Paper ID #25118

Implementation and First-Year Results of an Engineering Spatial Skills Enhancement Program

Dr. Alexander John De Rosa, Stevens Institute of Technology (School of Engineering and Science)

Alexander De Rosa is a Teaching Assistant Professor at Stevens Institute of Technology. He gained his Ph.D. in 2015 from The Pennsylvania State University. Alex specializes in teaching in the thermal-fluid sciences and has a background in experimental combustion. At Stevens he advises the Society of Automotive Engineers and enjoys research in various areas of engineering education including diversity and deeper learning.

Dr. Maxine Fontaine, Stevens Institute of Technology (School of Engineering and Science)

Implementation and First-Year Results of an Engineering Spatial Skills Enhancement Program

Maxine Fontaine and Alexander J. De Rosa

Stevens Institute of Technology

Abstract

Spatial visualization skills are correlated with higher-level problem solving ability and associated with increased performance and retention in STEM fields. These skills are malleable but not typically taught in schools. To identify and assist first-year engineering students with low spatial ability, all first year engineering students in the Stevens Institute of Technology class of 2021 (N=459) took the Purdue Spatial Visualization Test: Rotations (PSVT:R). Students who scored below 70% were encouraged to participate in a 4-week spatial skills training workshop. Of the 134 female and 325 male first-year students, 37% of women and 19% of men did not initially pass the PSVT:R. Eighty-three percent (83%) of these women and 67% of these men elected to participate in the workshop. After completion of the workshop, the overall pass rate increased from 63% to 81% for women, and from 80% to 91% for men. The success of this workshop was notable based on participation, as well as post-workshop improvements in test scores, particularly for women.

Keywords

First-year programs, spatial visualization skills, gender differences.

Introduction

Research has shown that spatial visualization skills (SVS) are correlated with higher-level problem solving capabilities and increased performance in STEM fields[1-3]. While several studies have demonstrated the importance, as well as the malleability of spatial visualization skills, few schools or colleges explicitly teach them[4]. Typically, spatial abilities are instead developed through life experiences such as playing certain sports or video games, and building things with LEGO. The high dependence of spatial skills on these experiences often leads to significant gender differences in levels of spatial skills competence, with women and underrepresented minorities displaying lower spatial skills ability[5,6]. In many cases, these students struggle with, and eventually drop out of engineering programs, simply because they have not been given the chance to develop these skills.

The good news is that spatial visualization skills are not innate. Spatial skills can be developed with practice[7] and several schools and researchers have implemented programs to aid the development of SVS[8]. Sorby's "Developing Spatial Thinking" curriculum is the most wide-spread program and has been implemented in over 41 engineering schools with the help of the NSF-funded ENGAGE Engineering initiative[9]. Data collected over the past two decades at Michigan Technological University clearly show significant improvement in spatial skill test scores after the course, from an average pre-workshop score of approximately 50% to an average post-workshop score of approximately 75%. Students typically complete Sorby's standard ten-module curriculum over 10 weeks. During each of the suggested 1.5-hour weekly lab sessions, students work through an instructional software module and complete workbook sketching exercises.

The "Developing Spatial Thinking" curriculum is often offered as an additional, 'out-of-class' workshop since implementing this spatial skills curriculum as a required course is a challenge at many universities given the level of bureaucracy involved in curricular change. Segil et al.[10] have adapted Sorby's curriculum into a workshop format, which is taken outside of class rather than as a required course at the University of Colorado Boulder. Over a period of five semesters and with various implementations of the spatial skills workshop, the most effective student incentive was found to be the inclusion of spatial skills workshop participation as 5% of the course grade. Hands-on (physical) workshop activities were also developed to supplement Sorby's software and workbook based activities.

A spatial skills enhancement program was introduced at Stevens Institute of Technology in fall 2016. The program was modeled after the workshop system used by CU Boulder. The Purdue Spatial Visualization Test: Rotations (PSVT:R) was the assessment tool used to measure spatial ability at the start, middle, and end of the semester[11].

Implementation

At Stevens Institute of Technology, the spatial skills enhancement program was piloted in 2016 as a part of E 120: Engineering Graphics, a required course for all incoming freshmen in engineering. To assess initial spatial ability, all first-year engineering students were required to take the PSVT:R during the first week of the semester. Students were then placed in one of three categories based on their test scores: Spatial Novice, Spatial Intermediate, and Spatial Master. A different point value was associated with each category, as shown in Table 1, with a maximum of five points translating to full credit for the 5% of the semester course grade as suggested by Segil et al.[10].

