Improvement of Spatial Ability Using Innovative Tools: Alternative View Screen and Physical Model Rotator

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Abstract

Spatial ability, which is positively correlated with retention and achievement in engineering, mathematics, and science disciplines, has been shown to improve over the course of a Computer-Aided Design course or through targeted training. However, which type of training provides the most beneficial improvements to spatial ability and whether other means would be more effective, is not known. In this research project, two tools for use in spatial ability training were developed and evaluated. One tool, a Physical Model Rotator (PMR), rotates a physical model of an object in synchronous motion with a model of the same object in CAD software. The other training tool, the Alternative View Screen (AVS), provides the user of CAD software with both a solid model (including shading) and a line version view of the object. Students with poor spatial ability were identified through standardized testing and they were then trained over a four week period for one hour each week. The effectiveness of the training tools was evaluated by comparing spatial ability test scores before and after training. Results showed an increase did exist when targeted training was provided. However, this effect was not statistically significant, possibly due to the small sample size.

INTRODUCTION

Contero, Naya, Company, and Saorin (2005) define spatial ability as the "ability required to both understand and solve descriptive geometrical problems and reading and sketching technical drawings". From this definition, and many others given in the literature (Jensen, 1986; Bertoline, 1988; Sorby & Baartmans, 2000; Miller, 1990; Pleck, 1991), it is clear that spatial ability is a critical skill needed in the practice of engineering. Secondly, spatial ability skills have been shown to be correlated to retention in STEM disciplines. Sorby and Baartmans (2000) developed and presented a course aimed at improving the spatial ability of students in a technical university and showed that the retention rates in engineering improved from 52.0% to 61.2% for males and 47.8% to 76.7% for females. The retention of female students at this technical university increased significantly from 68.3% to 88.9%. Hsi, Linn, and Bell (1997) in their study, in which students with poor spatial ability were invited to participate in training to improve their spatial ability, showed the elimination of pre-course gender differences. They also found that the overall course grade was better for students with good spatial ability skills. Finally, Kinsey, Towle, O'Brien, and Bauer (2007) investigated the retention between Freshman and Sophomore years of engineering and undeclared students in a College of Engineering and Physical Sciences (CEPS) in a comprehensive state university and found that there is a positive correlation between spatial ability test scores and retention in STEM disciplines. However, Devon, Engel, and Turner (1998) in their study at a state university where a student was considered retained if they remained within the college of engineering, did not find any correlation between spatial ability and retention. This study also did not find any correlation between SAT maths and SAT verbal scores and retention in engineering.

Spatial ability improves with the provision of appropriate spatial training such as is offered in Computer-Aided Design (CAD) courses (Sorby & Baartmans, 2000) or other targeted training (Kinsey et al., 2007). However, which type of training provides the most beneficial improvements to spatial ability and whether other means to improve spatial ability would be more effective, is not known. In this research project, two tools developed for use in spatial ability training, the Physical Model Rotator (PMR) and the Alternative View Screen (AVS) were used. This study is focused on the ability of a student to correctly visualize a three dimensional object when it is represented in two dimensional space.

The objective of this research was to investigate the effect of targeted training on the spatial ability and self efficacy of mechanical engineering freshmen in a College of Engineering and Physical Sciences (CEPS) in a comprehensive state university. The study found that while all subjects who had poor spatial ability at the beginning of the semester showed some improvement at the end of the semester, those that participated in a targeted spatial ability training module developed as part of this study showed greater improvement in the absolute mean scores than those that did not. However, in comparing the mean improvements of the Control (13.3%) and Trained (18.0%) groups a statistical significance was not found. This may be due to the relatively small sample sizes.

