Long-term Results from Spatial Skills Intervention among First-year Engineering Students

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Abstract

Michigan Tech has been offering a course in developing spatial skills since 1993. During the first offering of the course, freshmen students were randomly assigned to the spatial skills course. For the next 15 years of its existence, the course was recommended to students who failed the Purdue Spatial Visualization Test: Rotations (PSVT:R) during orientation and enrollment was strictly voluntary. Beginning in the fall of 2009, the spatial skills course was required of all engineering students who scored 60% or lower on the PSVT:R. This paper compares the results obtained through these three distinct "eras" in offering the spatial skills course—randomly assigned, strictly voluntary, and required. Variables to be examined include: gains in spatial skills test scores, grades in the spatial skills course, grades in subsequent courses, and retention rates.

Background

Numerous studies have shown that highly developed spatial skills are important to success in a number of STEM (Science, Technology, Engineering and Mathematics) fields. For engineering, mental rotation has been shown to be particularly important. The Johnson O'Connor Research Foundation tested nearly 32,000 individuals across the country (approximately half women and half men) on a number of cognitive variables, including visualization factors. Individuals also input their undergraduate degree code. Data was normalized to obtain Z-scores with the results from the visualization questions presented in Figure 1 (Johnson O'Connor, 2005).

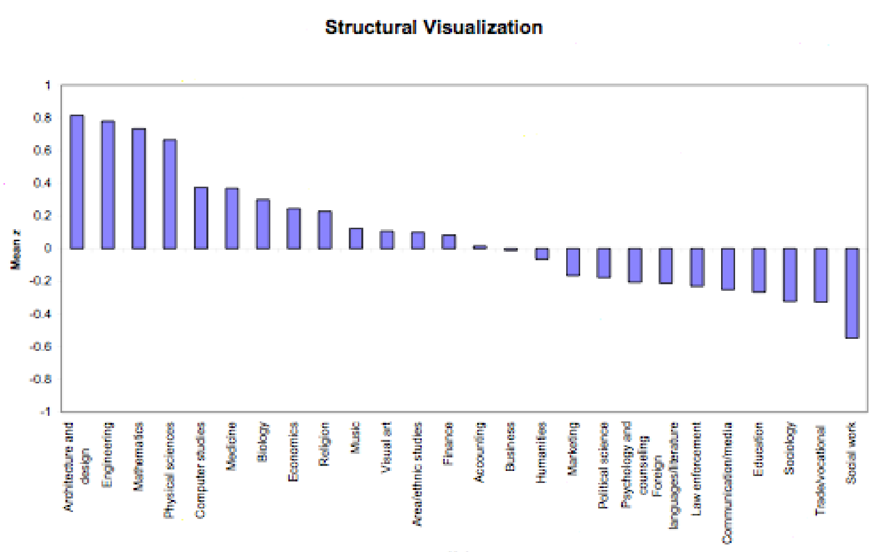

Figure 1. Spatial Skills Testing with 32,000 Undergraduates

The Research Foundation also tested approximately 64,000 individuals currently working in specified career fields. The results from this study are presented in Figure 2 (Johnson O'Connor, 2004).

