment in engineering disciplines has fallen consistently since 1979, approximately 1.6% annually[2]. A report by the National Science Board estimated a 47% growth in science and engineering employment from 2000 to 2010[2]. Concerns related to this growth in engineering employment include the attraction, retention, and quality of students in engineering disciplines. Research has shown that achievement in engineering courses is correlated with spatial ability[3-6] and that spatial ability skills can be improved through training[3, 4]. However, whether a correlation between retention and spatial ability exists has been disputed in the literature.

Sorby and Baartmans[7] developed a course at Michigan Technological University entitled "Introduction to Spatial Visualization" to improve the spatial ability of freshman students who were identified as at-risk due to poorly developed spatial skills. These students were invited to take the course; however, the course was opened to any interested student. The course included topics such as isometric and orthographic sketching, flat pattern development, and rotation of objects. Data analysis showed that the spatial ability skills of the students after the course (i.e. the experimental group who opted to take the course) were significantly better than the students who opted not to take the course (i.e. the control group). Also, the retention rates in engineering disciplines increased from 52.0%

to 61.2% for male students and from 47.8% to 76.7% for female students, for the control (N=361, 200 men and 161 women) and experimental (N=175, 85 men and 90 women) groups respectively over the 6 years study[3]. Furthermore, overall retention of female students at the technical university increased from 68.3% to 88.9%, for the control and experimental groups respectively[3]. Finally, the GPA of students who opted to take the spatial ability training course was significantly better in graphics related courses, 2.61 and 2.93 for the control and experimental groups respectively[3]. In related work, Hsi et al.[4] conducted a similar study in which students in an introductory design course, that were identified as at-risk based on poorly developed spatial problem solving tasks, were invited to attend training to improve their spatial ability skills. The results showed that pre-course gender differences were eliminated as a result of the special spatial strategy instruction and that the overall course grade was significantly better for the students with stronger spatial ability.

Conversely, Devon et al.[8] found that such a correlation between spatial ability and retention did not exist. This research was conducted at a state university where retention was measured by whether students (N=283) were retained or transferred from a College of Engineering. In addition to retention not being correlated with spatial ability, other variables such as SAT math, SAT verbal, etc. were not found to be correlated with retention either. With respect to gender, the study also found that while a gender difference in spatial ability scores existed at the beginning of an introductory CAD course, these differences were nearly eliminated by the end of the course, similar to the finding of Hsi et al.[4]. One of the major differences between the Sorby and Baartmans[7] and Devon et al.[8] research projects was that one was conducted at a technical university where the choice of majors is somewhat limited and the other was conducted at a state university.

It should be noted that poorly developed spatial ability is only one cause of retention and achievement difficulties in engineering disciplines. Other factors such as peer support, student mentoring, exposure to skills in a non-threatening environment, and committed professors play a significant role. However, spatial ability is a necessary skill in engineering fields and thus was the focus of this research. Additional research projects have investigated the effect of other factors on spatial ability. For example, a gender difference with respect to scores on standard spatial ability tests has been reported[9-11] and improvements in spatial ability after a semester long CAD course have been found[12, 13].

In this paper, the effect of spatial ability on retention between the freshman and sophomore years for engineering and undeclared students from a College of Engineering and Physical Science (CEPS) will be presented. The study found that those students who remained in CEPS (either change majors within CEPS or stayed in the same major) performed better on a standard spatial ability test and reported higher scores on a self efficacy test developed for this research than those students who changed colleges or withdrew from the university. When analyzing engineering students alone, such an effect was not found. Thus, the importance of spatial ability with respect to the retention of undeclared students in STEM disciplines was clearly found while such an effect for engineering students was not found. Further data analysis investigated the effect of

engineering major on spatial ability and found that the spatial ability and self efficacy scores were the same for all engineering majors tested with respect to both underclassmen and upperclassmen. Thus, while some engineering majors may rely more heavily on spatial ability skills, for example, the need to interpret 3-D engineering drawings in Mechanical or Civil Engineering compared to 2-D schematics in Electrical Engineering, equivalent spatial ability skills were found for all engineering students regardless of major. Finally, upperclassmen were found to have higher spatial ability and self efficacy scores than underclassmen, suggesting an improvement in spatial ability from completing an engineering curriculum.

