Assessing the Self Efficacy and Spatial Ability of Engineering Students from Multiple Disciplines

Erick Towle, Jennifer Mann, and Brad Kinsey, Edward J. O’Brien, Christopher F. Bauer, Robert Champoux
etowle@unh.edu, jmm20@unh.edu, bkinsey@unh.edu, Edward.O’Brien@unh.edu, cfb@unh.edu, bobc@unh.edu
University of New Hampshire, Durham, NH 03824

Abstract – Spatial ability, such as the ability to correctly visualize three dimensional objects when they are represented in two dimensions (such as in Computer-Aided Design (CAD) software or in a detailed part drawing), is an essential skill for engineers. Research has shown that spatial ability is positively correlated with retention and performance of students within other disciplines which rely on spatial ability, (e.g. chemistry). However, whether spatial ability affects the retention of students in engineering has been disputed in the literature. Furthermore, research has not yet been conducted which assesses the relationship between self efficacy, that is the student’s confidence, with respect to spatial skills and retention. In this paper, results of both spatial ability, using a subset of the Purdue Spatial Visualization Test: Rotations (PSVT:R), and self efficacy, using a developed test for this research, will be presented for over 200 students from five different engineering disciplines. Statistically significant differences were found for gender, type of CAD training, class standing and whether or not the student is declared or undeclared in engineering with respect to self efficacy and/or spatial ability.

Index Terms – Spatial Ability, Spatial Visualization, Self efficacy, Computer Aided Design

INTRODUCTION

Spatial ability is an essential skill for Science, Technology, Engineering and Mathematics (STEM) fields. Research has shown that spatial ability is significantly correlated with achievement and/or retention in chemistry [1], physics [2], and the life sciences [3]. Also, a gender bias in favor of males has been reported in traditional spatial ability tests [4-9], which some have speculated is partially the cause of the under representation of women in engineering, while others point to social and support factors [10, 11]. For engineering, studies have shown a correlation between spatial ability and achievement [12-15]; however, the effect of spatial ability on retention in engineering has been disputed in the literature. Sorby et al. [5, 13] showed that the spatial ability of engineering students can be improved over the course of a semester through training which led to increased retention of students in engineering, in particular with respect to female students. This study was conducted at a technical college where retention was determined by measuring if the students left for a less graphically demanding curriculum, or dropped out of the university, since most of the students who do leave that particular university, do so for lack of non technology based curriculum. On the other hand, Devon et al. [14] did not find a correlation between retention and spatial ability; however, the research was conducted at a state university with a broader choice of disciplines and retention was measured by evaluating if the students left the college of engineering, which excludes students who leave for other technical and graphically demanding curriculums. Furthermore, Devon et al. [14] argued that the gender difference is corrected and males and females do not score differently on spatial ability tests after just one semester of CAD training. Research has also shown that the spatial ability of students improves over the course of a semester in classes where CAD software is taught [15].

The improved retention rates found in studies related to spatial ability, such as those by Sorby et al. [5], may be attributed to improved motivation of the student. One of the primary factors that determines motivation for learning in any domain is prior knowledge. It is a well-established finding in the psychology literature that individuals are interested and motivated to learn more about topics for which they already have some knowledge [16]. A significant aspect of this research project is the development of training tools which will be used to improve the student’s spatial ability and her/his self efficacy related to spatial tasks [17]. Bandura [18] hypothesized that self efficacy affects choice of activities (e.g. whether the student would choose an engineering discipline), effort, and persistence (e.g. whether the student would be retained in an engineering field). By providing students with stronger spatial visualization skills through training, it is hoped that the self efficacy of students will improve, as well as their spatial ability, which in turn will increase the retention rates among engineering students, particularly women. This retention component of the project is not covered in this paper, since data for only one semester is presented. Future research will track students throughout their college career to determine if a correlation exists between self efficacy, spatial ability, and retention in engineering fields.