Table 1: Fall 2016 incentive plan for spatial skills component

Spatial Novice (0 pts)	**Spatial Intermediate (3 pts)**	**Spatial Master (5 pts)**
Test score < 60%	Test score 60% - 69%	Test score $\geq$ 70%

Following assessment using the PSVT:R, all students were invited to attend the workshop although special emphasis was placed on students in the lower two categories attending for a chance to earn more points and improve their spatial skills. These students then completed a four week workshop session and those who attended all four sessions had the opportunity to re-take the PSVT:R. Students were again placed in one of the three categories based on their new test scores. Students in the first two categories were encouraged to continue on to a second four-week workshop session. Students who completed all sessions of the second workshop had a final opportunity to re-take the PSVT:R to improve their scores.

The second year of implementation in fall 2017 included two modifications to the incentive plan (Table 2) with the aim of increasing workshop participation. The first modification allowed for credit based on workshop participation as well as test performance. Students who completed the first workshop session would earn three additional points, regardless of their re-take test score. Similarly, students who completed both workshop sessions would earn the full five points, regardless of their final test score. The second modification allowed all students, whether they had attended the workshop or not, the opportunity to re-take the test at the end of the semester. Re-takes were offered mid-semester (for workshop participants only) and at the end of the semester (for anyone enrolled in the graphics class).

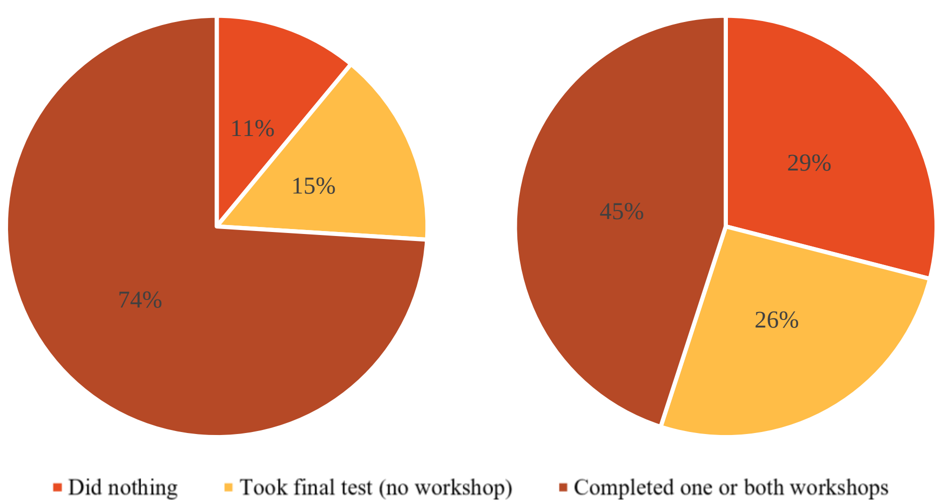
Table 2: Fall 2017 incentive plan for spatial skills component

Spatial Novice (0 pts)	Spatial Intermediate (3 pts)	Spatial Master (5 pts)
Test score < 60%	Test score 60% - 69% *or* Completed Workshop Session 1	Test score > 70% *or* Completed Workshop Sessions 1 & 2

Results

In fall 2016, a total of 495 first-year engineering students were enrolled in the freshman graphics class. The pilot spatial skills workshop was very well-attended with 95% of all Spatial Novices and 47% of all Spatial Intermediates completing the first workshop session. Following the success of the pilot, the study was formalized through the IRB process with data collection beginning in 2017. Results presented here are from the 2017-18 academic year.

A total of 459 first-year engineering students were enrolled in the fall 2017 graphics courses. Workshop attendance was good, although lower than the previous year with 74% of Spatial Novices and 45% of Spatial Intermediates completing workshop session one. Of the students who completed the first workshop session and who did not pass the PSVT:R midterm re-take, 50% went on to complete the second workshop session. The lower workshop attendance can perhaps be explained by the decision to offer a retake of the PSVT:R at the end of the semester without needing to complete the workshop, with 15% of all Spatial Novices and 26% of all Spatial Intermediates re-taking the test at the end of the semester without attending the workshop. These students may have attended the workshop had they not had the opportunity to re-take the assessment without participation. Figure 1 summarizes the behavior shown by students initially placed in the Spatial Novice and Intermediate categories after testing.



(a) Spatial Novices *(b) Spatial Intermediates*

Figure 1: Summary of behavior exhibited by students after initial testing

Following workshop session one, the average test score of the workshop participants increased from 53% on the pre-test to 70% on the post-test. The average test score of the workshop session two participants increased from 49% pre- to 58% post-workshop. Twenty-two students who were eligible, but did not complete the workshop, elected to take the test again at the end of the semester. The average test score of these students increased from 58% on the pre-test to 76% on the post-test. Figure 2 describes these results.

