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A First-Year Engineering Spatial Skills Workshop: Implementation, Effectiveness, and Gender Differences

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A First-Year Engineering Spatial Skills Enhancement Program: Implementation, Effectiveness, and Gender Differences

Abstract

Research indicates that women and under-represented minorities (URM) display lower levels of competence in the ability to visualize spatially, a malleable cognitive skill that is connected with success in engineering. To identify and assist first-year engineering students with low spatial ability, we launched a spatial skills enhancement program as part of the Engineering Graphics course. All first-year engineering students (N=465) were required to take the Purdue Spatial Visualization Test: Rotations (PSVT:R) to assess spatial ability. Students who scored below 70% were encouraged to participate in a 4-week spatial skills training workshop. The success of the workshop is notable based on (voluntary) participation level, as well as differences in pre- and post-workshop test scores for all students, but particularly women and URM students. After completion of the workshop, the overall pass rate for first-year students increased from 53% to 89% for women, and from 83% to 91% for men. The overall pass rate for URM increased from 55% to 82%, and from 77% to 92% for non-URM students.

Introduction

Spatial visualization is a critical foundational skill that has been correlated with higher-level problem solving ability, and thus higher performance in core courses like mathematics and chemistry [1]. Research indicates that the ability to visualize spatially is important to persistence in an engineering program, however, this skill is never explicitly taught at the pre-college or college levels [2]. Instead, spatial ability is usually developed through life experiences, such as building with LEGO©, playing video games, playing certain sports, and other activities.

There are significant gender differences in spatial skills competence, with women and underrepresented minorities displaying lower spatial skills ability than men [3-8]. These students often struggle and eventually drop out of engineering programs, simply because they are not given the opportunity develop these skills.

Research indicates that spatial skills are malleable, not innate and can be learned by practicing [9]. Sorby's "Developing Spatial Thinking" curriculum has been implemented in over 41 engineering schools with the help of the NSF-funded ENGAGE Engineering initiative [10]. Data collected over the past two decades at Michigan Technological University clearly show significant improvement in spatial skill test scores after participation in the new curriculum, 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 1.5-hour weekly lab session, students work through an instructional software module and complete workbook sketching exercises.

Sorby's curriculum is usually offered as an additional workshop since implementing this spatial skills curriculum as a required course is a challenge at many universities because of the bureaucracy involved in curricular change. One such example is Segil et al. [11] who adapted Sorby's curriculum into a "workshop" format, which is taken outside of class at the University of Colorado Boulder (CU Boulder). Over a period of five semesters and with various implementations of the spatial skills workshop, the most effective student incentive for workshop participation was found to be including workshop attendance as 5% of the related course grade. Hands-on (physical) workshop activities were also developed to supplement Sorby's software- and workbook- based activities.

In order to investigate and examine any potential SVS deficit between men and women at Stevens Institute of Technology, we launched the spatial skills enhancement program in fall 2016, modeled after CU Boulder's workshop format. 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 [12].

Implementation

The spatial skills enhancement program was piloted in 2016 as a part of a freshman engineering graphics course, with the spatial skills component counting 5% towards the course grade. 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 5 points translating to full credit for the 5% of the semester course grade.

Table 1. Incentive Plan for Spatial Skills Component (Fall 2018)

Spatial Novice (0 pts)	Spatial Intermediate (3 pts)	Spatial Master (5 pts)
Test score < 60%	Test score 60% - 69% Or Completed Workshop A	Test score $\geq$ 70% Or Completed Workshops A &B

Following the test, all students were invited to attend the workshop, although Spatial Novices and Intermediates were especially encouraged to complete the workshop for a chance to earn more points and improve their spatial ability. While participation in the workshop was incentivized, it was still voluntary. Students completed the first 4-week workshop session (Workshop A), followed by the opportunity to re-take the PSVT:R. Following this test, students were again placed in one of the three categories based on their new test scores. Students who again scored below 70% were encouraged to continue on to the second 4-week workshop session (Workshop B), followed by a final opportunity to re-take the PSVT:R.

The incentive plan allows for credit based on workshop participation as well as test performance. Students who completed the first workshop session would earn 3 additional points, regardless of their re-take test score. Similarly, students who completed both workshop sessions would earn the full 5 points, regardless of their final test score. Based on prior years, it was reasoned that including a participation based grade would encourage students to volunteer for the sessions by reducing anxiety associated with retaking the PSVT:R. All students, whether they had attended the workshop or not, had the opportunity to re-take the test offered mid-semester and at the end of the semester.

Results and Discussion

A total of 465 first-year engineering students participated in the study presented here (data from fall 2018). The initial assessment at the start of the semester placed 75% of these students as Spatial Masters, 14% as Spatial Intermediates, and 11% as Spatial Novices. The overall average test score was 78.1% for the freshman cohort.

