Development of Spatial Visualization Skills through Engineering Curricula

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Abstract

Practicing engineers have high spatial visualization skills and these skills have been found to be correlated to the academic success of engineering students. This paper describes a study in which engineering students were given the Purdue Spatial Visualization Test: Rotations at the beginning of their academic career and then again at the end of their academic career to determine if their spatial visualization skills improved over the course of their academic studies and if students in disciplines considered to be more highly visual showed higher gains in their spatial skills. From this study, it appears that engineering students experience significant gains in spatial skills levels as they complete their curricula, however, it does not appear that certain engineering curricula contribute more to the development of spatial skills than other curricula.

Background

Spatial visualization skills are critical to the success of engineers and many studies have found correlations between spatial visualization skills and success in an engineering curriculum (Hamlin, Boersma, and Sorby (2006), Gimmestad (1989), and Blasko, Holliday-Darr, Mace, & Blasko-Drabik (2004)). Condon and Schroeder of the The Johnson O'Connor Research Foundation (2004) tested 63,558 individuals and found that engineers have the highest level of spatial ability compared to all other occupations in the study. In a comparable study conducted by the Foundation of more than 33,000 undergraduates, the top two fields for spatial abilities were engineering and architecture. Blasko and Holliday-Darr (2010) and Sorby (2001) examined how spatial training can improve the spatial visualization skills of engineering students. However, no studies have examined if or how an engineering education contributes to the development of spatial visualization skills. This paper describes a study to determine if engineering students' spatial visualization skills improve over the course of their academic studies and if a greater improvement is found in some engineering disciplines as compared to others.

Description of Study

Spatial skills of incoming freshmen engineering students have been assessed with the Purdue Spatial Visualization Test: Rotations (PSVT:R) at Michigan Tech since 1993 for the purpose of identifying students with weak spatial visualization skills. In the 2013-2014 academic year, engineering students were given the PSVT:R in their senior design course. These scores were then compared to their scores on the test taken during orientation in order to determine if their spatial skills have improved over the course of their education.

About 2/3 of Michigan Tech students enroll in senior design course(s), while approximately 1/3 of the engineering students fulfill the senior (capstone) design requirement through multi-year involvement in the enterprise program. All engineering majors at Michigan Tech take a two-semester senior design course with the exception of civil and environmental engineering students who take senior design in a single semester. The PSVT:R was administered to all senior design students in the spring 2014 semester, with the exception of some civil and environmental engineering students who were taking senior design in the fall 2013 semester.

Graphics instruction at Michigan Tech takes place in two introductory engineering courses taken by all engineering majors within their first three semesters at Michigan Tech. In the first course in the sequence, students learn the principles of isometric, oblique, and orthographic projection. They also complete exercises involving object rotations about one or more axes, identify planes of symmetry, and draw objects' reflections across a plane. The graphics portion in the second introductory engineering course includes orthographic projection of oblique surfaces, section views, view selection, reading engineering drawings, dimensioning, and solid modeling. Most of the senior design students in this study would have completed these introductory engineering courses and the corresponding graphics instruction three to four years prior to taking the PSVT:R in their senior design course.

Average scores on the PSVT:R administered during orientation versus senior design were compared for each student in this study. The highest possible score on the test is 30. 299 senior design students took the test. Of these, pre-test scores were not found for 26 students, so their scores are not included in the analysis. 36 of the senior design students had completed an introductory spatial visualization course as freshmen due to scoring 60% or below on the PSVT:R during orientation. Because the students who took the introductory spatial visualization course received specialized training, their scores were also excluded from this study.

Results

In order to determine if the curricula of particular engineering disciplines had a larger impact on spatial visualization skills than other curricula, the pre- and post- scores are compared by the engineering major students designated in their senior design course. As shown in the Table 1 below, gains in PSVT:R scores ranged from 0.48 to 2.33 for each engineering major, with an average gain of 1.21 out of 30 for all majors combined. The gain in average score was statistically significant for biomedical, civil, and geological engineers and nearly statistically significant for mechanical engineering students. Geological, civil, and biomedical engineering students had the largest gains in scores, while electrical and computer engineering students had the smallest gain in scores. A reason for the small gains for electrical and computer engineering students could be that they started out with the highest average scores on the orientation tests, so they had little room for improvement, while the other majors had more room for improvement.