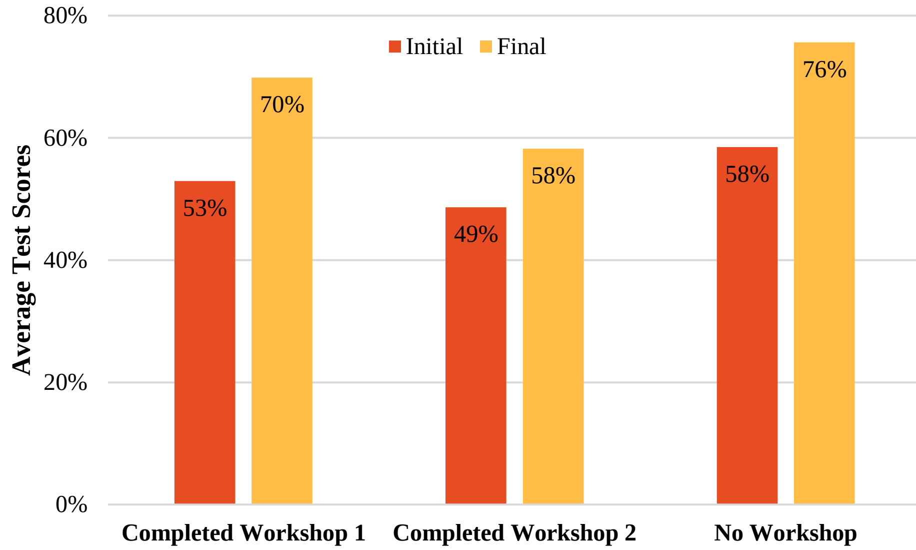


Figure 2: Comparison of average test scores at the start and end of the semester

Figure 3a details the placement levels of all workshop participants at the start, middle, and end of the semester. Of the 69 students who completed the first workshop session, 39 (57%) became Spatial Masters (i.e., test score > 70%). Of the 30 students eligible to continue on to the second workshop, 15 students completed the second workshop session. Of these fifteen students, three became Spatial Masters after the final test. In addition, three out of five students who completed only workshop session one became Spatial Masters after the final test, increasing the total number of Spatial Masters to 45 (65%). Figure 3b shows the placement levels of the 22 students who were eligible, but did not complete any workshop and elected to retake the test again at the end of the semester. Fifteen of those 22 students (68%) became Spatial Masters.

While both workshop sessions were effective in improving spatial ability, a more significant improvement was seen following the first session than after the second workshop session (see Figs.2 and 3a). The second workshop session may have been less effective due to waning student motivation as the semester progressed, or due to a lack of effort on the post-test since these students would receive workshop-based credit no matter how they performed on the test. Figures 2 and 3b also show a significant improvement for the students who did not attend the workshop, possibly indicating that the graphics course was also effective in improving spatial ability. This raises the question of whether offering a supplemental spatial skills workshop is necessary or if exercising spatial skills indirectly in the graphics course is adequate. Though Fig. 2 shows that the non-workshop group achieved higher test scores than the workshop groups, it should also be noted that Spatial Novices comprised a much larger proportion of the workshop group than the non-workshop group (67% vs. 41%), and thus started from a lower average test score (53% vs. 58%).