Students placed in the Novice and Intermediate levels were encouraged to attend the spatial skills workshop. Fifty-eight percent of all Novices and 44% of Intermediates completed the first workshop session (Workshop A). Of the 16 students who completed Workshop A but did not pass the PSVT:R midterm re-take, only six students went on to complete the second workshop session. It is possible that scoring three out of the five possible points for workshop was enough for these students and that the incentive scheme needs to be revisited to further encourage participation in the second session.

The workshop was effective in improving spatial ability. As shown in Figure 1, the first workshop session (Workshop A) was attended by a total of 59 students (28 Intermediates, 31 Novices). Upon completion of Workshop A, 71% of these workshop participants passed the test offered mid-semester. Figure 1 also shows that of the 36 students who took the test mid-semester but did not complete the workshop, 78% went on to pass the mid-semester PSVT:R. This result could indicate that the graphics course itself also helped to improve spatial skills as it similarly involves some repeated practice of the required SVS for the PSVT:R.

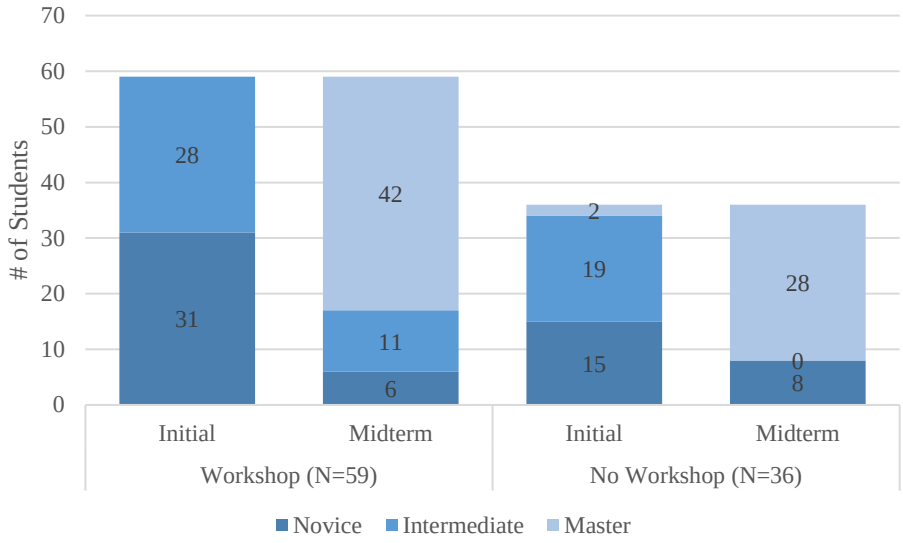

Figure 1. Distribution of placement levels among the 59 workshop participants and 36 workshop non-participants at the start and middle of the semester.

Following Workshop A, the average test score of the workshop participants increased from 55.9% to 73.0%. The average test score of the students who did not complete the workshop increased from 56.7% to 75.6%. Figure 2 shows these results. Again this result is indicative of the success of the workshop in improving SVS as measured by the PSVT:R but also in the effect of the class itself in doing so.

Paired t-tests indicated significant differences between initial and midterm PSVT:R test scores for both populations: students who completed the first workshop session ($t(59) = -9.98$, $p=.000$), and students who did not complete the workshop session ($t(36) = -7.36$, $p=.000$). The similarities in scores leads to questions regarding the efficacy of providing a workshop versus the development of spatial skills through completion of the course. Further work will examine these effects and whether there are other, ancillary benefits to the workshop outside of simple SVS skill improvements.

Spatial Ability in Women

As many other studies have shown [3-6], data collected in this work also demonstrated that women had lower initial scores on the PSVT:R than men ($F(1, 463) = 58.79$, $p=.000$). Figure 3 shows that only 53% of women initially passed the test, compared to 83% of men. By the end of the semester, the percentage of women that passed the test increased from 53% to 89%, and the percentage of men that passed the test increased from 83% to 91%. This result is encouraging in that it demonstrates the effectiveness of the workshop, that SVS can be indeed be learned, and that a relatively simple intervention such as the workshop employed here can be used to reduce the deficit in SVS between male and female students.

