120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #7976

Assessment of Spatial Visualization Skills in Freshman Seminar

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Abstract

This paper presents an initiative taken at the University of South Alabama to assess and improve the spatial visualization skills of the first year freshman engineering students. The University of South Alabama is currently listed as a team member of the NSF funded ENGAGE (Engaging Students in Engineering) program. In an effort to implement one of the three strategies of ENGAGE to improve student retention, a spatial visualization component was introduced in the Freshman Seminar/ Introduction to Engineering course in the Fall of 2012. The objective of incorporating spatial visualization into Freshman Seminar was to provide the incoming engineering students the prerequisite spatial skills required to become successful in their subsequent engineering courses. The Purdue Spatial Visualization Test: Rotations (PSVT:R) was administered as a pre-test to assess the spatial visualization ability of the students in the beginning of the semester. Following the pre-test, a series of brief lectures along with a set of computer based exercises was used to improve the spatial visualization skills of the students. A post-test and a survey were used at the end of the semester to assess the effectiveness of the initiative. An observation of the mean pre- and post-test scores indicated an overall improvement in student's spatial visualization skills. This improvement appeared more pronounced in female students than their male counterparts. There was an 11.8% increase in the mean score of the female students, whereas there was a 6.9% increase in the mean score of the male students. A statistical analysis of the pre- and post-test scores also demonstrated a statistically significant gain in average sores of the students. In addition to test results, student's response to the assessment survey indicated that this initiative was effective in raising awareness in the students that spatial visualization skill is very useful to become successful in engineering studies.

1. Introduction

This paper describes an attempt made at the University of South Alabama to assess and improve the spatial visualization skills of engineering freshman students. The College of Engineering at the University of South Alabama is currently listed as a team member of an NSF funded Extension Services project entitled ENGAGE (Engaging Students in Engineering)[1]. The primary goal of ENGAGE is to improve the retention of undergraduates in engineering programs by encouraging the implementation of research-proven techniques. One of the three strategies for improving retention is to assess and improve the spatial visualization skills of the students.

Spatial visualization skill is essential for understanding and solving a majority of engineering problems. Spatial visualization is the ability to correctly visualize three dimensional objects when they are represented in two dimensions (such as in a construction plan or in a detailed part drawing). In recent years, with the development of sophisticated computer hardware and software, the Computer Aided Design (CAD) has become ubiquitous in all engineering discipline. Studies show that enhanced visualization ability is essential to fully utilize this computer based technology.[2,3]

There are several standardized tests available to measure a person's spatial visualization ability. The Purdue Spatial Visualization Test: Rotations (PSVT:R)[4] is one of such tests that is widely used in engineering programs at different colleges and universities. The PSVT:R test is widely used in engineering programs because it uses isometric drawings for spatial visualization.[5] Basically, the PSVT:R test can be used as an assessment tool for diagnosing and improving students' spatial visualization skills in any engineering course that requires basic understandings of visual representation of objects.

Several ENGAGE institutions have documented the positive impact of spatial visualization trainings on student performance. In recent years, an effort was taken at Kettering University to improve spatial visualization skills of freshman students.[6] The PSVT:R test was used as a pre-test to assess the spatial visualization skill of all engineering and science freshman students enrolled in a graphics course. The test was also used as a post-test to assess the effectiveness of the course in improving their spatial visualization skills. Based on the results of the pre-test and post-test, the course contents were modified to increase the effectiveness of the course in improving the visualization skills of the students. The next year, the Kettering University ENGAGE team used the PSVT:R test again as a pre-test to assess the spatial visualization skill of all engineering and science freshman students.[7] The students who scored less than 60% in the test were required to take a spatial visualization training incorporated into their existing graphics course. Only 16 out of 221 students received training to improve their spatial visualization skill. Following the training, the PSVT:R test was used as a post-test to assess the improvement in their visualization skills. The pre-test scores showed difference in performance between male and female students. The post-test scores demonstrated an overall increase in the scores; however, detail information on the post-test was not provided. Also, the study did not present any plan to assess performance of the students in other courses in the curriculum following the spatial visualization training.