Methodology

Two web-based tests with automated data collection were used to obtain a measure of a student's spatial ability and self efficacy. These tests consisted of three dimensional representations of different objects in both shaded and no hidden line representations. The web-based software recorded the radial button the student selected for each of the test questions. To ensure anonymity, an encrypted identification (ITID) was used as opposed to the student's name for data analysis purposes. Using this identification, the retention of a student could be tracked through the Dean's Office of CEPS.

The self efficacy test includes three example questions to provide instruction to the student followed by twenty questions. A question begins with two images of an object being shown on the screen before (left image) and after (right image) rotation (see Fig. 1). These images are presented for three seconds and then removed from the screen. This short amount of time allows the student to visualize the situation without completely discerning the exact nature of the rotation. Next, a second object in a different orientation is displayed in only the before rotation orientation (i.e. the after rotation image is not shown) (see Fig. 2). This second object is shown without time restriction. The student must then choose from seven radial buttons on the computer screen her/his confidence in being able to rotate this second object in the same manner that the first object was rotated. The seven point scale ranges from "Not at All Confident" for the left most radial button to "Extremely Confident" for the right most radial button. This test procedure was based on a similar technique which was used to assess the self efficacy of students with respect to solving an algebra problem[14]. This technique provides a measure of a student's self confidence related to specific visualization tasks, as opposed to a general response regarding how confident the student is in performing visualization tasks.

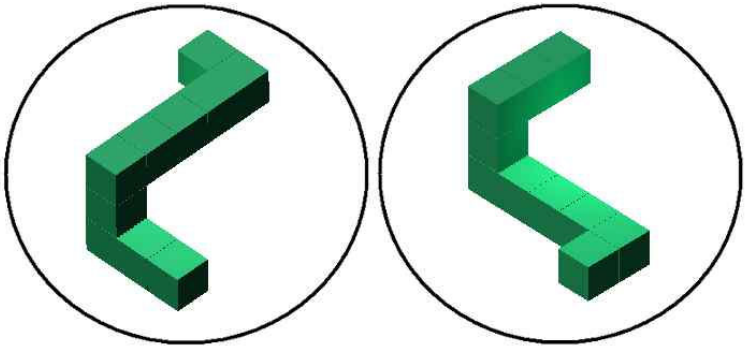

Figure 1. Images from the self efficacy test of an object before (left) and after (right) rotation, which are shown for 3 seconds.

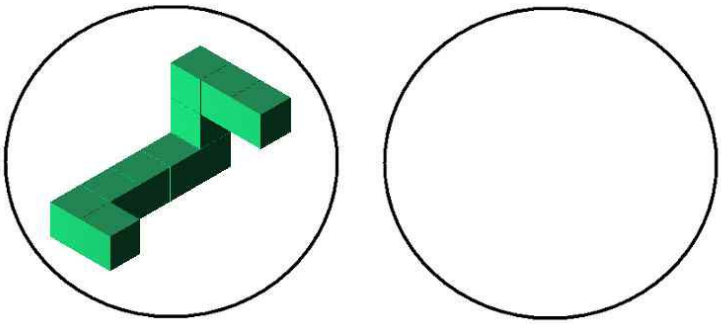

Figure 2. Question from the self efficacy test showing an object before rotation only. The student is asked to rate on a 7 point scale her/his confidence in being able to rotate the object in the same manner as the object shown in Figure 1.

A second test which was administered to measure the student's spatial ability consisted of forty questions from two different sections of the Purdue Spatial Visualization Test (PSVT)[15]. Twenty questions were based on the mental rotation of an object section, and twenty were based on the mental rotation of perspective section. Half of these questions were shaded images (see Fig. 3) while the other half were no hidden line images (see Fig. 4). In the mental rotation of an object questions (example shown in Fig. 3), an object is shown in the before and after rotation orientation. A second object is provided with five choices of possible after rotation orientations. The student is asked to choose the correct after rotation orientation to rotate the second object in the same manner as the first object. The correct answer for the question in Fig. 3 is E. In the mental rotation of perspective questions (example shown in Fig. 4), an object is shown in the center of a transparent cube in an isometric orientation. A dot is present in one of the corners of the cube. The student is asked to choose from five alternatives the correct orientation of the object if viewed from the location of the dot. The correct answer for the question in Fig. 4 is A.