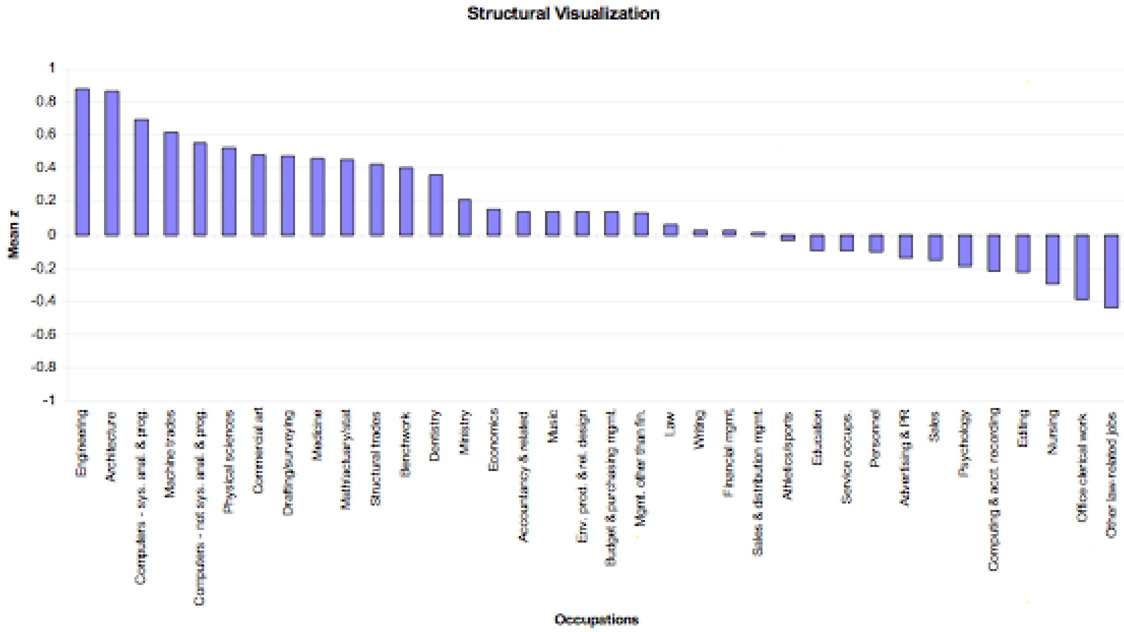

Figure 2. Spatial Skills Testing with 64,000 Practitioners

Upon examination of the data presented in these figures it is clear that the visualization skills of engineers, both as students and as practitioners, are highly developed compared to other professions. It is unclear at this time if the development is causal in nature, i.e., people with well-developed spatial skills are attracted to engineering, or if it is an engineering education that helps to develop these critical skills. Further research into this is required and is not the primary focus of this paper.

Gender Differences in 3-D Spatial Skills

Of all cognitive processes, spatial skills, particularly mental rotation, exhibit some of the most robust gender differences favoring males. Numerous studies have found significant mental rotation gender differences over the years. In research conducted by the authors over the past several years, these gender differences are significant and consistent. For example, in 1993 the average score for first-year engineering women was 65.7% on a test of mental rotation; for men, the average score was 79.23%. During that year, 39% of the women failed the mental rotation test with a score of 60% or lower; only 12% of the men failed the same test. Conversely, 10% of the men received a perfect score on the test compared to only 2% of the women. These gender differences are statistically significant.

In data collected over a fourteen-year period at Michigan Tech, gender differences in mental rotation skills have been consistent through time. Figure 3 shows the test results by gender from 1996-2009 (Sorby and Veurink, 2010).

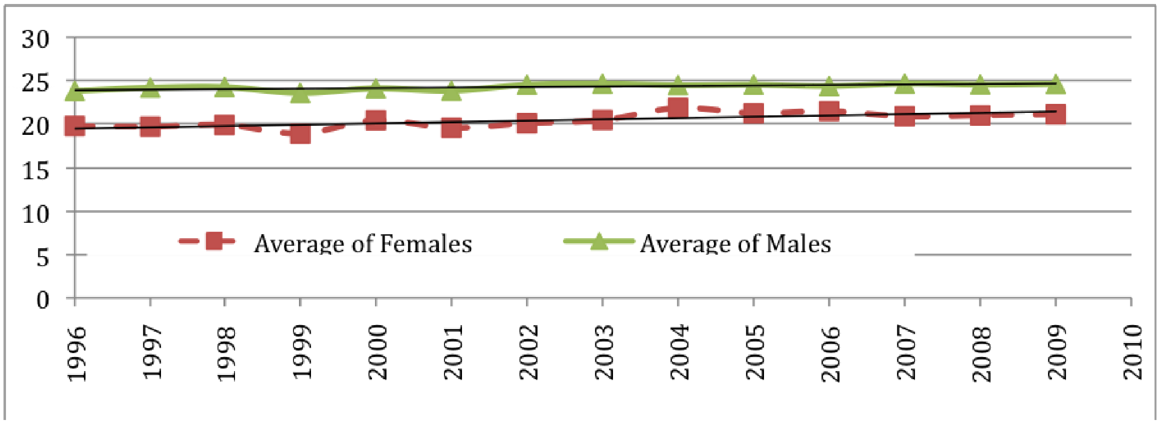

Figure 3: Mental Rotation Scores by Gender Over 14-year Time Period

Figure 4 shows the gender difference in mental rotation ability across 53 countries in a study conducted by Lippa, Collaer, and Peters (2010). In this study, they also found positive correlations between mental rotation ability among women, gender equity, and economic development across these nations.

