The Role of Geometry Skills in Statics Problem Solving

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Comparing Level of Improvement vs. Level of Achievement on a First-Year Spatial Skills Test as Predictive Indicators of Student Outcomes

Abstract

Spatial visualization skills (SVS) are critical to success in an engineering program. SVS refer to the ability to mentally manipulate 2D views and 3D objects in various ways. Women are disproportionately affected by low SVS, often leading to lower retention and graduation rates when there is no intervention to help them build these skills. Prior work shows that SVS can be learned through a relatively short period of targeted practice and training.

At Stevens Institute of Technology, all first-year engineering students take a spatial skills assessment at the start of the semester to determine their initial placement into the low, medium, or high SVS group. After completing a set of spatial skill building assignments over several weeks, students take the assessment again in the middle of the semester to determine their final placement in the low, medium, or high SVS group. In the majority of students that were initially in the low or medium SVS groups, significant improvements are observed, as many other studies have shown. Some students, however, show little to no improvement, which could indicate a need for more practice or different exercises. It could also be attributed to low self-efficacy or lack of persistence.

This study seeks to determine whether achieving these early gains has an impact on student retention and graduation rates. Students are separated into six groups based on their initial and final placements: Low-Low, Low-Medium, Low-High, Medium-Medium, Medium-High, and High-High. SVS are assessed using the Purdue Spatial Visualization Test: Rotations (PSVT:R).

Results suggest that graduation rates in STEM are correlated with final SVS placement level (post-test scores) but not with the amount of improvement in SVS level. Although two of the improvement groups (Low-High and Medium-High) were observed to have the highest graduation rates, differences in graduation rates compared with the groups that remained at the same SVS level (Medium-Medium and High-High) were not significant.

Introduction

Spatial ability has long been recognized as a foundational skill that is critical to success in engineering and other STEM disciplines [1, 2]. The ability to mentally manipulate and rotate objects, interpret graphical information, and visualize three-dimensional relationships is required for mastering concepts across multiple STEM fields, such as chemistry and mathematics [3-5]. Extensive research has demonstrated that engineering students enter university with widely varying levels of spatial ability, and these differences can have meaningful consequences for academic outcomes, persistence, and degree completion [6, 7]. Studies across engineering and technology programs show that students who score lower on standard spatial visualization assessments are less likely to progress successfully through their early engineering coursework and are at greater risk of attrition than peers with stronger spatial skills [6, 8].

There is significant evidence that spatial visualization skills (SVS) are malleable and can be strengthened through targeted instruction [9, 10]. A variety of spatial-skills training interventions—often implemented through first-year engineering graphics or design courses—have been shown to produce measurable gains on spatial assessments that often translate to increased student retention within engineering programs [11-15]. Such findings have led many engineering educators to adopt spatial ability training as a strategic tool for supporting student success, especially for underrepresented student groups.

Though it is well established that strong SVS are predictive of student success in an engineering program, it is less clear whether the amount of growth in these skills also has an impact on student outcomes. Does the need to build these skills early on in their degree program translate to improved persistence and learning capacity long term? Or does the need to build these skills over a condensed 4-week training period have detrimental effects on long term spatial ability when compared to their counterparts that likely built these skills over many years of various life experiences?

This study examines the relationship between spatial ability levels (measured through pre- and post-test performance on a standardized spatial assessment) and engineering program completion. Using graduation rates as an indicator of long-term academic success, this research seeks to determine whether students' initial spatial ability or the magnitude of their improvement over time is more strongly associated with earning an engineering degree.

Methods

All first-year engineering students were required to take a first-year engineering design course at Stevens. In the first week of classes, students take the Purdue Spatial Visualization Test of Rotations (PSVT:R) to assess their initial level of spatial ability. The PSVT:R is a standardized timed test of mental rotations of 30 questions in 20 minutes, developed by Bodner and Guay [16]. Students were placed into 3 groups based on their initial test score, with thresholds of 60% and 80% to separate the Low, Medium, and High SVS groups.

After 4 weeks of spatial skill building exercises in a sketching workbook, students took the assessment again. Students were once again divided into three groups, based on their final test score, using the same thresholds.

In this study, “level of achievement” is defined by final placement into the Low, Medium, or High SVS group, based on post-test scores in Week 5. For “level of improvement”, students are divided into 6 groups, based on their initial and final placements in the SVS groups: Low-Low, Low-Medium, Low-High, Medium-Medium, Medium-High, and High-High.