Research has been conducted which evaluates self efficacy and persistence in engineering [19]. However, the self efficacy test which was administered asked only general questions about self efficacy related to engineering disciplines...
(e.g. “what is your confidence that you could complete a mechanical engineering major”). A self efficacy test was developed for this research to assess a student’s perception of her/his spatial ability with a direct connection to the spatial ability tasks performed, as opposed to a general question regarding her/his spatial ability. Furthermore, a subset of the PSVT:R [20] was used to measure the actual spatial ability of the students. In this fashion, both a measure of spatial ability and a measure of self efficacy were obtained, which have both been related to retention and achievement in engineering.

In this paper, results from data collected for one semester of the study with over 200 students from five different engineering disciplines and undeclared students will be presented. Data analysis found that differences exist between the spatial perception and/or spatial ability of males and females, students in a 2-D and a 3-D CAD course, upperclassmen and underclassmen as well as declared engineering majors and undeclared students.

**METHODOLOGY**

Two web-based tests with automated data collection were used for the analysis of student’s spatial ability and self efficacy. The purposes of these tests were to acquire a measure of a student’s perception of her/his spatial ability and to gain information on her/his current level of spatial ability. These tests consisted of three dimensional representations of different objects, where the student chooses her/his answer from a series of radial buttons on the computer screen. The compilation of the data was done without recording of the individual student’s name to insure anonymity, but through an encrypted identification the data could be analyzed for this research and the student’s retention can be tracked throughout her/his college career. One of the goals of this research is to track individual students, so that the benefits of any particular training can be assessed, as well as the retention rates of individual students.

The self efficacy or perception test is comprised of 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 in the before (left image) and after (right image) rotation orientations (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. 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 [21]. 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.

Next, a second object in a different orientation is displayed in only the before rotation orientation, that is the after rotation circle is left blank (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 that she/he could 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.

A second test to measure the student’s spatial ability was administered which consisted of twenty questions from two different question sections of the PSVT:R [20]. Ten questions were based on the mental rotation of an object section, and ten were based on the mental rotation of perspective section.

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 D.

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 C.
The web-based tests were administered to 219 University of New Hampshire students in the College of Engineering and Physical Sciences (CEPS) and the Thompson School of Applied Sciences (TSAS) from Mechanical Engineering, Civil Engineering, Electrical Engineering, Computer Science, Civil Technology and undeclared backgrounds during the Fall semester of 2004. Students were enrolled primarily in freshman level introductory courses for the given disciplines. Two of the courses tested were courses in which CAD software was taught. The students in these courses, sixty-seven students from Mechanical Engineering in CEPS and seven-teen students from Civil Technology in TSAS, were administered the tests twice, once at the beginning of the semester and then again at the end of the semester.

RESULTS

In order to determine if a correlation exists between our developed self efficacy test and the subset of the PSVT:T used in this research, a correlation analysis was performed for all students and subgroups. The results for all 219 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:T (see Table I). 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. Students who are declared engineering majors showed a correlation between self efficacy and spatial ability while undeclared students did not.

<table>
<thead>
<tr>
<th>Number of Students</th>
<th>Correlations (Pearson r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Students</td>
<td>219</td>
</tr>
<tr>
<td>Males</td>
<td>191</td>
</tr>
<tr>
<td>Females</td>
<td>28</td>
</tr>
<tr>
<td>Engineering Majors</td>
<td>170</td>
</tr>
<tr>
<td>Undeclared Majors</td>
<td>49</td>
</tr>
</tbody>
</table>

** p < 0.01, * p < 0.05

T-tests were performed in order to determine if a reliable difference exists between various groups in our study. For example, males performed significantly better on the subset of the PSVT:T (i.e. actual measured spatial ability) than females (t(217) = 3.17, p < 0.01). (See Table II. The mean value of self efficacy is out of a seven point scale (for example 4.78 out of a seven point scale for males tested which would relate to approximately a “Fairly Confident” to “Extremely Confident” assessment of her/his spatial ability), and the value reported for spatial ability is the percent correct out of the twenty questions asked.) However, no difference existed between the reported self efficacy between the males and females (t(217) = 0.32, p > 0.7). Upperclassmen (i.e. Juniors and Seniors) showed a higher, marginally significant spatial ability (t(213) = -1.96, p < 0.06) than underclassmen (i.e. Freshman and Sophomores). Also upperclassmen scored better on single axis (easier) rotations than underclassmen (t(213) = -2.75, p < 0.01); however, the upperclassmen and underclassmen did not show any difference on double axis (more difficult) rotations (t(213) = -1.035, p > 0.3). The self efficacy of the underclassmen and upperclassmen was not significantly different for the students tested.