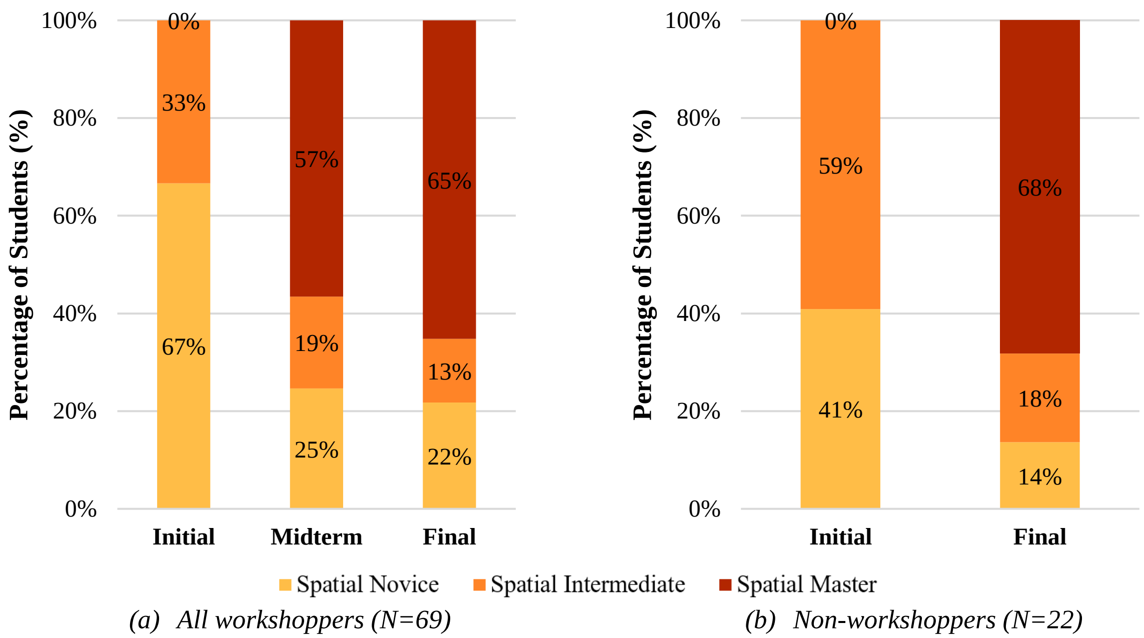


Figure 3: Distribution of test placement levels among student groups at the start, middle and end of the semester

As many other studies have shown[5-9], women had lower scores on the initial PSVT:R test than men ($F(1, 457) = 33.11$, $p=.000$). Figure 4 shows that only 63% of women initially passed the test, compared to 80% of men. By the end of the semester, the percentage of women that passed the test increased from 63% to 81%, and the percentage of men that passed the test increased from 80% to 91%. The significant increase in women passing the test may be attributed to the fact that more women completed the workshop than men. Twenty-four (24) out of 29 (83%) female Spatial Novices completed workshop session one, compared to 22 out of 33 (67%) male Spatial Novices. Similarly, 12 out of 20 (60%) female Spatial Intermediates completed workshop session one, compared to only 11 out of 31 (35%) male Spatial Intermediates.

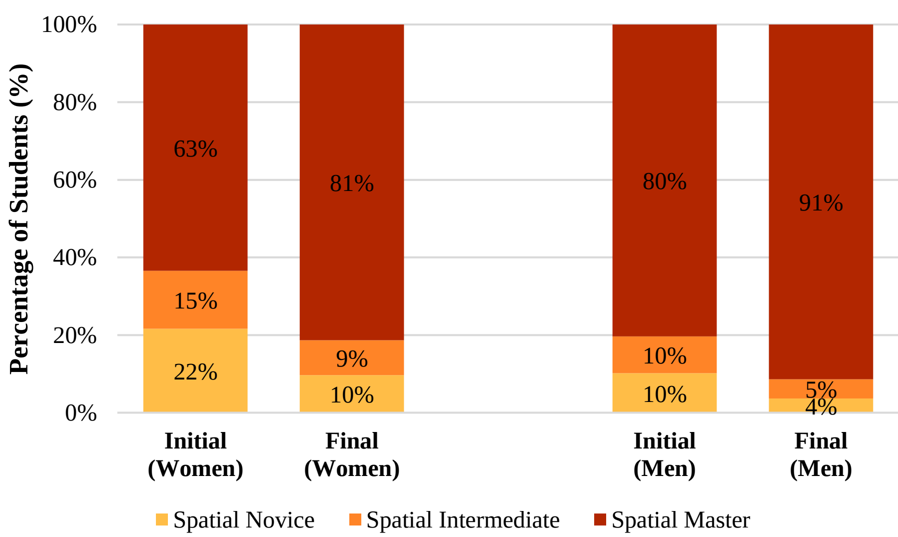


Figure 4: Distribution of placement levels among all female (N=134) and male (N=325) first-year engineering students, at the start and end of the semester

Conclusions

A spatial skills enhancement program was introduced at Stevens Institute of Technology in fall 2016. The program was modeled after the workshop system used by CU Boulder. The results of the workshop-based implementation are promising and results indicate that the voluntary workshop is clearly an effective means for students with low spatial ability to practice and improve their spatial skills - students who completed the workshop showed statistically significant increases in their PSVT:R scores.

The implications of this study on increasing gender diversity in engineering are very encouraging. Since women are disproportionately affected by low spatial ability, the spatial skills training workshop could be a vital tool in retaining women in engineering. Our results show that women's test scores significantly increased upon completion of the workshop, and because the majority of women with low spatial ability opted to complete the workshop, the overall percentage of women who passed the test increased dramatically by the end of the semester, closing the gap in spatial ability initially observed between women and men at the start of the semester.