DEVICES

Physical Model Rotator (PMR)

The PMR, which is integrated with SolidWorks CAD software, uses three arms and four axes (with a stepper motor driving each arm and one driving the object) to rotate an object in synchronous motion with a model of the same object in the CAD software. See Fig. 1 for a solid model of the PMR device. The choice to use a four axis device was based on experimentation that showed an improvement in rotational ability of the object over a three axis device and a desire to keep the complexity of the system to a minimum. An object has three rotational degrees of freedom; however, due to the physical limitations of the PMR, more than three axes are required to rotate the object about each of its rotational degrees of freedom at a given instance. This is due to the fact that during rotation, two or more axes of the PMR may align (or nearly align) with each other (e.g. axes 1 and 3 in Fig. 1). If there were only three axes on the device, this would prevent the object from being able to be rotated about one of its rotational degrees of freedom. By having more than three axes on the device, the PMR has fewer "locking positions", i.e. unobtainable rotational movements. However with additional axes, a more complicated design is needed (which would require higher torque, physically larger motors and more expensive motor drivers) and the size of the PMR would increase significantly. These factors limited the number of arms that could be used. Through experimentation, it was determined that only a limited improvement was obtained for a five axis device over a four axis device; therefore, a four axis device was developed.

The PMR is controlled through a typical mouse interface. Every time the student moves a component of the model in the CAD package, that component's transformation matrix changes with respect to the screen coordinate system. This transformation matrix is captured for each component (i.e. axis with one rotational degree of freedom) using the SolidWorks Application Programming Interface (API) through a Visual

Basic .NET (VB.NET) program. The distance the component has rotated about its axis is computed in degrees using the transformation matrix in VB.NET. Once the angle is obtained it is saved to a file. A LabView program reads in the angles from the file and, using an algorithm for calculating the trajectory in relative coordinates, drives the corresponding stepper motor through National Instrument control cards in the computer. The loop time to complete such a rotational move is approximately 100 msec.

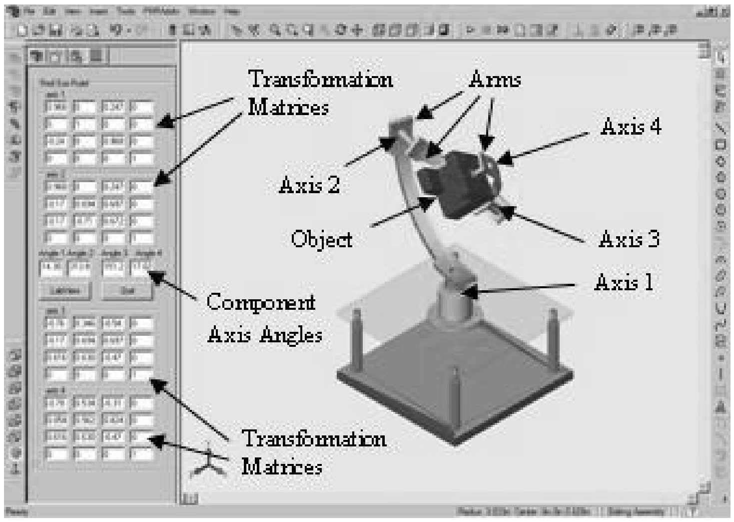

Figure 1: *Computer-Aided Design model of the Physical Model Rotator device.*

Since the desire of the training tool is to help students visualize rotations, translations are ignored, and the model is fixed about its center and only rotates. The device has a 30.5 cm (12 inch) square footprint and stands 61 cm (24 inches) tall. These dimensions allow the device to sit next to the computer monitor on the desktop as shown in Fig. 2.

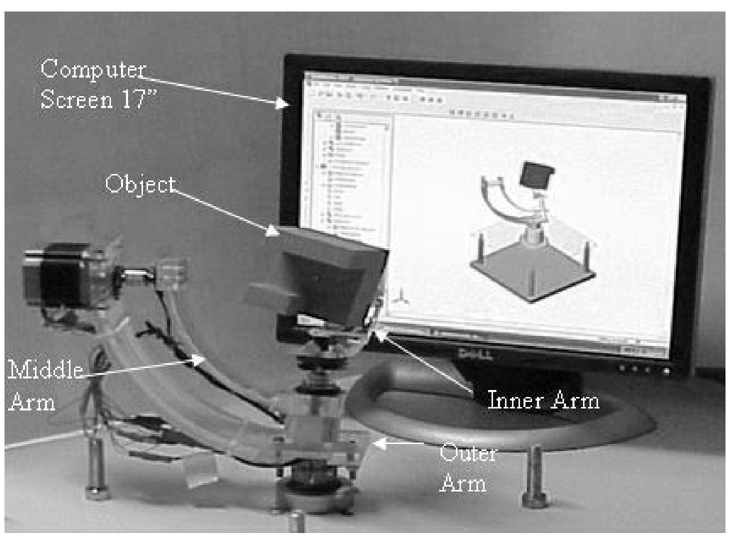

Figure 2: *Physical Model Rotator device.*

Alternative View Screen (AVS)