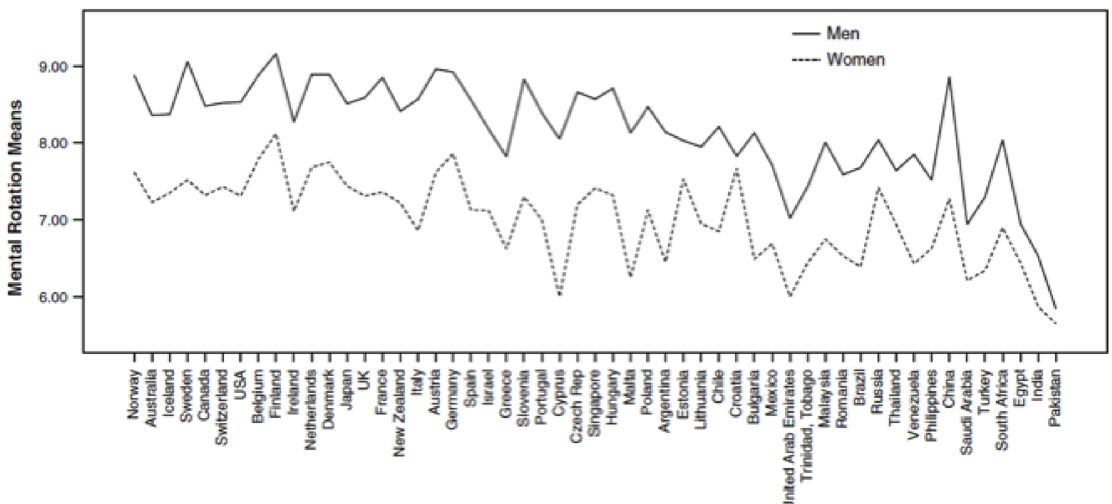

Figure 4: Gender Differences in Mental Rotation Ability Across 53 Countries

Spatial Skills Course at Michigan Tech

In 1993, Baartmans and Sorby received a grant from the National Science Foundation to develop a course and course materials for a course designed to improve the 3-D spatial skills of first-year engineering students, particularly women. In the initial year of this body of research (1993), there were 96 students who failed the Purdue Spatial Visualization Test: Rotations (PSVT:R) (Guay, 1976) during orientation. Of these students who failed the PSVT:R, a random sample of 24 students was selected for participation in the spatial skills course. From 1994 to 2008, engineering students were given the PSVT:R during orientation, and those who failed the exam with a 60% or lower were encouraged to enroll in the spatial skills course. Some chose to do so, others did not. Beginning in the fall of 2009, students who failed the PSVT:R during orientation are now *required* to enroll in the spatial skills course. The remainder of this paper details the findings from a recent analysis of the impact of changing the policy surrounding this course, i.e., what is the impact of requiring students to take the course? This impact is examined by comparing the results obtained to results obtained when the students were randomly assigned and results when enrollment in the course was strictly voluntary. For purposes of clarity, these will be referred to throughout the remainder of this paper as Case 1 (randomly assigned), Case 2 (voluntary enrollment), and Case 3 (mandatory enrollment). It should be further noted that Case 2 data is further subdivided into Case 2a and Case 2b (Case 2a is self-selected students in the quarter version of the course and Case 2b is self-selected students in the semester version of the course.)

Improvements in Spatial Skills

The PSVT:R has been the primary instrument used for assessing spatial skills through all years of data gathering; however, a number of other testing instruments have been used on and off through the years since 1993. Thus, the data presented in the following is perhaps not available for each Case in its entirety, but the data do reflect typical findings.

Table 1 includes pre- and post-test results obtained with the PSVT:R across all Cases in this study.