Recently, a longitudinal study was conducted at Michigan Technological University that compared the success of students by comparing their grades in freshman level math and science classes by dividing them into three groups.[8] The experimental group consisted of students who had failed the PSVT:R test in their freshman year and completed the spatial visualization course with a C or better grade; the control group consisted of students who failed the PSVT:R test in their freshman year and did not take any course to improve their visualization skill; and the marginally passing group of students who passed the test with their scores between 60 and 70%. The study also compared the retention rates for these three groups of students at the institution, in the fields of STEM (Science, Technology, Engineering and mathematics) and in the College of Engineering. The results of the study revealed that students, who had received training on spatial visualization skills, performed better than the students who belonged to the other two groups. The group of students with spatial visualization training also showed higher retention rates compared to the other two groups. Based on the findings of the study, it was suggested that spatial visualization training should be provided to broader group of students to improve retention and success.

A review of literature indicates that in majority of the past studies, spatial visualization trainings were provided to students who received low scores in the PSVT:R test.[7,8] None of the studies have shown the impact of spatial visualization training on retention and academic success if the training was provided to all incoming freshman level students. Therefore, in an effort to implement one of the three strategies of ENGAGE to improve student retention, a spatial visualization component was incorporated in the Freshman Seminar/Introduction to Engineering course at the University of South Alabama in the Fall of 2012. The PSVT:R test was used as a pre-test to measure the spatial visual ability of students at the beginning of the semester.

Following the pre-test, all the students received spatial visualization training to improve their visualization ability. At the end of the semester, the PSVT:R test was used as a post-test to assess improvement in their spatial visual ability. This paper provides a detail description of the above initiative for assessing and improving the spatial visualization ability of engineering students.

2. Methodology

2.1 Participants

In the fall of 2012, a web-based version of the Purdue Spatial Visualization Test was used in the Engineering Freshman Seminar/Introduction to Engineering course at the University of South Alabama to obtain a measure of student's spatial visualization ability. A total of 157 students from four engineering disciplines were enrolled in 7 sections of the course. Data on scores of pre- and post-test could be collected for 68 students including 8 females and 60 males from 4 sections.

2.2 Pre-Test

At the beginning of the semester, the PSVT:R test was administered to the students as a pre-test to assess their spatial visualization ability. The PSVT:R is an extended version of the subtest, "Rotations", of the previously developed PSVT test. The test is designed to measure 3-D mental rotation ability of individuals aged 13 or older. The test used in this study is a 25-minute online test consisting of 30 questions. Each question begins with an example that shows an object in its initial and rotated views. The test question then shows another object, along with its five different rotated views, and the student has to choose the correct rotated view that has resulted from the same rotation as the given example. Figure 1 shows an example of PSVT:R test questions. Score of the pre-test for each student was recorded at the end of the test.