Graduation and retention data are used to define the following student outcomes:

1. Graduated with STEM degree
2. Graduated with non-STEM degree
3. Did not graduate

The third category includes students who transferred, withdrew, or were dismissed from the university.

Results

A total of 396 students participated in the study, representing the incoming class of first-year students in fall 2020. Figure 1 shows the initial and final distribution of students placed in the low, medium, and high SVS groups. The percentage of high visualizers increased from 47% to 61% after the spatial skill building period, and the percentage of low visualizers decreased from 17% to 3%, indicating improved spatial ability across multiple groups. Post-test scores (M=24.4, SD=0.245) were significantly higher than pre-test scores (M=22.3, SD=0.163), $t(395)=10.835$, $p<.001$).

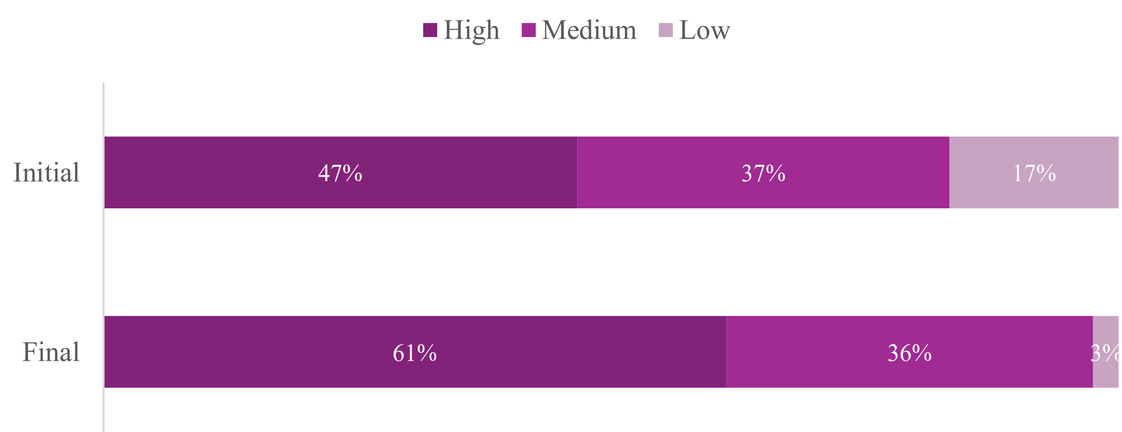

Figure 1. Distribution of students in the low, medium, and high SVS groups before and after the spatial skill building period.

Student outcomes, by initial SVS level

Student outcomes based on initial SVS placement are shown in Figure 2. STEM graduation rates are similar at 79%, 86%, and 83% for the low, medium, and high SVS groups.

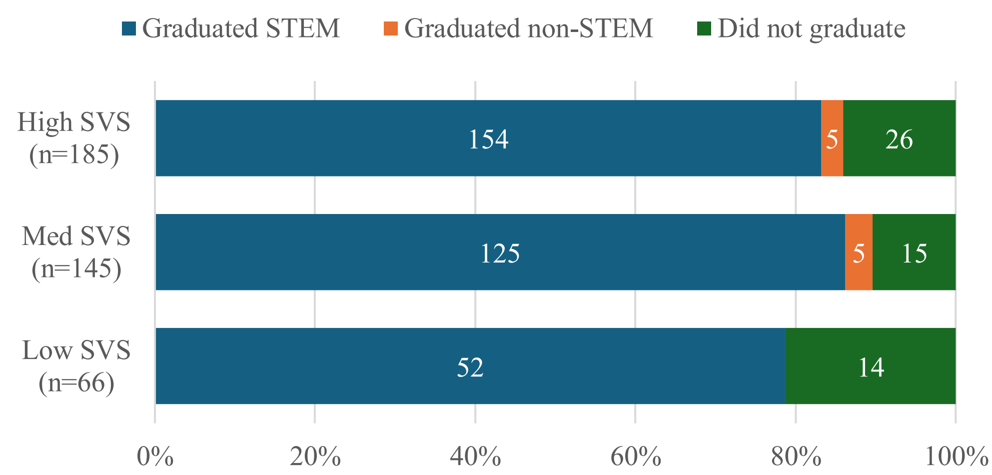

Figure 2. Student outcomes based on initial SVS placement

A chi-square test of independence found that there were no significant differences in the distribution of student outcomes among the three SVS groups, $\chi^2(4, N = 396) = 6.35, p =$ $.175$. The effect size was small, $V = 0.090$, suggesting little practical difference among groups.