Table 1. Results from Pre- and Post-Testing with PSVT:R

	Case 1	Case 2a	Case 2b	Case 3
	n=24	n=184*	n=157	n=84
Average Pre-Test	51.7%	50.5%	48.3%	53.6%
Average Post-Test	82.0%	76.9%	73.7%	75.4%
Average Gain	30.3%	26.4%	25.4%	21.8%
Significance of Gain	p<0.0001	p<0.0001	p<0.0001	p<0.0001

*Includes data from Case 1

From the data reported in Table 1, it appears that the impact of requiring the course (Case 3) resulted in a reduction in the gains on the PSVT:R. Part of this difference could be due to the higher pre-test score for that group. It should be noted that their post-test score is nearly identical to that obtained by the students in Case 2 who self-selected into the spatial skills course.

The Mental Cutting Test (MCT) (CEEB, 1939) has also been utilized occasionally throughout the years. Table 2 includes the data obtained from the administration of this test of spatial skills.

Table 2. Results from Pre- and Post-Testing with MCT

	Case 2a	Case 2b	Case 3
	n=99	n=109	n=90
Average Pre-Test	37.9%	34.8%	35.5%
Average Post-Test	51.4%	52.6%	47.7%
Average Gain	13.5%	17.8%	12.2%
Significance of Gain	p<0.0001	p<0.0001	p<0.0001

It appears from the data presented in this table that the gain in scores on the MCT were lower for Case 3 than they were for Case 2. This is likely a result of the change in self-selection versus mandatory enrollment. Students who voluntarily enroll in an "extra" course are likely to be more motivated than those who enroll because they are required to do so. However, the gains for both groups were statistically significant.

Grades in Spatial Skills Course

Grades that students achieved in the spatial skills course itself were also examined to see if there was an impact due to the change to mandatory status for the course. For this analysis, only the grades from 2006-2008, and 2009 were compared. It should be noted that 2006-2008 are in the "Case 2" category and 2009 is in the "Case 3" category. The decision was made to only examine grades in these four years because it was felt that grading scales and course expectations likely changed significantly between 1993 and 2008 and therefore, going back too far in time might result in "comparing apples to oranges." Figure 5 includes the grade distributions for these Cases, as a percentage of total grades awarded (n=179 for Case 2 and n=97 for Case 3).

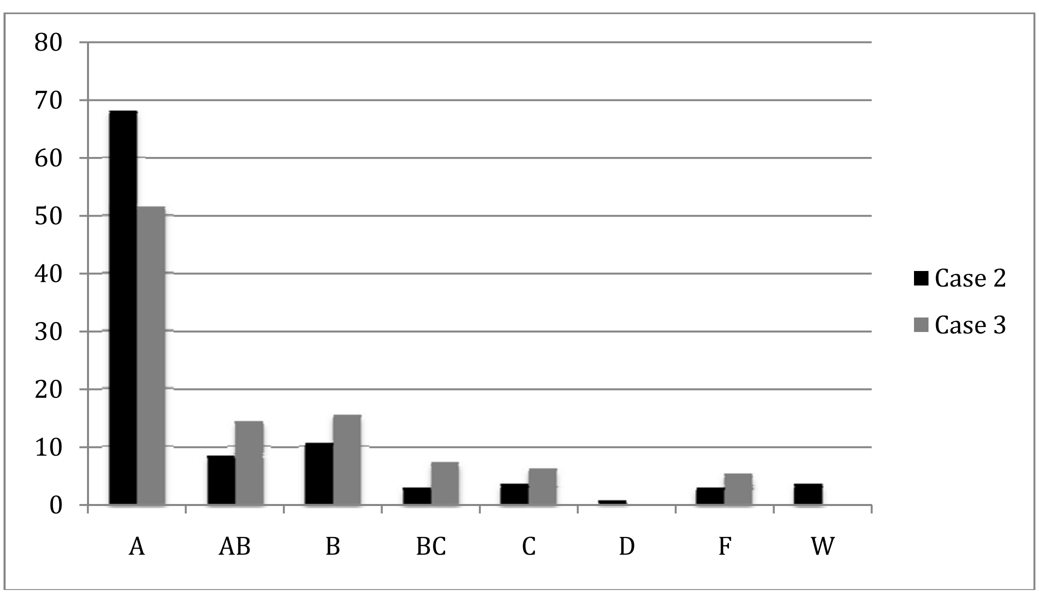

Figure 5. Grade Distribution in Spatial Skills Course for 2006-2009

The average GPA in the spatial skills course for Case 2 was 3.60 and the average GPA for Case 3 was 3.34. Thus, it appears that the less motivated students (Case 3) also did not earn the type of grades achieved by students who self-selected into the course. One interesting phenomena, however, was the apparent slight reduction in DFW grades earned by students in Case 3 (5.2%) compared to students in Case 2 (6.7%). This could be due to the fact that students in Case 3 knew that they would be required to re-take the course during the following semester if they were not successful the first time through.