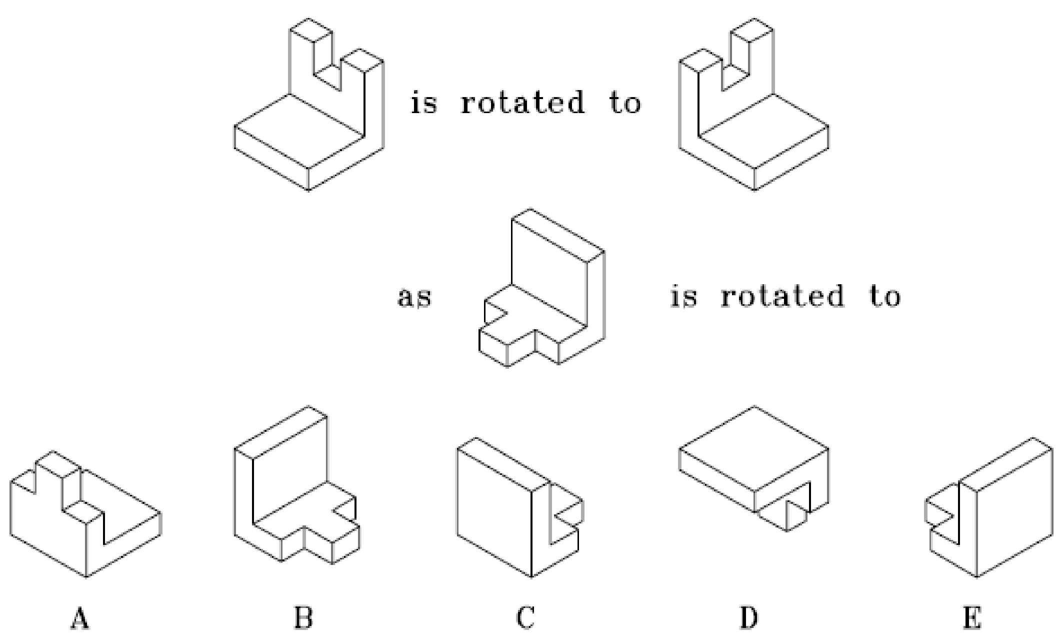

Figure 1: Spatial Visualization by Rotations [4]

2.3 Visualization Exercises

Following the pre-test, all the students participated in four training sessions to improve their visualization skills. These sessions were incorporated into the existing curriculum of the Engineering Freshman Seminar/Introduction to Engineering course. Each training session consisted of approximately 15-20 minutes of lecture and discussion of a visualization concept. The lectures were followed by visualization exercises from “Developing Spatial Thinking Workbook”, developed by Sheryl Sorby.[9] Students were also introduced to the software that complemented the workbook. Spatial visualization lectures were based on the lesson plans outlined by the workbook. The instructors used the companion lecture notes posted on the ENGAGE website for the topics chosen from the workbook. Each week after the lecture, the students worked independently on the assigned visualization exercises in the workbook and were given feedback on their performances. The instructor and one student teaching assistant were available to assist students as needed. Exercises were of two formats: multiple-choice selection of a manipulated 3D object, and sketching a 3D object post-manipulation. The following modules in the workbook were covered in four sessions:

Week 1: Surfaces and Solids of Revolution

In this module, students were introduced to the concept of how surfaces and solids are formed when a 2 dimensional shape is rotated around an axis. Examples were provided to explain how a hollow object can be created from revolution, how the shape of an object varies with the magnitude of rotation etc. to help students visualize the process of revolution. At the end of the lecture and a brief discussion, students were worked on several problems from the workbook using the surfaces and solids of revolution module of the software.

Week 2: Combining Solid Objects

In this module, students were introduced to the concept of how complicated objects can be created through combining multiple solid objects by cutting, joining or intersecting. The objective was to help them visualize the combination process. At the end of the lecture and a brief discussion, students worked on several problems from the workbook using the combining solids module of the software.

Week 3: Isometric Drawing and Coded Plans

In this module, students learned how to construct an isometric view of an object and how the object appears differently depending on the viewpoint. Topics for this module included the axes used for isometric drawings, how a coded plan can help to draw the object in isometric view etc. Students worked on problems from the workbook that included selecting the correct isometric view for a given coded plan, developing coded plans for a given isometric drawing, drawing an isometric sketch from a given coded plan etc. The isometric sketching module of the software was available for the students as well.

Week 4: Orthographic Drawings

In this module, the students were introduced to the concept of orthographic projection. Examples were provided to explain how to draw orthographic views of an object and how to draw an isometric sketch from a given set of orthographic views. At the end of the lecture and a brief discussion, students worked on several problems from the workbook using the orthographic projections module of the software.

EG 101: Spatial Visualization Assessment

1. What academic class do you belong to?
   - ☐ Freshman
   - ☐ Sophomore
   - ☐ Junior
   - ☐ Senior
2. What is your major?
   - ☐ Chemical and Biomolecular Engineering
   - ☐ Civil Engineering
   - ☐ Electrical and Computer Engineering
   - ☐ Mechanical Engineering
3. Gender
   - ☐ Male
   - ☐ Female
4. Have you taken any graphics course before?
   - ☐ Yes
   - ☐ No
5. What math class are you taking this semester?