The AVS tool is an OpenGL add-in module for the SolidWorks CAD software package. This add-in will allow the student to see two representations of an object in the CAD software at the same time, one in a solid model view and one in a line representation, alternative view (either wire-frame, hidden line, or no hidden lines). See Fig. 3. As the student moves the object around in SolidWorks, the alternative view screen updates continuously, in real time with SolidWorks, to rotate the object in synchronous motion with the solid model in SolidWorks. The student has the benefit of switching between the three line representation types while the program is running so that correlations can be made between all the alternative views and the solid model.

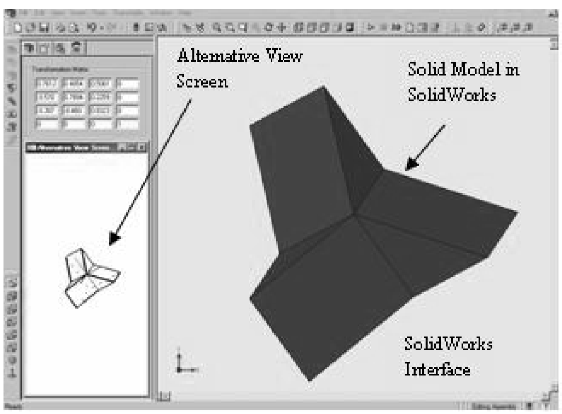

Figure 3: *Alternative View Screen.*

When the student changes the orientation of the object in the SolidWorks CAD software, the transformation matrix relating the object to the screen coordinate system changes. Like the PMR, the transformation matrix is captured with VB.NET, saved directly to a file without any calculations and shown on the screen. The file is read with Visual C++ and loaded into memory. Using the OpenGL API the AVS is created by using multiple rendering and computer graphics algorithms.

METHODOLOGY

The students' spatial ability was determined using portions of the Purdue Spatial Visualization Test (PSVT) and a self efficacy (SE) test, which was developed to assess the self confidence of students related to spatial tasks, see Kinsey et al. (2007) for details. These web-based tests consisted of three dimensional representations of different objects with both solid and no hidden line objects. 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.

The tests were administered to 86 freshmen mechanical engineering students in CEPS who were enrolled in ME 441 Engineering Graphics during the fall semester of 2006. This course consisted of three 1-hour lectures and a one 2-hour laboratory meeting each week. There were 10 females and 76 males in the group out of which 7 females and 20 males were identified as having poor spatial ability (scored less than or equal to 60% on the subset of Purdue Spatial Visualization Test questions used) at the beginning of the semester. Of those with poor spatial ability, 11 (6 females, 5 males) opted to take the targeted training (Trained group) while the Control group consisted of the others who did not (1 female, 15 males).

The targeted training consisted of two 1-hour sessions working with the AVS system, and two 1-hour sessions working with the PMR. The students were provided with written instructions, introductory support in the use of the tools and additional help as required from a graduate teaching assistant for all the four sessions. The training exercises consisted of activities such as creating engineering drawings, rotating to a specified view (e.g. isometric) and using the devices to check the results. Overall the training lasted for four weeks. The students were again tested at the end of the semester with the same instruments used at the beginning of the semester. A flowchart of the methodology is provided in Fig. 4.