<table>
<thead>
<tr>
<th>Male</th>
<th>Female</th>
<th>Under-Classmen</th>
<th>Upper-Classmen</th>
</tr>
</thead>
<tbody>
<tr>
<td>191</td>
<td>28</td>
<td>194</td>
<td>21</td>
</tr>
<tr>
<td>Self Efficacy</td>
<td>4.78 (0.08)</td>
<td>4.70 (0.22)</td>
<td>4.74 (0.08)</td>
</tr>
<tr>
<td>Spatial Ability</td>
<td>71% (1.5%)</td>
<td>57% (4.0%)</td>
<td>69% (1.5%)</td>
</tr>
<tr>
<td>Single Axis Spatial Ability</td>
<td>78% (1.6%)</td>
<td>62% (4.9%)</td>
<td>75% (1.7%)</td>
</tr>
<tr>
<td>Double Axis Spatial Ability</td>
<td>66% (1.6%)</td>
<td>53% (4.6%)</td>
<td>64% (1.7%)</td>
</tr>
</tbody>
</table>

Data in parenthesis are standard error means. Data outside parenthesis are means.
One of the questions that this research is attempting to answer is “Does the type of training a student receives in CAD courses affect spatial ability?” Table III shows the analysis from the students who took the tests upon entering a graphical CAD course and then again upon the completion of that course, specifically students in a Mechanical Engineering Design course where 3-D CAD software is taught and a Civil Technology course where a 2-D CAD software is taught. Because males and females differ in their spatial ability significantly and because there was a disproportionately higher number of males in these classes (twelve out of seventeen in the Civil Technology course and sixty-one out of sixty-seven in the Mechanical Engineering course), only male students were used in this analysis. At the beginning of the semester there were no significant differences in self efficacy (t(71) = 1.59, p > 0.1) or spatial ability (t(71) = 1.58, p > 0.1) between students in the 3-D CAD course and students in the 2-D CAD course. At the end of the semester however a difference was found for both self efficacy (t(71) = 3.59, p < 0.05) and spatial ability (t(71) = 2.30, p < 0.05). These results show that the students who had completed the 3-D CAD based course had significantly higher spatial ability and self perception of their spatial ability than did the student who had enrolled in the 2-D CAD course.

### TABLE III

<table>
<thead>
<tr>
<th></th>
<th>MEAN VALUES FOR SELF EFFICACY (OUT OF A 7 POINT SCALE) AND SPATIAL ABILITY (% CORRECT OUT OF 20 QUESTIONS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beginning of Semester</td>
</tr>
<tr>
<td></td>
<td>2-D CAD Course</td>
</tr>
<tr>
<td>Number of Students</td>
<td></td>
</tr>
<tr>
<td>Males Only</td>
<td>12</td>
</tr>
<tr>
<td>Self Efficacy</td>
<td>4.37 (0.36)</td>
</tr>
<tr>
<td>Spatial Ability</td>
<td>69% (4.7%)</td>
</tr>
</tbody>
</table>

Data in parenthesis are standard error means.
Data outside parenthesis are means.

**DISCUSSION**

The results presented in this paper are for one semester of data collection and analysis. The spatial ability of students at UNH was comparable to that of students from another university [5]. The process will be repeated at least three more times, which will increase the sample sizes and allow further data analysis to be performed. For example, an ANOVA was not performed due to the disparity in sample sizes and the low sample number for some categories. Also, t-test analyses were not able to be performed on some categories of the data due to a low sample size, for example the number of upperclassmen who took the tests both at the beginning and the end of the semester. While all the upperclassmen tested thus far in this study were entering a CAD course, future plans include testing outgoing engineering students who have completed an engineering curriculum.

The self efficacy test was developed for this research; therefore, it is still being validated. However, the results from this initial study are promising. For example, engineering students were found to have a significant correlation between their self efficacy and spatial ability while undeclared students in engineering courses were not. This is an informative finding and shows a better perception of ability of 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.