6. Did you use the software for working on the visualization exercises in class?

   For questions 7 and 8, on a scale of 1 to 5, how would you rate your learning experience? (1 means strongly agree; 2 means agree; 3 means neither agree nor disagree; 4 means disagree; 5 means strongly disagree)

7. Spatial visualization ability is very useful for engineers. __1 __2 __3 __4 __5
8. Exercises in this course have improved my spatial visualization skill. __1 __2 __3 __4 __5

Figure 2: Spatial Visualization Assessment

2.4 Post-Test and Assessment

Following the training session, the PSVT-R test was used as a post-test to assess the improvement in spatial visualization skill of the students. The score for each individual student was recorded and compared to their pre-test score. Following the post test, each student was asked to complete a simple survey to assess the effectiveness of the aforementioned initiative to improve their visualization skills. The survey questionnaire is shown in Figure 2. As shown in Figure 2, the survey contained eight questions. The first six questions were designed to obtain general information about the participants. For example, these questions were designed to obtain information about their academic level, academic major, their gender, the math and graphics classes they were taking or had previously taken etc. The final two questions (Question Nos. 7 and 8) were important in assessing the effectiveness of the program. Student's responses to these two questions and author's interpretations to them are provided in the following section.

3. Results and Discussion

A total of 157 students from four engineering disciplines were enrolled in the Engineering Freshman Seminar/Introduction to Engineering course in the Fall semester of 2012. All the students took the PSVT:R test at the beginning of the semester as a pre-test to assess their spatial visualization skill. The students took the PSVT:R test again during the last week of the semester as a post-test to determine if the spatial visualization instructions had any positive effect in their visualization skills. Data on scores of the pre- and the post-test could be collected for 68 students including 8 females and 60 males from 4 sections. A qualitative assessment of the spatial visualization training, in the form of a survey, was also conducted following the post-test. The results of the pre- and post-test and the survey are discussed in the following sections.

3.1 Results of the Pre- and Post-test

The mean test scores of the PSVT:R pre- and post-test and their gender breakdown are presented in Table 1 and Figure 3. The maximum possible score in both tests was 30. It is evident from Table 1 and Figure 3 that the spatial visualization skill of the students improved after they participated in the spatial visualization exercises as discussed earlier in this paper. It is interesting to note in the figure that the improvement in the visualization ability appears to be more pronounced in female students than in male students. The mean pre-test score of female students (18.77) was lower than their male counterparts (20.23); however, the mean post-test scores were observed to be similar for both female and male students (22.30). This observation supports the well documented observations by other researchers that the visualization skills of women lag behind those of their male counterparts.[3,10,11,12] Therefore, training on spatial visualization skills similar to the one described in this paper can help female students address a deficiency in their 3-D visualization background so that they are more likely to succeed in their engineering studies.

To further study the effectiveness of the initiative described in this paper in enhancing the visualization skills of the students, a simple statistical analysis was performed on the average gain in scores for the students. The Student's *t*-test was performed taking as the null hypothesis (H_0) the fact that there was no difference between mean pre-test and post-test scores. The *t*-test for paired series was applied and the *p* values are shown in Table 2. The table shows that the level of significance was less than 0.05 for all three cases (i.e. all students, female students and male students). Hence we can reject the null hypothesis and conclude, with a significance level of higher than 95 percent, that the mean scores demonstrated a positive variation (gain).

Table 1: Mean and Standard Deviation of Spatial Ability Measures from Pre- and Post-test

	All Students		Male		Female	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Pre-test	20.06 (66.85%)	5.695	20.23 (67.42%)	5.828	18.77 (62.58%)	4.691
Post-test	22.29 (74.32%)	4.997	22.29 (74.32%)	5.188	22.30 (74.33%)	3.478

