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Analysis of Self-efficacy and Ability Related to Spatial Tasks and the Effect on Retention for Students in Engineering*

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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 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 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. Furthermore, data are presented comparing the spatial ability and self-efficacy of upperclassmen versus underclassmen and males versus females, also analysing the effect of the number of rotations in the spatial ability questions.

Keywords: spatial ability; retention; self-efficacy; visualization

INTRODUCTION

SHORTAGE OF ENGINEERING STUDENTS and fear that the United States will lose its global technological advantage are well documented [1] while enrolment in engineering disciplines has been down for several decades and has only recently began to recover [2]. A report by the United State's National Science Board estimated a 47 per cent 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 [3–7] 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 [8] 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, which was also open 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 52.0–61.2 per cent for male students and from 47.8–76.7 per cent 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 six-year study [3]. Furthermore, overall retention of female students at the technical university increased from 68.3 per cent to 88.9 per cent, 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.* [9] found that such a

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correlation between spatial ability and retention did not exist. Their 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 and SAT verbal 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 [8] and Devon *et al.* [9] research projects was that one was conducted at a technical state university [7] where the choice of majors is somewhat limited and the other was conducted at a comprehensive state university [8].

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. Other investigators have explored the effect of different factors on spatial ability. For example, a gender difference with respect to scores on standard spatial ability tests has been reported [10–12] and improvements in spatial ability after a semester-long CAD course have been found [13, 14].

In short, our 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 analysing engineering students alone, the same effect was found for spatial ability, while there was no effect with respect to self-efficacy. Thus, the importance of spatial ability test scores with respect to the retention of engineering and undeclared students in STEM disciplines was confirmed. Further data analysis showed that upperclassmen scored higher on the spatial ability and self-efficacy tests than underclassmen, demonstrating the fact that spatial skills are being trained when completing an engineering degree. Furthermore, males had higher spatial ability scores than females; however, their self-efficacy scores were equivalent.

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

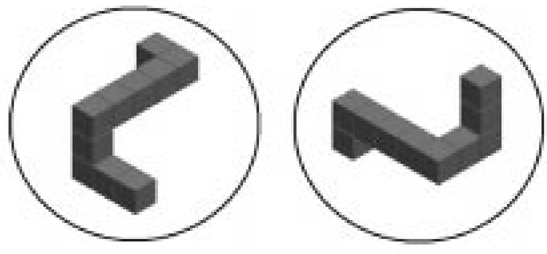

Fig. 1. Images from the self-efficacy test of a solid object before (left) and after (right) rotation.

tests consisted of three dimensional representations of different objects in solid and no hidden line representations. The web-based software recorded the radio button the student selected for each of the test questions. To ensure anonymity, an encrypted university identification code was used as opposed to the student's name for data analysis purposes. Using this identification code, the retention of a student was 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 allowed the student to visualize the relative spatial positions 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 then chooses from seven radio buttons on the computer screen (i.e. check boxes in the webpage) 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 radio button to 'Extremely Confident' for the right-most radio button. This protocol was based on a similar technique used to assess the self-efficacy of students with respect to solving algebra problems

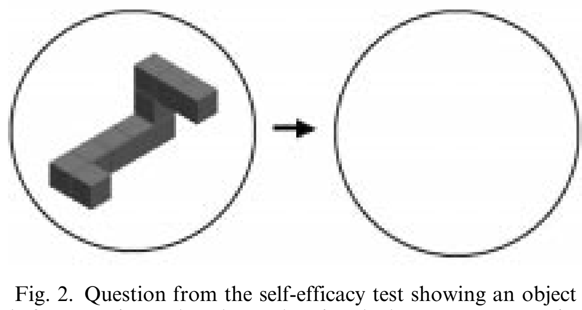

Fig. 2. Question from the self-efficacy test showing an object before rotation only. The student is asked to rate on a 7-point scale her/his confidence in being able to rotate the object in the same manner as the object shown in Fig. 1.