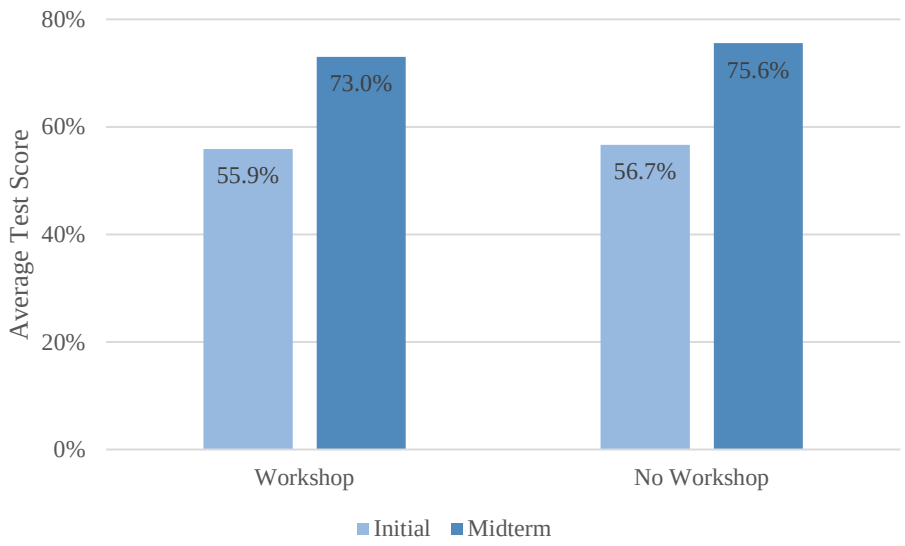

Figure 2. Comparison of average test scores at the start and middle of the semester for students who completed the first workshop session, and did not complete the first workshop session.

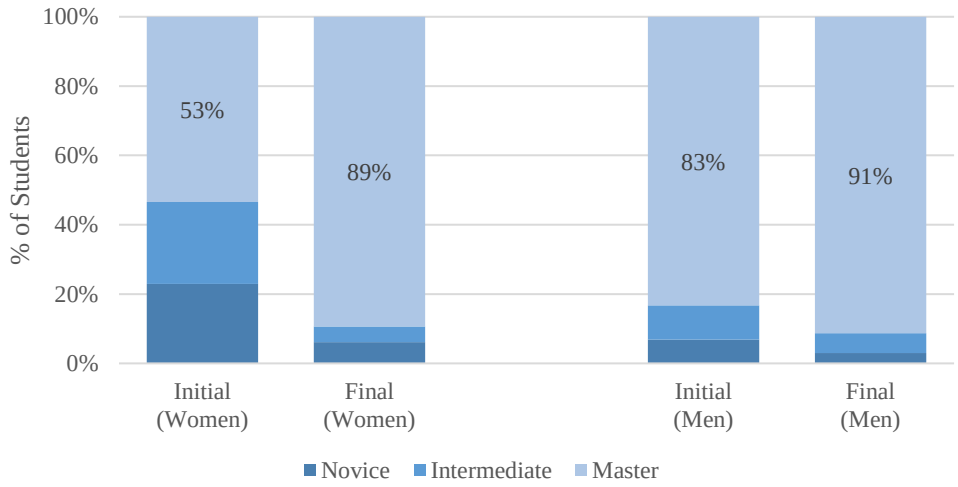

Figure 3. Distribution of placement levels among all female (N=131) and male (N=334) first-year engineering students, at the start and end of the semester.

The significant increase in women passing the test may be attributed to the fact that more women completed the workshop than men. 19 out of 30 (63%) female Spatial Novices completed Workshop A, compared to 12 out of 23 (52%) male Spatial Novices. Similarly, 17 out of 30 (57%) female Spatial Intermediates completed Workshop A, compared to only 11 out of 33 (33%) male Spatial Intermediates. Upon completion of Workshop A, the overall pass rate for women jumped to 75% (from an initial pass rate of 53%). The overall pass rate for men increased from 83% to 87% after the first workshop.

The full progression of pass rates for both men and women over the course of the semester is outlined in Figure 4. The midterm and final test results reflect those students who elected to re-take the PSVT:R but did not participate in the workshop. Female students who took the midterm test but did not attend

Workshop A contributed to the overall pass rate of 86% by mid-semester. Following the second workshop session (Workshop B), the overall pass rate for women increased slightly to 88%, and female students who took the final test without the workshop contributed to the overall pass rate of 89% by the end of the semester.

