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10 Minute Labs: A Case Study in Teaching Spatial Visualization Strategies with Minimal Instruction

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Abstract

It has been recognized for many years that many students could benefit from remedial instruction in spatial visualization techniques. At Central Connecticut State University (CCSU) however, we have found it difficult to incorporate this topic in our curriculum because of constraints on time and technology access, and because not all students require it. At CCSU, student participation in a voluntary online screening test paired with an optional, ten-hour, non-credit seminar was disappointing, with only a small fraction of the students deemed eligible for the seminars electing to participate. In the Fall of 2020 the students in an Introduction to Engineering course (ENGR 150), were screened for weakness in spatial visualization using the Purdue Spatial Visualization Test: Rotations (PSVT:R). Those students in need of remediation were provided instruction during break-out sessions during regular class time over the course of ten class meetings. The breakout sessions lasted about ten minutes each, resulting in two hours of direct instruction. Test results after training showed significant improvement by students who received the intervention despite the extreme brevity of instruction. Considering only those students who needed training, scores rose by 18.6% after receiving training. The magnitude of improvement was found to be statistically significant. These results are consistent with the improvements seen in previous research which generally involved more extensive instructional efforts.

Introduction

Sorby [1] presents several different attempts to define spatial skills. None are labeled as completely satisfactory, recalling Justice Potter's 1964 analysis of what constitutes lewdness: "I know it when I see it"[2]. Tartre [3] divided spatial skills into visualization tasks and orientation tasks. She further categorizes visualization tasks as either requiring Mental Rotation or Mental Transformation. Practically, engineers must be able to effortlessly perform such tasks as mentally rotating arbitrary objects, folding and unfolding flat objects, and constructing complicated shapes from simpler ones (solids of revolution and extrusions, for example). These abilities are required in the very earliest science and technology classes as professors sketch 3D problems on 2D whiteboards and expect their students to immediately grasp the problem being considered.

Methods to develop spatial reasoning in undergraduates have been the focus of significant research [4-6]. A focus on a reduction in the time and effort required of faculty are features of both [5] and [7]. These studies and others have used tests such as the Purdue Spatial Visualization Test: Rotations (PSVT:R) [8] to determine which students need the training and to quantify the effectiveness of the same training. The PSVT:R does not test all aspects of spatial ability, but it is a convenient proxy. An example question from this test is shown in Figure 1.

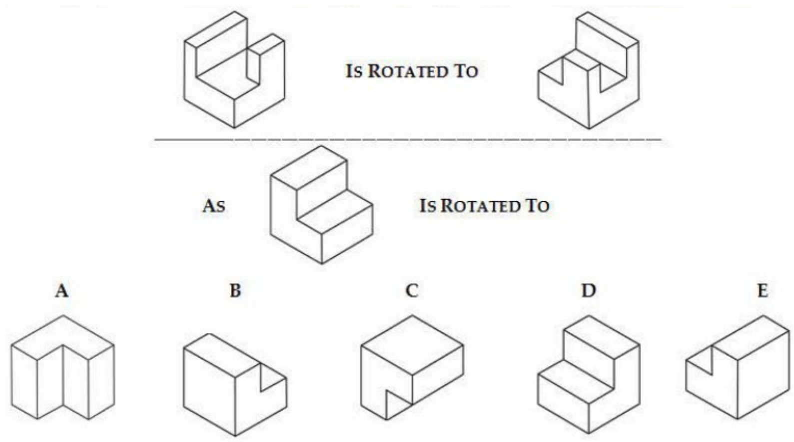

Figure 1 – Example of a question from the Purdue Spatial Visualization Test: Rotations

Further research implied that the training worked better if it was graded rather than offered pass/fail [9], and if it was required that students participated in the course if testing showed that it was warranted [10]. Students also benefit if participation is accompanied by reassurance from the instructor that needing the training was not a sign that failure in STEM is preordained, but that they simply lack a tool that they can acquire with a bit of effort [11]. Longitudinal studies demonstrated that training can increase retention and student performances as measured by GPA [7], and these benefits are especially pronounced among women [12].