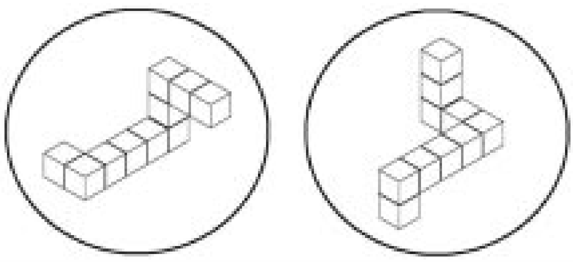

Fig. 3. Images from the self-efficacy test of a line object before (left) and after (right) rotation, which are shown for 3 seconds. This is a single-axis rotation.

[15]. This technique provides a reliable measure of a student's self confidence based on a set of specific visualization tasks, as opposed to a general question regarding how confident the student is in performing visualization tasks as a whole.

Half of the questions in the self-efficacy test are solid images, with shading to represent a light source (see Figs. 1 and 2) while the other half are line images (see Fig. 3). Note that the object in Fig. 3 is rotated about one isometric axis (i.e. a single-axis rotation) while the object in Fig. 1 is rotated about two of the isometric axes (i.e. a double-axis rotation) to achieve the rotation. Validation of this test is currently being conducted.

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) [16]. 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 solid images (see Fig. 4) while the other half were no hidden line images (see Fig. 5). In the mental rotation of an object questions (example shown in Fig. 4), 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. 4 is E. Note that the object in Fig. 4 has been rotated about two isometric axes (i.e. a double-axis rotation). In the mental rotation of perspective questions (example shown in Fig. 5), an object is shown in the centre 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. Note that these mental rotations cannot be categorized as a single or double-axis rotation. Also note that there are other spatial ability tests that could have been used in this work, e.g. the Mental Rotations Test (MRT) [17] and the Mental Cutting Test (MCT) [18]. However, since the PSVT is specifically for mentally rotating an object in an isometric orientation, it was the best test for our study of engineering students.

The web-based tests were administered to 497 students in CEPS and a School of Applied Science from various engineering disciplines and undeclared CEPS students during the Fall semesters of 2004 and 2005. Students were enrolled primarily in Freshman level introductory courses for the given disciplines; Senior level required courses for Mechanical Engineering, Electrical Engineering and Civil Engineering. The break down of these engineering majors includes Mechanical Engineering (N=164 and 55), Electrical Engineering (N=44 and 19), and Civil Engineering (N=31 and 17) for underclassmen and upperclassmen respectively. Here, upperclassmen refers to Juniors and Seniors and underclassmen refers to Freshmen and Sophomores. The remaining students were from various other engineering and science disciplines as well as part-time students. The same questions were presented to all of the students and the solid and line objects and the types of objects were randomly mixed.

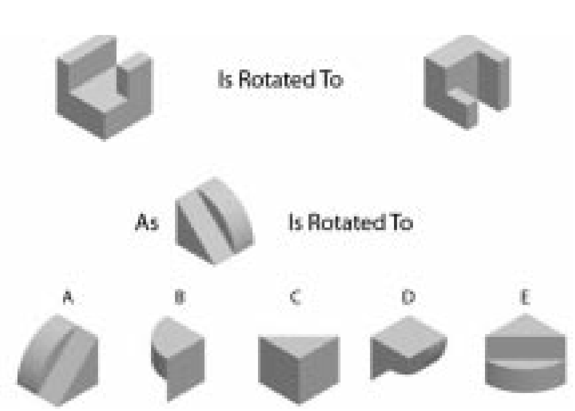

Fig. 4. Question from the PSVT Mental Rotation of an object [16]. Note that the objects in this question are solid images and that this is a double-axis rotation.

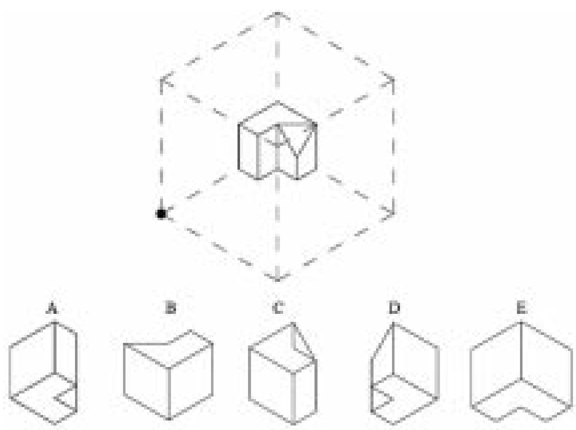

Fig. 5. Question from the PSVT Mental Rotation of Perspective [16]. Note that the objects in this question are not hidden line images.