Another finding which supports the validity of the self efficacy test is that a statistically significant difference was found between subgroups tested, that is students enrolled in a 3-D CAD course versus those enrolled in a 2-D CAD course. This indicates that the test is able to establish a difference in self efficacy between subgroups. However, further validation of the test is necessary in order to substantiate, for example, the finding that males and females have the same perceived spatial ability despite measured differences in this ability.

The higher spatial ability scores by upperclassmen compared to underclassmen could be attributed to all of the engineering courses that upperclassmen have taken in their college careers which have developed their spatial ability. The upperclassmen in our study were enrolled in either a course in which CAD software was taught or an introductory engineering course, for various reasons, e.g. a transfer student, fulfilling a minor requirement in another engineering discipline, etc. Tracking students during their entire college career will allow improvements in spatial ability of specific students to be assessed. In addition, additional upperclassmen will be tested in our research to increase the sample size for this subgroup to further measure this effect.

Another point of discussion related to the presented data is with respect to the findings for students in 3-D and 2-D CAD courses. While there may be a difference in spatial ability of students in these different types of engineering CAD courses, the reasons for these differences could be attributed to various causes, for example, other courses taken sequentially to the CAD course, etc. What is interesting however is that the spatial abilities of students in both types of CAD courses improved from the beginning of the semester to the end of the semester, which supports findings from past research [15]. Similar results were seen with respect to gender in past research [22, 23], (see Fig. 5); however, there was no significant difference between the increases in scores on the PSVT:R between males and females (t(82) = -0.929, p > 0.3). In addition, there was also not a difference in the increase in scores on the PSVT:R between students in the 2-D CAD course and the 3-D CAD course (t(71) = 0.413, p > 0.6). This was also the case for self efficacy, where there was no difference in increase in scores between males and females.
(t(82) = .199, p > 0.8) and 2-D CAD course and 3-D CAD course (t(71) = 1.41, p > 0.1).

Finally, the retention data collected from this research will help to determine if spatial ability does in fact affect retention in engineering. A benefit of conducting this research at the University of New Hampshire is that engineering is a part of a college which includes the physical sciences (e.g. chemistry, physics, etc.) which also require a strong spatial ability. The research by Devon [14] 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 [5, 13], the results will not be affected by students with strong spatial ability who simply choose to pursue a major which also requires strong spatial ability.

CONCLUSION

Prior research has shown that spatial ability affects achievement and retention in Science, Technology, Engineering, and Mathematic disciplines. However, to the authors’ knowledge, no research has investigated the effect of self efficacy, that is the self confidence, and retention or achievement in any discipline including engineering. Also, whether spatial ability is correlated with retention in engineering has been disputed in the literature. In this research a self efficacy test was developed and used in conjunction with a standard spatial ability test to assess both a student’s perception of her/his spatial ability and a measure of her/his actual spatial ability. Data analysis showed that an engineering student’s self efficacy, related to her/his spatial ability, is directly correlated with her/his spatial ability, as measured by a subset of the PSVT:R. This was not the case however for undeclared students tested. Furthermore, males and females had equivalent self efficacy; however, males scored higher on the PSVT:R than females, which supports past research [22, 23]. Finally, a student’s spatial ability and self efficacy improved after a semester of CAD software training, regardless of the type of CAD software used (2-D versus 3-D). However, students from a 3-D CAD course had higher self efficacy and spatial ability scores than students in a 2-D CAD course by the end of the semester.

The long term goal of this research project is to determine if a correlation exists between spatial ability, self efficacy, and retention in engineering and to develop more optimal training methods to improve the spatial ability of students. The hope is that with improved self confidence and spatial ability, retention rates in engineering will improve, in particular with respect to female students.

ACKNOWLEDGMENT

Support from the National Science Foundation, Engineering Education and Centers Division (EEC-0343862) is gratefully acknowledged.

REFERENCES


[9] Seale, R.M., Brownlow, S., and Hicks, J.L. “Gender Differences in Spatial Task Performance as a Function of Speed or Accuracy Orientation”, Sex Roles, Vol. 43, Nos. 5/6, 2000, pp. 359-76.