Maximum possible score = 30.0

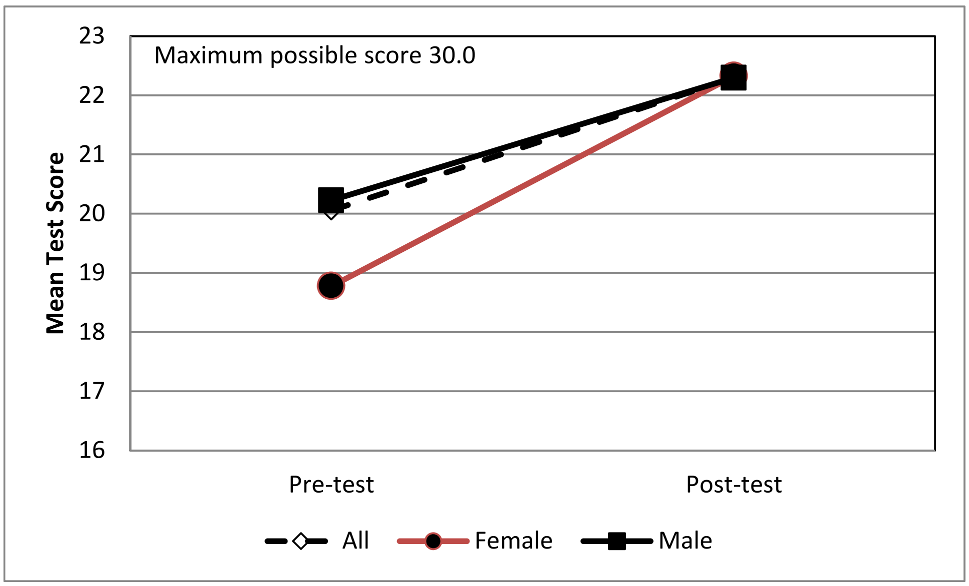

Figure 3: Pre-test and Post-test Results

Table 2: Average Gain in Scores

Group	Average Gain (S. Dev)	t-value	Level of Significance
All Students (n=68)	2.24 (4.04)	4.57	P=0.00002 (<0.0001)
Female Students (n=8)	3.55 (4.22)	2.38	P=0.049 (<0.05)
Male Students (n=60)	2.07 (4.02)	3.73	P=0.0002 (<0.05)

3.2 Results of the Qualitative Assessment

In addition to the quantitative assessment of the effectiveness of the spatial visualization training by comparing the scores of the pre- and post-test, a qualitative assessment was also performed in the form of a survey. The students took the survey following the post-test. A total of 70 students took the survey. Out of the 70 students, 17 students belonged to Civil Engineering, 14 of them belonged to Chemical and Biomolecular Engineering, 14 belonged to Electrical and Computer Engineering, and 25 of them belonged to Mechanical Engineering. Majority of these students were freshmen; there were only seven (7) sophomores. Of these 70 students, both pre- and post-test scores were available for 68 students. Therefore, pre- and post-test scores were analyzed for these 68 students. Table 3 provides information about the students who took the assessment survey after completion of the post-test.

TABLE 3: Background Information about the Survey Participants

		CE (n=17)	**ChBE (n=14)**	**ECE (n=14)**	**ME (n=25)**	**Total (n=70)**
Level	freshman	17 (100%)	12 (85.71%)	13 (92.86%)	21 (84%)	63 (90%)
	sophomore	0 (0%)	2 (14.29%)	1 (7.14%)	4 (16%)	7 (10%)
Gender	male	14 (82.4%)	11 (78.57%)	13 (92.86%)	23 (92%)	61(87.14%)
	female	3(17.7%)	3 (21.43%)	1 (7.14%)	2 (8%)	9 (12.86%)

CE –Civil Engineering; ChBE-Chemical and Biomolecular Engineering; ECE- Electrical and computer Engineering; ME- Mechanical engineering

Student's responses to Question Nos. 7 and 8 of the assessment survey are presented in Figures 4 and 5 respectively. The figures show that the students, in general, provided positive feedback regarding the program described in this paper. Figure 4 demonstrates that the program was able to generate awareness in majority of the student participants that the spatial visualization skill is useful to become successful in engineering. Figure 5 shows that a significant portion of the students felt that the visualization exercises included in the program were able to improve their visualization skills.

4. Scope for Future Work

Based on the positive results and student feedback from the initial implementation, the team plans to continue the initiative of providing spatial visualization training to the students in the Freshman Seminar course. The current study can provide the base-line for further research on the effectiveness of the spatial visualization training offered to the engineering students as an effective tool to improve student success and retention. Though the results of this study are interesting, they are preliminary and more research is necessary using larger sample sizes (especially for female students).