Central Connecticut State University (CCSU) is a medium-sized public university with about 10,000 undergraduate students and a primary focus of teaching. About 30% of the students are underrepresented minorities (Underrepresented Minority includes the following ethnic/racial identities: Black or African American, Hispanic, Other, and Native Hawaiian and Pacific Islander, American Indian or Alaska Native), and while 50% of all students live on campus their first year, only about 5% of seniors do so. Faculty conduct all lectures and grading activities in engineering courses and classes typically have 24 students. Finally, 53% of CCSU undergraduates finish within 6 years. This value is impacted by the large number of students who work full time and attend school only part-time, delaying their graduation. However, this graduation rate is unacceptably low. The School of Engineering, Science, and Technology offers engineering degrees in mechanical and civil, as well as engineering technology degrees in the disciplines of mechanical, manufacturing, computer, and robotics/mechatronics. All engineering and engineering technology students are required to take a course titled Introduction to Engineering. There are no prerequisites, so no prior Computer Aided Drafting (CAD) experience or mathematical skills can be taken for granted by the instructor.

To mold well-rounded citizens, CCSU requires all students to study fine arts, literature, equity and justice, foreign languages, and other knowledge areas in addition to the many topics that must be understood by practicing engineers as defined by the Accreditation Board for Engineering and Technology (ABET) [13]. This leaves the faculty with little freedom to explore adjacent material such as spatial visualization. The faculty at CCSU have been considering how to best incorporate spatial visualization into the curriculum for nearly a decade. In 2012 an optional workshop was offered to students who showed a need for additional instruction based on their performance on the PSVT:R. Unfortunately, only a handful of students elected to participate, and the experiment was not repeated. Attempts to include the topic in credit-bearing courses did not move past the discussion stage until recently. Instructors in courses such as CAD, introduction to engineering, and statics were consulted, but none were willing to concede the ten hours of lecture time we estimated would be needed based on existing curriculum materials [11]. When the author was tasked with teaching Introduction to Engineering (ENGR 150) for the first time in the Fall of 2020, he immediately set to work finding a way to shoehorn spatial visualization into the syllabus. These efforts are documented in the next section.

Methods

Ultimately, the goal of this work was to improve performance and graduation rates of the students. Improvement on the PSVT:R test was used as a proxy. In an earlier effort, incoming freshmen were screened with the PSVT:R test (>60% to pass), and it was found that about half of the students would benefit from training in spatial visualization. This meant that the number of students who would need training was likely large enough to justify including the training in a regular class. It was decided that the high visualizers who did not need training could engage in other self-directed activities in breakout sessions, such as discussing carefully selected academic papers, NASA Tech Briefs, and the like.

As the screening test results were shown to the students, the expected impact of training was described in considerable detail. The point was made so convincingly that several students who passed the PSVT:R test elected to partake in the training. The scores of students who passed the pre-test and opted into the training are not reported here or included in the analysis.

As many other topics must be covered in Introduction to Engineering, it was decided that no more than two hours total could be given over to spatial visualization. Rather than use two full class meetings, the time was spread out over 10 weekly meetings. This allowed each session to be aligned with one of the 10 modules of the freely available ENGAGE educational system [11] which we elected to use for the training. The ENGAGE training covers many key aspects of spatial visualization including isometric and orthogonal views, solids of revolution, and flat patterns.

In Fall 2020, most classes, including Introduction to Engineering, were conducted online due to measures required to combat the COVID-19 pandemic. Lectures were broadcast live and recorded for later viewing. This modality limited or prevented the implementation of most of the recommended activities, such as the examination and use of physical manipulatives, cooperative games, and small group work. In each session, the topic was first introduced using the lecture slides supplied by ENGAGE and placed in context by describing situations when students could expect to use the skill. Sheetmetal processing was used to motivate the study of flat patterns, for instance. Next, the example problems provided in the ENGAGE lecture slides were solved by the instructor. Finally, problems were assigned as homework, but little to no time was allotted in class to work on them. As not all students were required to complete the assignments, performance on the homework problems was not factored into final grades. This policy was made clear to students, but it was not unduly emphasized. Students could resubmit homework until they achieved a grade that satisfied them. They frequently took advantage of this option, but the time invested by students outside of class was not measured. After 10 weeks all the training modules had been completed and the PSVT:R was retaken to evaluate the student's progress.

Results

The class had 23 students. Information about the class is presented in Table 1. The majority of the students who failed the PSVT:R had completed a class in trigonometry but had not yet completed a course in calculus. One student had completed a second calculus course, and two had only completed algebra. The level of mathematical training on performance is not investigated in this study because the sample size is too small.

Table 1 - Summary of Basic Information of All the Students in the Class

	Count	Percentage
Class Size	23	
Female	2	9
Underrepresented Minority*	7	30
Failed PSVT:R Pre-Test	10	43

Because the number of women and underrepresented minorities (URM) is small, the performance of these students is not analyzed separately. Of the 10 (43%) students who failed the pre-test, 7 both participated in the training and took the post-test. The results of the post-test of this group are summarized in Table 3.