Table 1: Comparison of PSVT:R scores from prior to and near completion of engineering education by major

	Average score of test taken during orientation	Average score of test taking during senior design	Gain	Statistical significance (p)
Biomedical Engineering (n=35)	24.7	26.5	1.74	0.0099
Chemical Engineering (n = 31)	25.1	26.1	1.00	0.1268
Civil Engineering (n=51)	24.6	26.5	1.80	0.0016
Computer Engineering (n = 10)	27.4	27.9	0.5	0.2109
Electrical Engineering (n=25)	26.1	26.6	0.48	0.2693
Environmental Engineering (n=11)	24.4	25.6	1.27	0.1675
Geological Engineering (n=6)	25	27.3	2.33	.0434
Materials Science and Engineering (n=15)	23.9	24.5	0.53	0.3803
Mechanical Engineering (n = 53)	25.1	26.0	0.94	0.062
All majors (n = 237)	25.0	26.2	1.21	<0.0001

The results from this testing was analyzed using a one-way ANOVA. An ANOVA test is used to determine if there are significant differences between several averages, i.e., is the gain in score for Electrical Engineering students significantly different from the gain in score for Biomedical Engineering students? Performing pair-wise tests of significance when there are multiple conditions will increase the likelihood of introducing a Type I error in the statistics. [Type I errors occur when you detect a difference that is not really there.] ANOVA tests were run for the average pre-test scores, the average post-test scores, and the average gains scores. In each case no significant differences were found between these means., meaning that they all statistically started at the same place, they all ended at the same place, and they all gained statistically the same during their undergraduate degree programs.

We also performed an ANOVA on a subset of the data. For this second test, we did not consider environmental, geological, or materials engineering due to small sample sizes. We also combined electrical and computer engineering since their curricula have many courses in common and there is a large number of students in those groups who are dual-majoring in both programs. No significant differences were found between the groups in this second analysis.

In order to determine if there was a difference between the study group and all students who entered an engineering major, the orientation scores of the study group were compared to the four-year average orientation PSVT:R score. Because students who scored 60% or below on the test and took an introductory spatial visualization course were removed from the study group, the scores of all students who scored 60% or below were removed from the comparison group also. As can be seen from Table 2 on the following page, for most majors, the study group's average PSVT:R score was within 0.3 points (or 1 %) of the long term average. One exception to this is the computer engineering students in the study group whose average was 3.9 points higher (13%) than the long-term average computer engineering student. This could imply that the students who initially declared a major of computer engineering who had relatively weak spatial skills left the program before graduation. An alternate theory is that they participated in enterprise in lieu of senior design.

Table 2: Comparison of study group average orientation PSVT:R scores to long term averages

	Average score for all students who scored 19 or higher on orientation test from 2006 - 2009	Average orientation score for students in current study group
Biomedical Engineering	24.5 (n=198)	24.7 (n=35)
Chemical Engineering	24.8 (n=275)	25.1 (n=31)
Civil Engineering	24.8 (n=291)	24.6 (n=51)
Computer Engineering	23.5 (n=213)	27.4 (n=10)
Electrical Engineering	25.5 (n=208)	26.1 (n=25)
Environmental Engineering	24.5 (n=90)	24.4 (n=11)
Geological Engineering	24.7 (n=14)	25 (n=6)
Materials Science and Engineering	25.2 (n=53)	23.9 (n=15)
Mechanical Engineering	25.4 (n=778)	25.1 (n=53)

Conclusion

It appears that engineering students experience significant gains in spatial skills levels as they complete their curricula. From this study, it does not appear that certain engineering curricula contribute more to the development of spatial skills than other curricula. However, with larger sample sizes, a difference may be found. Future work could include examining the impact of summer internship or co-op experiences on the development of spatial skills. It may also be insightful to compare spatial test scores from immediately after completion of the graphics curriculum and to spatial test scores from near the end of an undergraduate engineering education.

References

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