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 tested and several 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 stronger relationship, 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 significant correlation between self-efficacy and spatial ability ($p < 0.01$) while undeclared students did not ($p > 0.25$). 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.

T-tests and analyses of variance were performed in order to determine if a reliable difference exists between various groups in our study. For example, upperclassmen (i.e. Juniors and Seniors) performed better on the PSVT questions than underclassmen (i.e. Freshmen and Sophomores) ($t(485) = 3.51$, $p < 0.01$). (See Table 2).

The value reported for spatial ability is the percent correct out of the forty questions asked. In addition, upperclassmen reported higher self-efficacy scores than underclassmen ($t(485) = 3.52$, $p < 0.01$). (See Table 2). The average value of self-efficacy is out of a seven point scale. For example, a score of 5.37 out of the seven point scale for upperclassmen tested would relate to approximately a 'Fairly Confident' to 'Extremely Confident' assessment of her/his spatial ability.) Note that some of the students tested were graduate and part-time students; thus, the upperclassmen and underclassmen subjects do not sum to the total number of all subjects.

The effect of gender on spatial ability scores was also investigated. Males performed better on the PSVT questions than females ($t(495) = 3.20$, $p < 0.01$); however, the self-efficacy scores reported by males and females were statistically equivalent ($t(495) = 1.37$, $p > 0.15$). (Note that the numbers reported are with undeclared students included in the analyses. However, since undeclared students' spatial ability and self-efficacy scores are not correlated as shown in Table 1 above, the effects were confirmed to be the same with undeclared students removed from the data set.). Furthermore, a twoway ANOVA was conducted to confirm that an interaction does not exist between underclassmen/upperclassmen and males/females, for spatial ability ($F(1,483) = 0.623$, $p > 0.4$) and for self-efficacy ($F(1,483) = 0.606$, $p > 0.4$). Finally, the cause of the standard error being larger for females compared to males is due to the smaller sample size. The standard deviation values were nearly identical for males and females (20.26 and 20.21 for PSVT scores and 1.10 and 1.29 for self-efficacy scores respectively).

To determine if the number of rotations affects the ability and self-efficacy of upperclassmen, underclassmen, males and females, easier, single-axis rotations were compared to more difficult, double-axis rotations. (See Fig. 1 for a self-efficacy question and Fig. 4 for a PSVT question with double-axis rotations, and Fig. 3 for a single-axis rotation self-efficacy question.) For all subjects, performance on single-axis rotations was better than on double-axis rotations for both spatial ability ($t(496) = 16.77$, $p < 0.01$) and self-efficacy ($t(496) = 6.70$, $p < 0.01$). Upperclassmen performed consistently better than underclassmen on both single-axis ($t(485) = 3.57$, $p < 0.01$) and double-axis ($t(485) = 2.84$, $p < 0.01$) rotation questions. In addition, upperclassmen reported higher self-efficacy scores for both single-axis ($t(485) = 3.34$,

Table 1. Correlations between spatial ability and self-efficacy

	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 2. Average Values for Self-efficacy (out of a 7 point scale) and Spatial Ability (per cent correct out of forty questions). Values in parentheses are the standard error for the measure