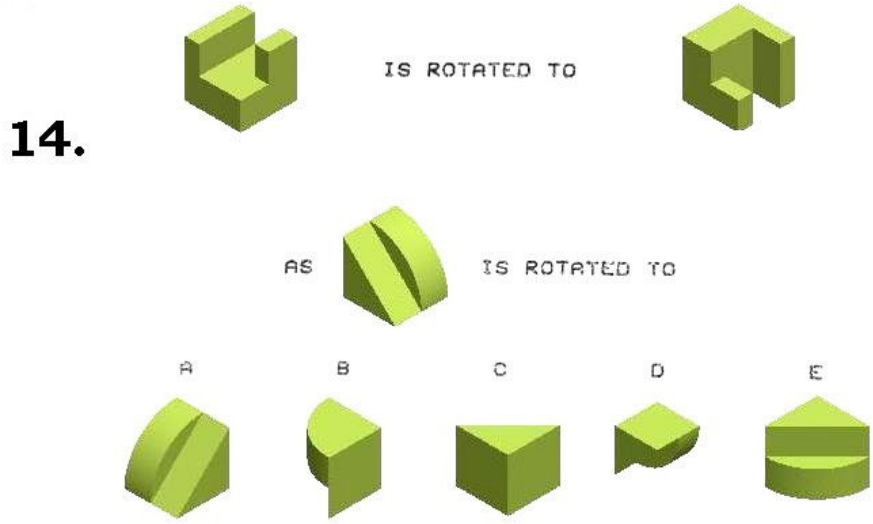

Figure 3. Question from the PSVT Mental Rotation of an object[15]. Note the objects in this question are shaded representations. The first object is a "right angle only" object while the second object contains both an inclined plane and a cylindrical feature.

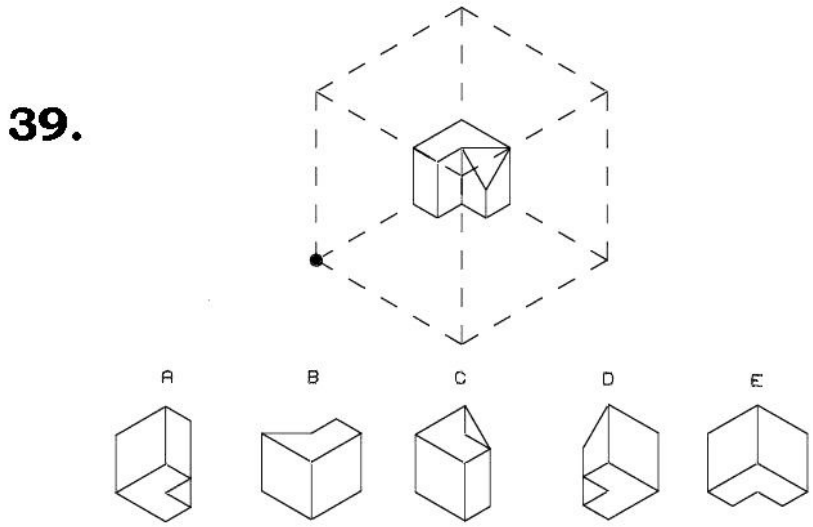

Figure 4. Question from the PSVT Mental Rotation of Perspective[15]. Note the objects in this question are no hidden line representations and contain an oblique surface.

The web-based tests were administered to 497 students in CEPS and a School of Applied Science from Mechanical Engineering, Civil Engineering, Electrical Engineering, Computer Science, Civil Technology and undeclared backgrounds during the Fall semesters of 2004 and 2005. Students were enrolled primarily in freshman level

introductory courses for the given disciplines and senior level required courses for Mechanical Engineering, Electrical Engineering, and Civil Engineering. Some data analyses, e.g. a comparison between upperclassmen and underclassmen, were only performed on the data from 2005 (N=272) since in 2004 upperclassmen were not tested explicitly. The break down of these engineering majors includes Mechanical Engineering (N=91 and 54), Electrical Engineering (N=19 and 17), and Civil Engineering (N=12 and 5) for underclassmen and upperclassmen respectively. The remaining students were from various other engineering and science disciplines as well as not enrolled students.

Results

In order to determine if a correlation exists between our developed self efficacy test and the subset of the PSVT used in this research, a correlation analysis was performed for all students and subgroups. The results for all 497 students showed that a student's perception of her/his spatial ability is significantly correlated with how well she/he will perform on the PSVT (see Table 1). Females showed a higher ability to predict their spatial visualization skills than did males, as is evident by the higher r value; however, for both males and females a statistically significant correlation existed ($p < 0.01$). Furthermore, students who are declared in engineering majors showed a correlation between self efficacy and spatial ability ($p < 0.01$) while undeclared students did not. (Note that some of the students tested were neither engineering majors or undeclared in the College of Engineering and Physical Science. Thus, the subjects in these two categories do not sum to the total number of all subjects.)