Table 2 - Summary of Results for Students who Failed the Pre-Test

Pretest Average (Standard Deviation)	**Post-test Average (Standard Deviation)**	**% Gain**
55.7% (7%)	74.3% (15%)	18.6% ($p_{0.05} < 0.01$, d = 8)

The test results are presented graphically in Figure 1.

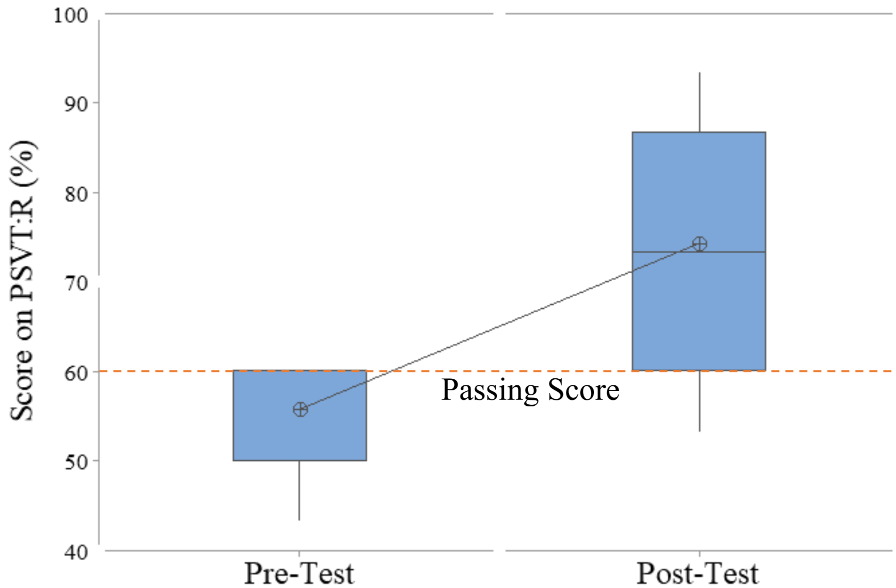

Figure 2- PSVT:R Results for Students Who Failed the Pre-Test

At the end of the semester students were surveyed about their general impressions of the class, but not specifically about the spatial skills training. Students could provide written, open-ended feedback, but few addressed spatial skills in their response. One student reported that "…at times it felt almost more like we were Professor Moore's guinea pigs…". Undoubtedly the student intended this as a criticism, but it can be seen as a reflection of the honest and forthright approach taken to explaining to students that engineering education is not an exact science and that every class we teach is an experiment intended to make their education better.

Discussion

Considering only students who failed the pre-test, the average student score on the PSVT:R post-test was 18.6 percentage points higher, which falls in the middle of the range reported by other universities [4], where reported gains ranged from 1% - 29%. The p value for the 1-sided t-test for the comparison of means was less than 0.001 with $\alpha = 95\%$, indicating that the improvement was statistically significant. The effect size of the training was $d = 8$, which is large. Not all students who received training passed the post-test (n = 2 of 7) but scores of students who failed the post-test still improved by at least 10%. The standard deviation of scores doubled between the pre-test and the post-test from 7% to 15%. The sample size was too small to investigate this result any further.

While the initial cohort of students did not self-select to participate, 30% of the students (3 of 10) who failed the pre-test elected not to take the post-test. Of the three, one did not take the final exam for the course, and so can be fairly described as discouraged. The other two did well in all other aspects of the course, and perhaps saw no personal benefit in retaking the PSVT:R.

Conclusion

A curriculum for training undergraduates in spatial reasoning was presented to a group of students at a medium-sized public university with a sizable URM population. As the class was given online, physical manipulatives and other features of on-ground teaching were absent. The time spent on the training during class was minimal so that it could be included in an existing class without crowding out other material, and without overburdening students with additional requirements. Despite all this, the students showed a statistically significant improvement in their spatial reasoning abilities as measured by the PSVT:R. The gains in test scores were in line with the results of previous studies. It remains to be seen whether these students will also see improvements in retention and GPA. The positive preliminary results presented here have motivated the department to incorporate spatial visualization into additional sections of Introduction to Engineering. The data generated by this effort will be used to verify the results of this study. The current study was conducted using an online modality because of restrictions imposed by the fight against COVID-19. With the anticipated resumption of in-person instruction, future sections will be able to utilize physical manipulatives, but the basic structure of instruction will remain the same. No investigation was made into the utility of enrichment activities provided to students who did not elect to participate in the spatial visualization training. This is an area that should be investigated and should also be an important consideration for instructors considering implementing a strategy similar to the one used in this study.

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