Student outcomes, by final SVS level

Student outcomes based on final SVS placement are shown in Figure 3. STEM graduation rates are 50%, 83%, and 86% for the low, medium, and high SVS groups, respectively.

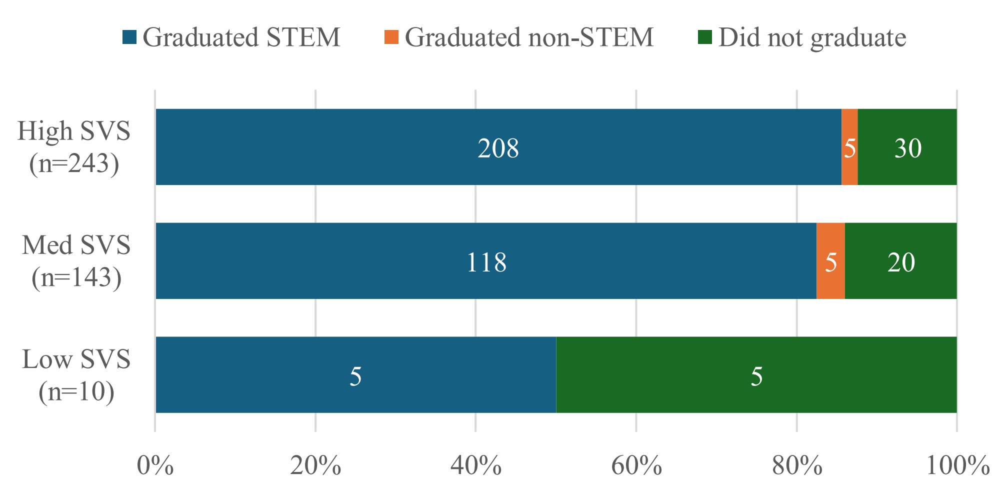

Figure 3. Student outcomes based on final SVS placement

Given the small counts in the "Graduated non-STEM" category, the three outcomes were collapsed to two outcomes: "Graduated STEM" vs "Did not graduate STEM" (combined "Graduated non-STEM" and "Did not graduate"). A chi-square test of independence indicated that STEM outcomes differed across the final SVS groups, $\chi^2(2, N = 396) = 9.06, p = .011$, with a small-to-moderate association (Cramér's $V = .15$).

Pairwise comparisons of outcomes across the final SVS placement groups were conducted using two-sided Fisher's exact tests with Holm correction (3 comparisons). Low SVS differed from High SVS (Holm-adjusted p = .032), whereas Low vs Med (Holm-adjusted p = .051) and Med vs High (Holm-adjusted p = .468) were not significant.

Low visualizers have significantly lower STEM graduation odds than high visualizers. These results compare well to other published studies, which indicate that strong spatial skills are critical to success in STEM fields.

Student outcomes, by change in SVS level

Student outcomes based on change in SVS level (initial to final) are shown in Figure 4. STEM graduation rates for groups that remained at the same skill level were 50%, 83%, and 83% for the Low-Low, Med-Med, and High-High groups. STEM graduation rates for groups that improved SVS were 82%, 87%, and 97% for the Low-Med, Low-High, and Med-High groups.

For the statistical analysis, the 3 outcomes were again collapsed to two outcomes: "Graduated STEM" and "Did not graduate STEM." With the two outcomes, differences across change groups were significant, $\chi^2(5, N = 396) = 13.25, p = .021, V = .18$. Post-hoc pairwise Fisher tests with Holm correction indicated the only significant difference was between the Low to Low and Med to High groups (adjusted p=.0166), which had graduation rates of 50% and 97%, respectively.

This agrees with results shown in Figure 3, which indicate that students with low SVS graduate at significantly lower rates than those with medium to high SVS. The level of improvement, however, was not found to be a significant factor in student outcomes:

- A 2×2 comparison of STEM graduation rates between students who remained in the high SVS group (83%) vs. those who improved to the high SVS group from the low or medium groups (93%) showed no significant difference (Fisher's exact $p = .085$).
- A 2×2 comparison of STEM graduation rates between students who remained in the medium SVS group (83%) vs. those who improved to the medium SVS group (82%) showed no significant difference (Fisher's exact $p = 1.00$).