	Number of Subjects	Correlations (Pearson r)
All Subjects	497	0.268**
Males	447	0.259**
Females	50	0.298**
Engineering Majors	387	0.274**
Undeclared	50	0.161

** $p < 0.01$

Table 1. Correlations between spatial ability and self efficacy. Note some students were neither engineering majors or undeclared.

T-tests were also performed in order to determine if a reliable difference exists between various groups in our study. For example, upperclassmen (i.e. Juniors and Seniors) reported higher self efficacy scores than underclassmen (i.e. Freshmen and Sophomores) ($t(87) = -2.523$, $p < 0.01$). See Table 2. (The mean value of self efficacy is out of a seven point scale, for example 5.15 out of a seven point scale for underclassmen tested which would relate to approximately a "Fairly Confident" to "Extremely Confident"

assessment of their spatial ability. The value reported for spatial ability is the percent correct out of the forty questions asked.) Furthermore, upperclassmen scored higher on the PSVT questions than underclassmen ($t(87) = -2.57$, $p < 0.01$). To determine if specific characteristics of a question affected the spatial ability score of students, questions were condensed based on single axis rotation versus double axis rotation. (For example, the rotation in Fig. 3 is a double axis rotation.) Furthermore, the questions were condensed based on "right angle only" objects versus "more advanced" objects. ("More advanced" objects includes objects with cylindrical, inclined plane, and oblique surface features. The first object in Fig. 3, which shows both the before and after rotation orientations, is a "right angle only" object, while the object the student is asked to rotate includes both a cylindrical feature and an inclined plane. The object in Fig. 4 includes an oblique surface.) The upperclassmen scored better on both single axis rotation ($t(87) = -2.51$, $p < 0.01$), double axis rotation ($t(87) = -2.391$, $p < 0.05$), and more advanced object questions ($t(87) = -2.64$, $p < 0.01$) than underclassmen. However, the two groups performed equivalently on right angle only object questions ($t(87) = -2.45$, $p > 0.80$). Thus, the shape of the object drives the difference found between upperclassmen and underclassmen. These right angle only objects may be more easily perceived by the students due to the familiarity of such shapes.

The effect of gender on spatial ability scores was also briefly investigated in this study. Males (N=447, mean=70%) performed significantly better on the PSVT questions than females (N=50, mean=60%, $t(49) = -2.824$, $p < 0.01$). In addition, males (mean=5.07) reported higher self efficacy than females (mean=4.84, $t(49) = -2.867$, $p < 0.01$).

	Underclassmen	Upperclassmen
Number of Subjects	184	88
Self Efficacy	5.15	5.49
Spatial Ability	66%	75%
Single Axis Spatial Ability	77%	84%
Double Axis Spatial Ability	59%	68%
Right Angle Only Object Spatial Ability	85%	84%
Advanced Object Spatial Ability	66%	75%

Table 2. Mean Values for Self Efficacy (out of a 7 point scale) and Spatial Ability (% correct out of 40 questions).

Retention data was obtained through the Dean's office of CEPS by providing the ITIDs for the students who took the spatial ability tests. A benefit of conducting this research at UNH is that engineering is a part of a college which includes the physical sciences (e.g. Chemistry, Physics, etc.) that also require a strong spatial ability. The research by Devon et al.[8] which did not find a correlation between spatial ability and retention, only tracked whether or not students transferred or stayed in engineering disciplines. In this research, as was similar to the research conducted by Sorby and Baartmans[7] at a technical university, the results will not be affected by students with strong spatial ability that simply choose to pursue a major which also requires strong spatial ability.

With regard to the spatial ability test, students who were retained (i.e. remained in their major or changed major) in CEPS performed better on the PSVT than students who withdrew from the university or changed colleges ($t = 2.085$, $p < .05$). (Table 3 lists the results for the retention analysis.) However, if considering engineering majors alone, this effect was not found ($p < .25$). It should be noted that the sample size for the engineering majors who transferred from CEPS (N=15) was small; thus, this result may change as the sample size increases from data collection in future years. But based on this analysis, there does not seem to be a correlation between spatial ability and retention in engineering, and the effect which is observed for all students tested is driven by the undeclared students who transferred from CEPS.