Longitudinal Results

It appears from the data presented in the previous paragraphs that the students in Case 3 were indeed less motivated and received lower grades in the spatial skills course and lower gains on the spatial skills tests. However, the real question is: Is there a difference in success rate between the two cases?

Several longitudinal studies have been conducted to assess the long-term results of the spatial skills intervention on student success. Student success has further been defined by two primary variables—grades in follow-on courses and retention rates. At this point in time, it is not possible to determine the impact on student retention from the change in policy regarding the spatial skills course. [Previous longitudinal retention studies were conducted 3+ years out. At the time of this analysis, we are only one year out from the spatial skills training in the fall of 2009.] We have been able to examine some grades earned in follow-on courses for these students. The results presented in the following are very preliminary and require further in-depth study; however, it appears that even though the students in Case 3 may be less motivated than those in Cases 1 and 2, the change in course policy has had positive impacts in terms of grades earned in follow-on courses.

For Cases 1 and 2, in conducting the longitudinal studies, students who failed the PSVT:R during first-year orientation were divided into two groups. Those who enrolled in the spatial skills course became the Experimental Group (EG) and those who chose not to enroll were the comparison group. Table 3 presents data obtained in examining grades in several follow-on courses for each group.

Table 3. Average GPAs in Follow-on Courses

	Case 1		Case 2a*		Case 2b	
	EG	CG	EG	CG	EG	CG
Engineering I/ Graphics	3.03 (n=44)	2.70 (n=44)	2.93 (n=237)	2.61 (n=406)	3.04 (n=169)	2.62 (n=173)
Engineering II					2.94 (n=169)	2.71 (n=173)
Calculus I			2.38 (n=161)	2.30 (n=300)	2.78 (n=137)	2.35 (n=128)
Physics I					2.25 (n=126)	2.02 (n=121)
Chemistry I					2.70 (n=152)	2.56 (n=173)

* Includes data from Case 1

For the data presented in Table 3, differences between the experimental group and the comparison group were not statistically significant for Case 1 (possibly due to small sample sizes) or for Case 2a for Calculus. Differences in Chemistry I grades for Case 2b were marginally significant. All other differences in grades earned were statistically significant.

In our new paradigm, there is no longer a well-defined comparison group, since all students who fail the PSVT:R are required to take the spatial skills course. For Case 3, a quasi-comparison group (CG*) has been selected consisting of those who marginally passed the PSVT:R, with a score of 63% to 70%, i.e., 19-21 out of 30 points possible on the test. We have gathered preliminary data that is suggestive of a positive impact from the spatial skills course under this new paradigm; this data will be presented here. Further analysis will be forthcoming as we delve into this new area in more depth.

At Michigan Tech, there are two curricular paths along which a first year engineering student embarks, depending on math preparation. Students ready for calculus (Math ACT of 26 or higher) enroll in the following set of courses during their first year:

Fall Semester:	Spring Semester:
Calculus I	Calculus II
Physics Lab I	Physics I
Engineering I	Engineering II
Chemistry I	One Course by Major
General Education	General Education

Engineering I includes exercises in sketching and orthographic projection (five days of instruction) along with general problem-solving and analysis, ethics, and introductions to solid modeling (three days) and computer programming. Engineering II includes additional sketching topics, and more in-depth instruction in solid modeling and computer programming. Both courses include a design project.

Students not ready for calculus (Math ACT 25 or lower) enroll in the following set of courses during their first year:

Fall Semester:	Spring Semester:
Pre-Calculus	Calculus I
General Education	Chemistry I/Course by major
Engineering Ia	Engineering Ib
Prep-Chem/Chemistry I	Physics Lab I
General Education	General Education

Engineering Ia and Engineering Ib combined are the equivalent of Engineering I and these students take Engineering II during the fall semester of their second year. Engineering Ia contains one to two days of solid modeling instruction and no sketching activities; Engineering Ib contains the graphics content equivalent to that found in Engineering I.