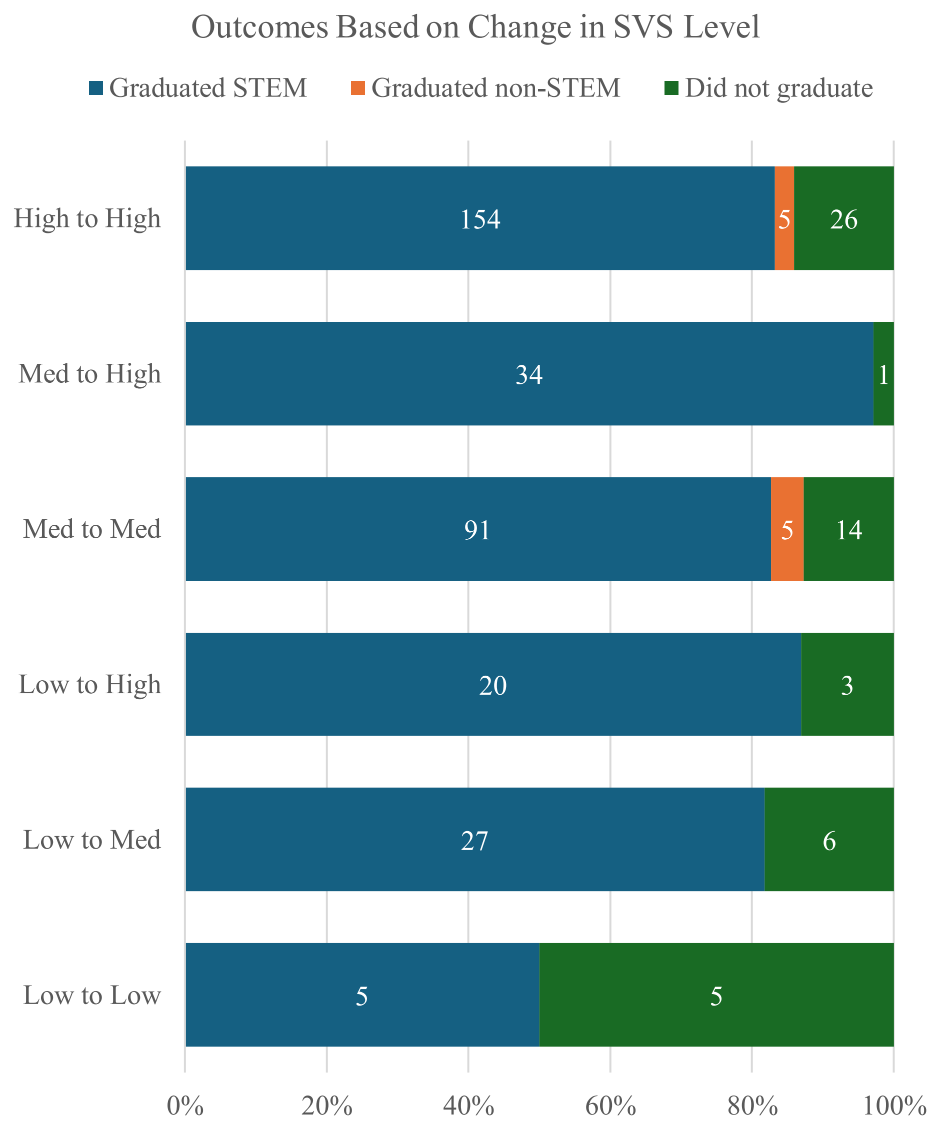

Figure 4. Student outcomes based on change in SVS placement

Conclusions

Results of this study indicate that student success outcomes are more strongly correlated to post-test rather than pre-test scores on a spatial assessment. It is encouraging that a student's lack of experience with SVS prior to college does not prevent successful outcomes, but this also underscores the importance of providing first-year students with opportunities to build their spatial skills as needed.

Medium and high SVS groups were found to have similar graduation outcomes, while the low SVS group had significantly lower graduation rates in STEM. This re-emphasizes the importance of spatial skills to succeed in a STEM program.

In this study, there was no evidence to suggest that students who worked to achieve a higher SVS level had any advantage over students who were already at that SVS level. However, the graduation rate for students who improved from medium to high SVS was unusually high at 97% when compared to the graduation rates among the other groups, which ranged from 82% to 87%. Future work includes repeating the study for the next cohort of graduating students to determine whether similar trends appear.

Acknowledgements

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