With regard to the self efficacy test, those students who were retained in CEPS performed better (mean=4.82) than students who withdrew from the university or changed colleges (mean=4.48); however, this effect was small and not reliable ($t = 1.54$, $p < .13$). Again, the small sample size (N=25) affects this result. If only considering engineering majors, this effect was not found ($p < .52$). Even with a sample size increase, it is unlikely that a statistically significant result will be found based on this initial data. Thus again the effect which is observed for all students tested is driven by the undeclared students who transferred from CEPS.

	All Students		Engineering Majors	
	Retained in CEPS	Transferred from CEPS	Retained in CEPS	Transferred from CEPS
Number of Subjects	165	25	134	15
Mean Spatial Ability	0.71	0.61	0.71	0.66
Mean Self Efficacy	4.82	4.48	4.84	4.69

Table 3. Spatial ability and self efficacy data for all students (engineering and undeclared students) and engineering students alone that were retained in and transferred from CEPS.

A final investigation evaluated whether the spatial ability of students in various engineering disciplines (Mechanical Engineering, Electrical Engineering, and Civil Engineering) were different. Data analysis showed that students in various engineering disciplines scored equivalently on both the PSVT questions and the self efficacy test

developed for this research. This is consistent with past findings from Devon et al.[8]. This result was confirmed for both upperclassmen and underclassmen.

Discussion

The results presented in this paper are for two years of data collection and only one year of retention analysis. This process will be repeated over the next few years to assure that the results are consistent and to increase the sample size for some analyses. Furthermore, students with poor spatial ability skills will be identified for potential spatial ability training[16]. These training exercises will be administered to both engineering and undeclared students to determine if retention can be affected through such efforts. Thus, the retention results will be of particular interest in future years of the study.

Since most of the students who took the spatial ability tests in the Fall of 2004 were in freshman introductory classes, the retention data presented in this paper was only from the freshman to the sophomore years. Thus, the students were not definitively "retained" in engineering yet. However, this has been shown to be the time where a majority of students change their college major. The students in this study will continue to be tracked to determine if they are indeed retained throughout their college careers.

The higher spatial ability scores by upperclassmen compared to underclassmen could be attributed to attrition of students from the engineering programs from e.g. their freshman to sophomore years. However, since retention was not found to be affected by spatial ability of engineering students, the improvements found between upperclassmen and underclassmen may be attributed to all of the science, mathematics and engineering courses that upperclassmen have completed in their college careers. As the study is continued for multiple years, the tracking of students from their freshman year to graduate will indeed confirm this effect.

The self efficacy test was developed for this research; therefore, it is still being validated. However, the results from these initial analyses are promising. For example, a statistically significant difference was found between subgroups tested. Upperclassmen scored higher on the PSVT questions than underclassmen and had higher self efficacy scores as well. The same effect was found for males versus females and students enrolled in a 3-D CAD course versus those enrolled in a 2-D CAD course[13]. This would indicate that higher spatial ability leads to higher self efficacy scores and vice versa.

In addition, engineering students were found to have a significant correlation between their self efficacy and spatial ability while undeclared students in engineering courses were not, further validating the self efficacy test developed for this research. This is an informative finding and shows a better perception of ability by students who are matriculated in an engineering discipline. While it is premature to speculate on why undeclared students did not show a correlation between self efficacy and spatial ability, one possible explanation is that the students who enter college declared in an engineering major have a stronger background with respect to spatial ability skills than undeclared students.

Conclusions

The data presented in this paper confirms the importance of spatial ability with respect to the retention of undeclared students between their freshman and sophomore years in a College of Engineering and Physical Science. However, a similar effect was not found for engineering students alone. These results were admittedly obtained with small sample sizes so continued data collection and analyses will be performed. Furthermore, the improvements in spatial ability from the freshman to the senior year of students enrolled in engineering disciplines were shown. Upperclassmen performed better than underclassmen on both single and double rotation questions as well as questions with objects that contain more advanced features (inclined planes, cylindrical features, and oblique surfaces), which lead to the statistically significant differences. However, both groups performed equivalently on seemingly easier to perceive right angle only objects. These improvements in spatial ability could be attributed to the courses which the students have completed during their college careers. Finally, the spatial ability and self efficacy of underclassmen and upperclassmen from various engineering disciplines (Mechanical Engineering, Civil Engineering, and Electrical Engineering) were analyzed and no differences were found with respect to spatial skills. Thus, while some majors may require stronger spatial skills, e.g. interpreting an engineering drawing, this did not appear to affect the major chosen.

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