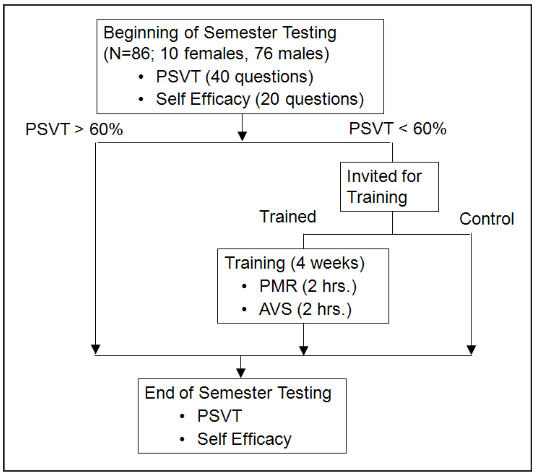

Figure 4: *Flowchart of Methodology.*

RESULTS

When considering PSVT scores it is observed that while females had lower scores at the beginning of the semester, their rate of improvement was higher than that of the males as is shown in Fig. 5. The females (N=10) had a statistically significant improvement of 8.50% (p=0.026), while the improvement for the males (N=76) was lower at 3.95% (p=0.037). However, comparing these two improvements no statistically significant difference was observed.

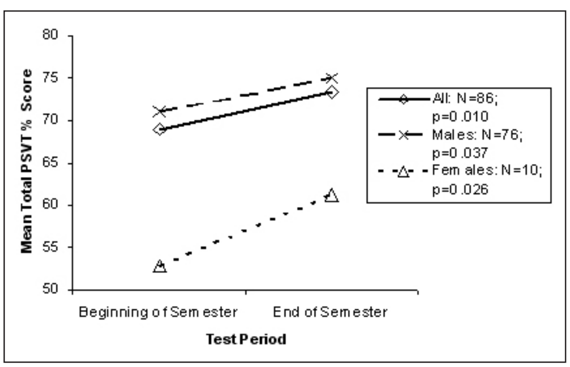

Figure 5: *Comparison of mean total PSVT percentage scores for all students, males & females, from the beginning of the semester to the end of the semester.*

The self efficacy scores, out of a seven point scale, shown in Fig. 6 indicate similar trends with the males scoring higher at both the beginning of the semester (5.236 on a seven point scale) and the end of the semester (5.602) than the females (beginning of semester =4.060; end of semester=4.990) but the rate of improvement of the scores for the female subjects was higher than that of the male subjects. Comparing the mean improvement in self efficacy of females (0.930) to that of males (0.366) showed a marginally significant difference with a p=0.057.

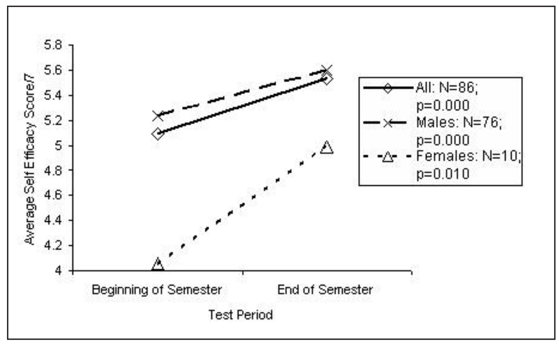

Figure 6: *Comparison of average self efficacy scores out of a seven point scale.*

For purposes of evaluating the effectiveness of the targeted training using the newly developed tools, the subjects were classified into three categories viz. those that scored 60% or less in the beginning of the semester PSVT test and opted not to take the training formed the Control group, those that scored 60% or less and opted to take the training formed the Trained group while those who scored higher than 60% in the beginning of the semester PSVT test made up the other group (PSVT > 60%). In breaking the data into the three categories of interest viz. Control (N=16, Males=15, Females=1), Trained (N=11, Males=5, Females=6) and PSVT > 60% (N=59, Males=56, Females=3), it was necessary to ignore the data for the females because women typically score lower on the spatial tests and there was a disproportionate number of females in the groups. Therefore the data in Figs. 7 and 8 refers to the data from the male subjects only. Figure 7 indicates that while the mean score for the Control group at the beginning of the semester (49.3%)

was slightly higher than that of the Trained group (47.5%), at the end of the semester the Trained group had a higher mean score (65.5%) than the Control group (62.7%). However, there is no statistically significant difference between the improvements.