For the Case 3 students we examined grades in the engineering courses and in the calculus courses with the results presented in Tables 4 and 5. In these tables, students designated as "Passed PSVT:R" scored 22-30 on the test; students in the quasi-comparison group (CG*) scored 19-21 on the PSVT:R; students in the experimental group (EG) scored 18 or lower on the PSVT:R. It should be noted that not all students completed all courses due to switching majors, transfer credit, or AP credit—only those who enrolled in courses at Michigan Tech are included in this analysis.

Table 4. Engineering and Math Grades for Calculus-Ready Students

	Passed PSVT:R (n=402)	CG* (n=79)	EG (n=49)
Average Math ACT	29.2	28.2	27.5
Average Composite ACT	27.7	26.4	26.2
Average GPA Calc I (%DFW)	2.70 (15.5%)	2.39 (25.0%)	2.80 (11.4%)
Average GPA Eng I (%DFW)	2.70 (8.0%)	2.65 (7.6%)	2.49 (12.2%)

Table 5. Engineering and Math Grades for non-Calculus-Ready Students

	Passed PSVT:R (n=95)	CG* (n=22)	EG (n=33)
Average Math ACT	23.6	23.1	22.9
Average Composite ACT	23.4	22.0	22.5
Average GPA Pre-Calc (%DFW)	2.18 (17.2%)	2.21 (9.5%)	2.22 (20.0%)
Average GPA Eng Ia (%DFW)	2.06 (21.2%)	2.32 (22.7%)	2.32 (15.2%)
Average GPA Calc I (%DFW)	2.00 (27.7%)	1.80 (30.0%)	2.48 (23.1%)
Average GPA Eng Ib (%DFW)	2.80 (7.3%)	2.42 (15.8%)	2.92 (11.5%)

From the data presented in Table 4, it appears that the students who failed the PSVT:R and were required to enroll in the spatial skills course performed slightly worse in the Engineering I course (with graphics content) when compared to the students who initially passed the PSVT:R and those who marginally passed the mental rotation test. However, it appears that they outperformed the students in CG* in Calculus I both in terms of Average GPA and %DFW. This difference is not due to differences in average Math ACT as students in the EG had slightly lower Math ACT scores than those in the CG* (27.5 vs. 28.2).

For students not ready for calculus (Table 5), the results are even more striking. The EG students in this group performed approximately equivalent to those in the CG* in both Engineering Ia and in Pre-Calculus; however, they outperformed the students in CG* in both Calculus I and in Engineering Ib (the course with graphics content) in terms of both average GPA and %DFW. Once again, average Math ACT and Composite ACT scores do not indicate that students in the EG are "stronger" students than those in the CG*.

Conclusions

In conclusion, it does appear that requiring all students who fail the PSVT:R to take the spatial visualization course has resulted in lower gains on spatial visualization tests and grades within the course compared to when students could chose whether or not to take the spatial visualization course. This is understandable as students who chose to take a course believing it will help them will likely have a more positive attitude toward the course and be more motivated to put forth their best effort in completing the class than students who are "forced" to take the class. However, students do make statistically significant gains in spatial visualization tests whether or not they are able to choose to take the course.

Also, previous studies showed that students who failed the PSVT:R and chose to take the spatial training course outperformed students who failed the PSVT:R and chose not to take the course in typical first-year engineering/math/science classes. This study showed students who failed the PSVT:R performed near or above the level of those students marginally passing the PSVT:R in typical first year engineering and math courses. The most striking difference was found in Calculus 1 grades, where the students taking the spatial course outperformed both students who marginally and handily passed the PSVT:R. It has long been suggested that spatial skills are related to mathematical ability, and this study appears to support that. It could also be that students taking the spatial skills class come to believe that although they may appear not to have mastered a critical skill, with work and effort, they can master skills that are initially difficult. Taking the spatial skills course and finding they are not the only engineering student with lesser-developed spatial skills and seeing their spatial skills improve, may give them confidence to apply themselves to other daunting courses as well.

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