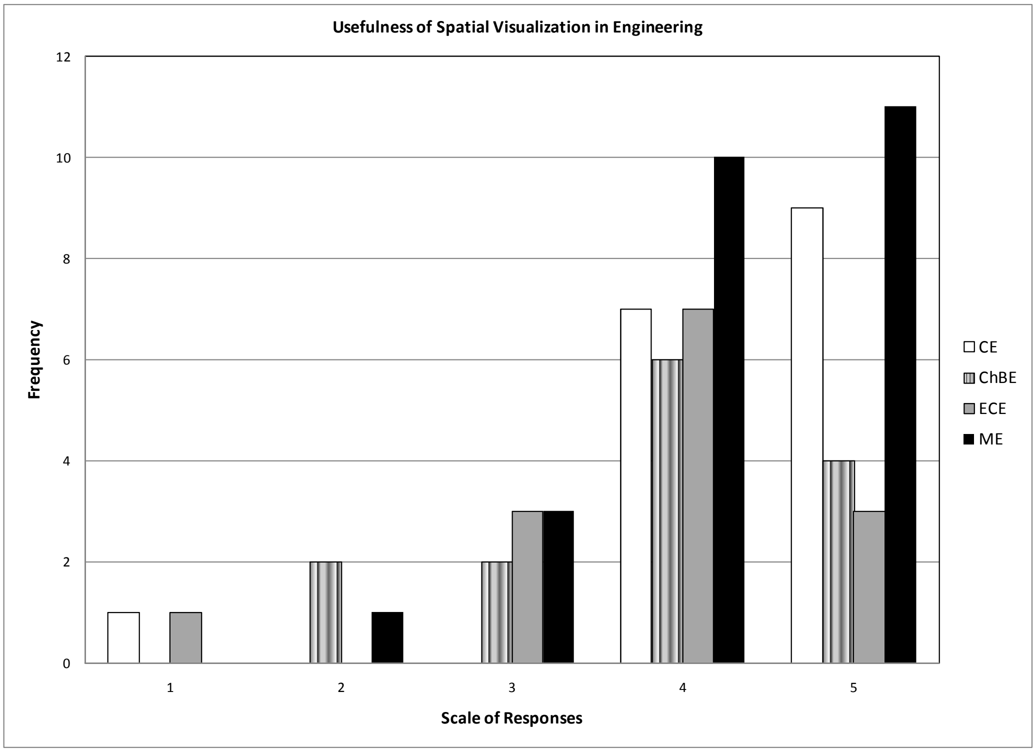

Figure 4: Student’s Response to Question No. 7

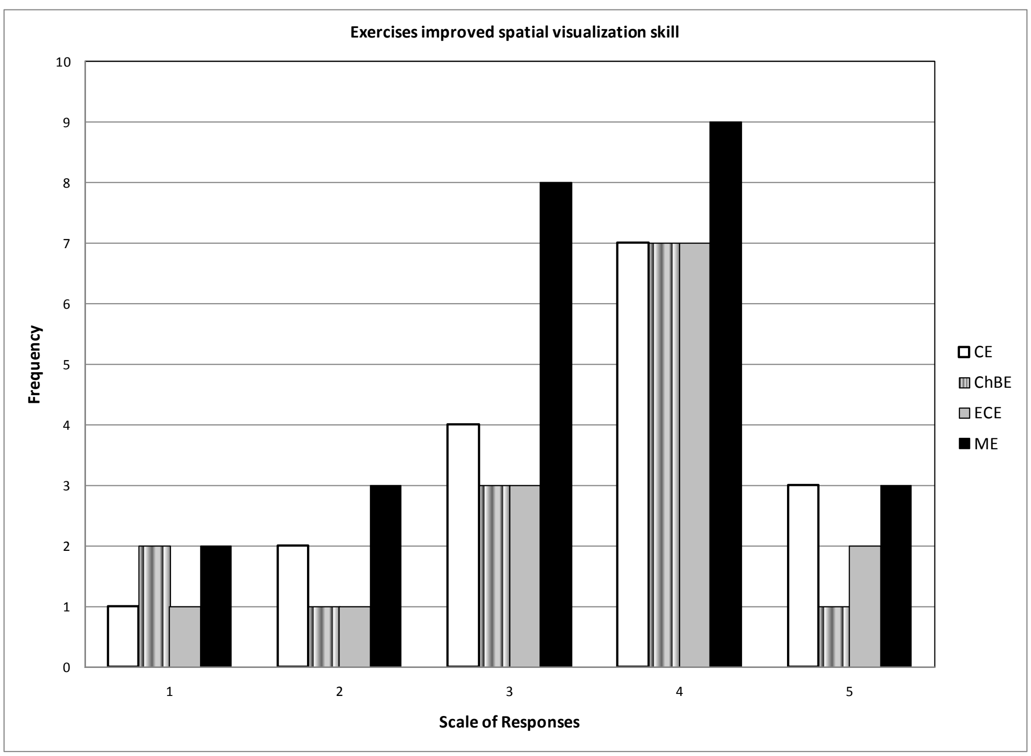

Figure 5: Student’s Response to Question No. 8

The authors plan to carry out a longitudinal survey on the effectiveness of the spatial visualization training for these students, as they progress further in the engineering curriculum. It would be interesting to find out the perceptions of the students about spatial visualization training and its effect on their performances in subsequent classes that involve engineering graphics. For example, Mechanical Engineering students enroll in a 3-credit engineering graphics course in the following semester after the Freshman Seminar class. Similarly, Civil Engineering students enroll in a 2-credit introductory level Civil Engineering course in the following semester, where they get an opportunity to utilize their spatial visualization skills. Students who received spatial visualization training from their Freshman Seminar course would constitute the experimental group. Students, who took the freshman seminar class prior to introducing the spatial visualization training, would constitute the control group for the study. It would be useful to find out if students in the experimental group outperform those in the control group in the subsequent classes where they use engineering graphics by comparing their grades.

The overall objective of introducing spatial visualization was to improve student success and retention. The authors plan to monitor the group of students for whom pre-test and post-test scores are available and compare their retention rates in the institution (and in the College of Engineering) to the respective rates for students who did not receive any spatial visualization training in the Freshman Seminar course. The retention rates for students in the experimental group and control group will be examined for all students and also by gender to assess the effectiveness of the spatial visualization component introduced in the Freshman Seminar course. In other words, the authors intend to find out the percentage of students that would complete an Engineering degree from the experimental group and the control group. Theoretically, an Engineering student should need 4 years to complete the degree. Therefore, a longitudinal study of this sort would take four to five years from the initiation of the effort to collect necessary data for analyses.

5. Summary and Conclusion