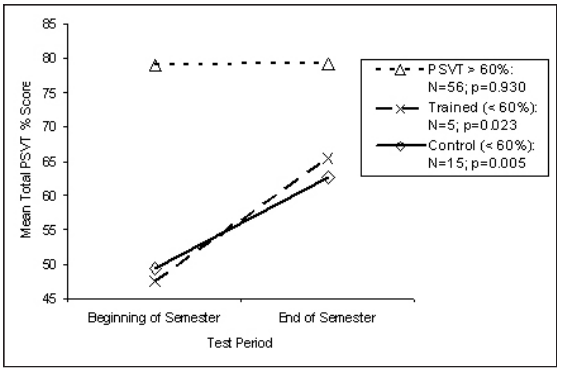

Figure 7: *Comparison of the total mean PSVT percentage scores for the control, trained and other (PSVT > 60%) groups for males only.*

The self efficacy (SE) tests produced some interesting results in which the Trained group had the highest scores at both the beginning and end of the semester with no significant change between the two scores as shown in Fig. 8. The Control group showed a marginally significant improvement between the beginning of the semester (SE=5.143) and end of the semester (SE=5.543, p=0.053) scores. These self efficacy scores were out of a seven point scale.

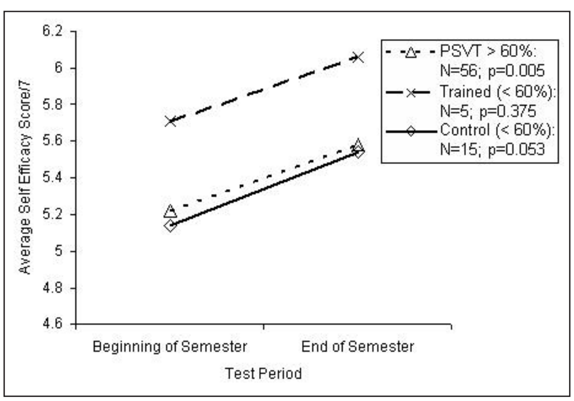

Figure 8: *Comparison of the average self efficacy scores for the control, trained and other (PSVT > 60%) groups.*

DISCUSSION

As has been argued from previous investigations (Miller & Bertoline, 1991; Lohman and Kyllonen, 1983; McGee, 1979; Liben, 1981), background experiences and sexual differences do cause individuals to score differently on spatial ability tests, but spatial ability can be developed through appropriate training courses such as CAD training programs or specific targeted training. Targeted training using the PMR and the AVS system has shown that spatial ability can be improved over a short period of time; therefore, this approach can be used to help mitigate spatial ability deficiencies a freshman student may have as they join an engineering program. The trainees found the PMR to be a very exciting tool to use and all those who used it said that it helped improve their spatial ability significantly. One recommendation that the trainees made with regard to the PMR was that it should be programmed so that there is a delay between the rotation of the CAD software object on the screen and that of the object itself. This delay will make it possible for a trainee to follow both motions consecutively instead of the current setup where there is synchronous motion. The AVS system was found to be helpful with complex objects.

While increases were observed in the mean PSVT percentage scores with the targeted training offered in this study, these increases were not found to be statistically different compared to CAD training only possibly due to the small sample size of the trained group. Furthermore, only male students were analyzed since there were a disproportionate number of females in the groups. The average self efficacy scores of the students who volunteered for the training were higher than those of the other two groups both at the beginning and at the end of the semester. This may be an indication that these students had higher expectations for themselves in terms of the spatial ability and when they found out from the first test that they did not do as well as they expected they were more motivated than the other students to volunteer for the training with the AVS and the PMR. The self efficacy scores for the three categories of students in Fig. 8 improved at about the same rate from the beginning to the end of the semester. Note that for the Trained group there was not a statistically significant increase possibly due to the small sample size. Thus, while an increased improvement was observed for the PSVT scores (see Fig. 7), a similar effect with self efficacy was not observed.

CONCLUSIONS

The newly developed training tools, the AVS and the PMR, have been shown to be effective at improving the spatial ability of students even when they are used over a relatively short period of time. The objective of this research was to investigate the effect of targeted training on the spatial ability and self efficacy of mechanical engineering freshmen in a College of Engineering and Physical Sciences (CEPS) in a comprehensive state university. The study found that while all subjects who scored below 60% in the portion of the PSVT test that was used, at the beginning of the semester showed some improvement at the end of the semester, those that participated in a targeted spatial ability training module developed as part of this study showed a greater increase in their mean PSVT scores than those that did not.

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