Students who did not attend the workshop also showed significant increases in their test scores however. This result indicates that completing the graphics course yielded similar improvements in spatial skills as completing the workshop. The question then arises, what advantage does the workshop provide over the engineering graphics course? If significant improvements in spatial ability can be made after a 4-week workshop session, in comparison to a 14-week graphics course, that could have a positive outcome in student self-efficacy and potentially stronger learning outcomes in the graphics course overall. This leads to the question: can spatial ability significantly improve after only partial completion of an engineering graphics course? Although this is unlikely given the content of the course, this hypothesis could be assessed by offering the PSVT:R to workshop participants as well as non-participants when the first workshop session is completed (after four weeks), rather than waiting until all students have completed the semester long engineering graphics course.

Future Work

Future iterations of the spatial skills workshop will involve reconsideration of the current incentive plan, specifically the workshop-based credit. By placing slightly more emphasis on test performance, students may be more inclined to attend the workshop and to do their best when re-taking the test. Disseminating a post-test survey to students who chose not to attend the workshop would also be helpful in gauging student motivation and revealing possible scheduling conflicts, heavy course loads, or other reasons for non-participation in the workshop. To further address the questions posed earlier, offering all students the option of re-taking the test in the middle of the semester (rather than only workshop participants) would help to evaluate the efficacy of the workshop versus the graphics course.

Our university is committed to this effort. Future plans also include assessing outcomes of under-represented minority students in 2018 when there is a more robust sample size, and a longitudinal study to track student performance and retention in our engineering program over time.

References

1. S. Sorby, "Educational Research in Developing 3-D Spatial Skills for Engineering Students," International Journal of Science Education, vol. 31, no. 3, 2009, pp. 459-480.
2. Norman, K.L., Spatial visualization – A gateway to computer-based technology. Journal of Special Educational Technology, XII(3), 1994, pp. 195–206.
3. Smith, I.M., Spatial ability - Its educational and social significance. London: University of London, 1964.
4. J. Wai, D. Lubinski, and C. P. Benbow, "Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance," Journal of Educational Psychology, vol. 101, no. 4, 2009, pp. 817-835.
5. J. L. Segil, J. F. Sullivan, B. A. Myers, D. T. Reamon and M. H. Forbes, "Analysis of multi-modal spatial visualization workshop intervention across gender, nationality, and other engineering student demographics," in 2016 IEEE Frontiers in Education Conference (FIE), Erie, PA, USA, 2016, pp. 1-5.
6. Linn, M.C., & Petersen, A.C., Emergence and characterization of sex differences in spatial ability: A meta-analysis. Child Development, 56, 1985, pp. 1479–1498.
7. Hsi, S., Linn, M.C., & Bell, J.E, The role of spatial reasoning in engineering and the design of spatial instruction. Journal of Engineering Education, 86(2) , 1997, pp. 151–158.
8. S. A. Sorby and A. F. Wysocki, Introduction to 3D Spatial Visualization: An Active Approach. New York, NY: Thomson Delmar Learning, 2003.
9. "Spatial Visualization Skills (SVS): Learn More," ENGAGE Engineering. [Online]. Available: https://www.engageengineering.org/spatial/whyitworks/learnmore. [Accessed: Aug. 27, 2017].
10. J. Segil, B. Myers, J. Sullivan, and D. Reamon, "Efficacy of various spatial visualization implementation approaches in a first-year engineering projects course," in 2015 ASEE Annual Conference & Exposition, Seattle, Washington, USA, 2015.
11. R. B. Guay, Purdue Spatial Visualization Test: Rotations. West Lafayette, In: Purdue Research Foundation, 1976.

Maxine Fontaine Ph.D.

Maxine Fontaine is a Teaching Assistant Professor in Mechanical Engineering at Stevens Institute of Technology. She received her Ph.D. in 2010 from Aalborg University in Aalborg, Denmark. Maxine has a background in the biomechanics of human movement, and she currently teaches several undergraduate courses in engineering mechanics. Her research interests are focused on improving engineering pedagogy and increasing diversity in engineering.

Alexander J. De Rosa Ph.D.

Alexander De Rosa is a Teaching Assistant Professor at Stevens Institute of Technology. He gained his Ph.D. in 2015 from The Pennsylvania State University. Alex specializes in teaching in the thermal-fluid sciences and has a background in experimental combustion. At Stevens he advises the Society of Automotive Engineers and enjoys research in various areas of engineering education including diversity and deeper learning.