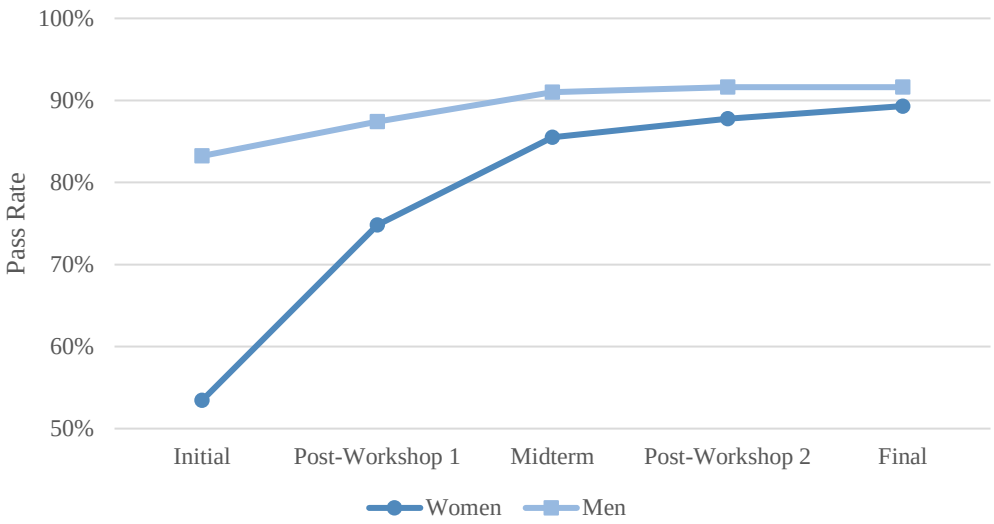

Figure 4. Overall PSVT:R pass rates for women and men over the course of the semester.

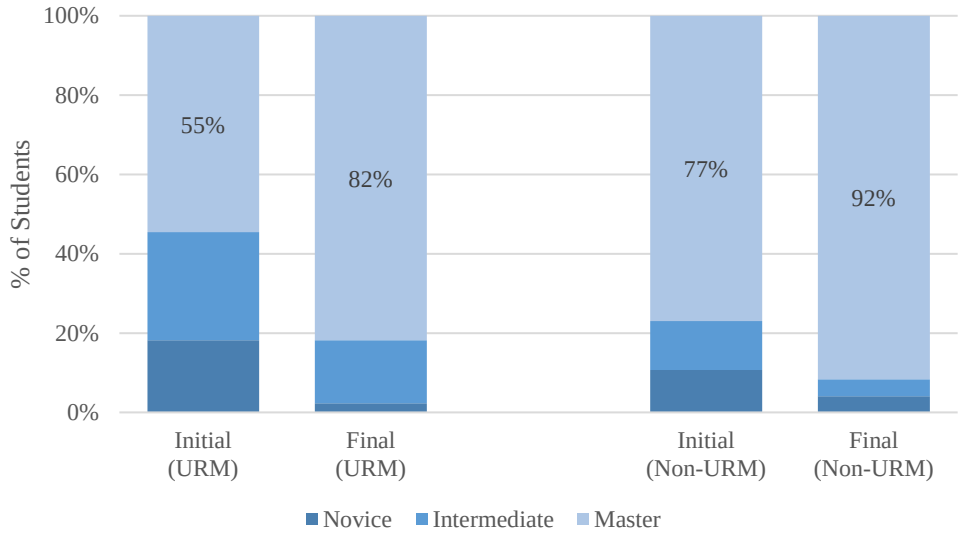

Figure 5. Distribution of placement levels among all URM (N=44) and non-URM (N=421) first-year engineering students, at the start and end of the semester.

Spatial Ability in Underrepresented Minorities

The workshop was well-attended by URM students. Twelve out of 20 (60%) URM students completed Workshop A, compared to 47 out of 97 (48%) non-URM students. The increased attendance amongst URM was encouraging given that underrepresented minorities (URM, N=44) had lower scores on the initial PSVT:R test than non-URM students ($F(1, 463) = 4.14$, $p=.000$). Figure 5 shows that only 55% of URM initially passed the test, compared to 77% of non-URM students. By the end of the semester, the percentage of URM that passed the test increased from 55% to 82%, and the percentage of non-URM that passed the test increased from 77% to 92%. This result is interesting in that it indicates that while the workshop is effective at increasing SVS as measured by the PSVT:R, URM students still lag behind their non-URM counterparts and further work with this group may be warranted to ensure academic success and retention of the URM population.

Conclusions

The results of the workshop-based implementation of the spatial skills curriculum at Stevens Institute of Technology are promising. The voluntary workshop is clearly an effective means for students with low spatial ability to practice and improve their spatial skills, skills that are critical to success in an engineering program. Students who completed the workshop showed statistically significant increases in their PSVT:R scores.

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

Students who did not attend the workshop also showed significant increases in their test scores however. This result could indicate that completing the graphics course yields similar improvements in spatial skills as completing the workshop. The question then arises: what advantage does the workshop provide over the engineering graphics course itself? If significant improvements in spatial ability can be made after a 4-week workshop session, in comparison to a 14-week graphics course, the workshop 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?

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 choose 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. Future work will also assess the effectiveness of the workshop relative to the benefits to SVS gained from participation in the class only.

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