		Underclassmen vs. Upperclassmen			Males vs. Females		
	All Subjects	Underclass men	Upperclass men	t value	Males	Females	t value
Number of Subjects	497	378	109	—	447	50	—
Spatial Ability	69.0 (0.92)	67.2 (1.07)	74.9 (1.76)	3.51**	70.0 (0.96)	60.3 (2.86)	3.20**
Single-axis Spatial Ability	77.6 (0.93)	75.8 (1.11)	83.8 (1.61)	3.57**	79.0 (0.95)	64.7 (3.21)	4.74**
Double-axis Spatial Ability	63.1 (1.04)	61.4 (1.21)	68.5 (2.05)	2.84**	63.7 (1.09)	57.6 (3.25)	1.78
Self-efficacy	5.05 (0.051)	4.94 (0.059)	5.37 (0.098)	3.52**	5.07 (0.052)	4.84 (0.183)	1.37
Single-axis Self-efficacy	5.15 (0.054)	5.04 (0.063)	5.47 (0.105)	3.34**	5.18 (0.056)	4.87 (0.196)	1.69***
Double-axis Self-efficacy	4.92 (0.052)	4.82 (0.061)	5.22 (0.100)	3.21**	4.94 (0.054)	4.79 (0.181)	0.84

*p < 0.05; ** p < 0.01; *** p < 0.05 (one-tailed).

$p < 0.01$) and double-axis ($t(485) = 3.21$, $p < 0.01$) rotation questions than underclassmen.

While males did score higher on single-axis rotations compared to females, which is consistent with results when evaluating all questions ($t(495) = 4.74$, $p < 0.01$), their scores were marginally different on double-axis rotations ($t(495) = 1.78$, $p = 0.08$). For single-axis self-efficacy questions, males did report a higher score than females when using a one-tailed test ($t(495) = 1.69$, $p < 0.05$). For double-axis rotations, male and female reported self-efficacy scores were equivalent ($t(495) = 0.84$, $p > 0.4$). Thus, the self-efficacy results agree with the spatial ability results. Males scored higher on spatial ability questions and reported higher self-efficacy scores on single-axis rotation questions, but not on double-axis rotations. Other aspects of questions, such as the effect of solid (see Fig. 3) versus line (Fig. 4) images and the effect of various object shapes (e.g. right angle only objects (the top object in Fig. 3), single incline surfaces (the bottom object in Fig. 3) and oblique surfaces (Fig. 4), etc.) are reported in another publication [19].

Retention data were obtained through the Dean's office of CEPS by providing encrypted university identification codes 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 strong spatial skills. The research by Devon *et al.* [9] 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 largely the case with the research conducted by Sorby and Baartmans [8] at a technical university, the results will not be affected by students with strong spatial ability that simply choose to pursue a non-engineering major which also requires strong spatial skills.

The data presented are for two years of the study; retention is from the Freshman to the Sophomore years. This has been shown to be the time when a majority of students change their college major, which is supported by the data collected in this study. With regard to the PSVT test, students who were retained in CEPS (i.e. remained in their major or changed major within CEPS) performed better on the PSVT than students who withdrew from the university or changed colleges ($t(312) = 2.609$, $p < 0.01$) (see Table 3). This effect was also obtained when considering engineering majors alone ($t(242) = 2.011$, $p < 0.05$).

With regard to the self-efficacy test, those students who were retained in CEPS rated their self-confidence with respect to spatial tasks higher than students who withdrew from the university or changed colleges; however, this trend was small and not reliable ($t(312) = 1.485$, $p = 0.14$). With engineering majors alone, this effect was not found ($t(242) = 0.777$, $p > 0.43$). Thus, the small effect observed when considering all of the subjects tested is dominated by the undeclared students who transferred from CEPS.

One of the cohorts has progressed from Freshman to Junior year, so data analyses were performed with respect to retention over this time-frame. With regard to the PSVT test, students who were retained in CEPS (N = 108, average PSVT score = 71.9) performed better on the PSVT than students who withdrew from the university or changed colleges (N = 36, average PSVT score = 64.0) ($t(142) = 2.032$, $p < 0.05$). With the self-efficacy test, a difference was not found between students who were retained in CEPS and those who withdrew from the university or changed colleges ($t(142) = 0.562$, $p > 0.5$). Data for engineering majors only is not reported as the sample size for this single cohort was too small to provide reliable statistical results (N = 25).