The spatial visualization initiative described in this paper is expected to become an effective instrument for assessing and improving visualization skills of engineering students at the University of South Alabama. In the fall of 2012, a spatial visualization module was incorporated into the Freshman Seminar course to improve student success and retention in the College of Engineering. The module consisted of a pre-test, a series of spatial visualization training/exercises, a post-test, and an assessment survey. An observation of the mean pre- and post-test scores indicated that this initiative resulted in an overall improvement in student's spatial visualization skills. This improvement appeared more pronounced in female students than their male counterparts. The maximum possible score in both pre- and post-test was 30.0. The mean pre-test score of female students (18.77) was lower than their male counterparts (20.23); however, the mean post-test scores were observed to be similar for both female and male students (22.30). There was an 11.8% increase in the mean score of the female students, whereas there was a 6.9% increase in the mean score of the male students. To further study the effectiveness of the initiative, a statistical analysis was performed using the Student's *t*-test taking as the null hypothesis (H_0) the fact that there was no difference between mean pre-test and post-test scores. Results of the analysis demonstrated a positive variation (gain) in the mean scores at a significance level of higher than 95 percent. Student's response to the assessment survey also indicated that this spatial visualization initiative was able to improve the visualization skills of majority of the students. In addition, their response indicated that this initiative was effective in raising awareness among the students that the spatial visualization skill is useful to become successful in the engineering field.

The overall objective of introducing spatial visualization was to improve student success and retention. The authors plan to carry out a longitudinal survey on the effectiveness of the spatial visualization training for these students, as they progress further in the engineering curriculum. They plan to monitor the group of students for whom pre-test and post-test scores are available and compare their retention rates in the engineering program to the respective rates for engineering students who did not receive any spatial visualization training in the Freshman Seminar course. A longitudinal study of this sort would take four to five years since an engineering student needs around 4 years to complete the degree.

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