DISCUSSION

The higher spatial ability scores by upperclassmen compared to underclassmen could be attributed to attrition of students from the engineering programmes, e.g. Freshman to Sophomore years. However, since the number of students who transferred out of CEPS was small in comparison to the number retained, 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 and subsequent testing from their Freshman year to graduate will indeed confirm this effect.

Furthermore, the spatial ability of students from various disciplines will be investigated for both

Table 3. Spatial ability and self-efficacy data for all students (engineering and undeclared students) and engineering students alone that were retained in or transferred from a College of Engineering and Physical Science (CEPS) from their Freshman to their Sophomore years. Data are average values for self-efficacy (out of a 7 point scale) and spatial ability (per cent correct out of forty questions). Values in the parentheses are the standard error for the measure.

	All Students		Engineering Majors	
	Retained in CEPS	Transferred from CEPS	Retained in CEPS	Transferred from CEPS
Number of Subjects	265	49	211	33
Spatial Ability	69.5 (1.19)	61.5 (2.94)	69.1 (1.35)	61.7 (3.47)
Self-efficacy	5.07 (0.066)	4.82 (0.146)	5.12 (0.072)	4.97 (0.171)

Table 4. Comparison of spatial ability scores for various engineering majors

Engineering Discipline	Number of Subjects	Spatial Ability	Self-efficacy
Mechanical	164	69.8 (1.47)	5.12 (0.081)
Electrical	44	68.1 (3.46)	5.06 (0.163)
Civil	31	64.4 (4.07)	4.62 (0.165)
Civil Technology	42	63.4 (3.59)	4.52 (0.227)

underclassmen and upperclassmen. Small sample sizes for upperclassmen prevented such an analysis of data at this time. However, underclassmen (primarily Freshman) from various engineering disciplines were equivalent (see Table 4). There was no difference with respect to PSVT scores between Mechanical, Electrical and Civil Engineering and Civil Technology students. (The lowest p-value was obtained when comparing Mechanical Engineering to Civil Technology students ($t(204) = 1.874$, $p > 0.05$).) For self-efficacy, there was only a difference in scores when comparing Mechanical Engineering students to Civil Engineering ($t(183) = 2.496$, $p < 0.05$) and Civil Technology students ($t(204) = 3.039$, $p < 0.01$).

Results from the self-efficacy test, which was developed for this research, are for the most part consistent with the results from the PSVT questions. For example, upperclassmen scored higher on the PSVT questions than underclassmen and had higher self-efficacy scores as well. In addition, males scored higher on PSVT questions than females with single-axis rotations and their self-efficacy was higher, while the two groups scored equivalently on double-axis rotation PSVT questions and their self-efficacy scores were equivalent. (Note that some of these results were marginally significant.) This may indicate that higher spatial ability leads to higher self-efficacy scores. Furthermore, the results obtained, e.g. regarding the difficulty of double-axis rotation questions for both male and female students, are important to help identify the skills which should be targeted during spatial ability training.

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 indicative 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.

In the future, students with poor spatial ability skills will be identified through testing for possible training. Past research efforts, which have included spatial ability training through pencil and paper activities [3], sketching on a Tablet PC [20] and computer games [21] have demonstrated the benefit of such training on improving the spatial ability of students. The training that will be conducted as part of this future research will consist of both a Physical Model Rotator device, which rotates a physical object in synchronous motion with the model in the CAD software, and a computer program that displays both a solid and a line representation of the object on the computer screen simultaneously [22]. These training exercises will be administered to both engineering and undeclared students to determine if retention can be affected through such efforts.

SUMMARY

The data presented in this paper confirms the importance of spatial ability with respect to the retention of engineering and undeclared students between their Freshman and Sophomore years in a College of Engineering and Physical Science, as well as the possibility of improvements. Upperclassmen performed better on both single and double rotation questions and reported higher self-efficacy scores than underclassmen. These improvements in spatial ability could be attributed to the courses which the students have completed during their college careers, again demonstrating that spatial ability is a skill which can be improved through training. Males scored higher than females on the spatial ability tests, in particular for single-axis rotation questions. However, the reported self-efficacy scores for male and female students were equivalent, in particular for the more difficult double-axis rotation problems.

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