An Online Intervention to Improve Spatial Skills

Peter J. Cole[1] and Stephanie Farrell[2]

[1]Department of Computer Science, Dublin Institute of Technology, Ireland
peter.cole@mydit.ie
[2]Department of Chemical Engineering, Rowan University, USA
farrell@rowan.edu

Abstract. A well-established link exists between spatial visualization skills and academic and professional achievement in STEM fields. It is also widely documented that men outperform women on tests of spatial ability. This disparity puts women at a relative disadvantage for academic success in STEM disciplines. Previous work has shown that spatial visualization ability can be improved relatively quickly through practice; interventions have successfully improved student scores on spatial skills tests as well as grades and retention in postsecondary STEM courses. This paper describes an online intervention to improve the spatial visualization ability of first year engineering students. Spatial ability was measured using two standard psychometric instruments for measurement of spatial visualization.

Keywords: spatial visualization, mental rotation, academic success, retention

1 Introduction

The link between spatial skills and academic and professional success in STEM fields is well documented [1-5]. A longitudinal study of 400,000 followed high school students for eleven years after graduation to demonstrate that tests of spatial ability can predict group membership in various engineering and physical science occupations [1] Research conducted at Michigan Technological University in the United States demonstrated that spatial skills were a strong predictor of academic achievement and retention in engineering [6].

Gender differences in spatial ability, favoring men, are broadly reported in the literature [7-11] The differences are mainly limited to mental rotation ability [11], which is also the ability most predictive of success in engineering and physical sciences [12-14]. Sorby and co-authors [3, 15, 16] reason that poorly developed 3-D spatial skills may be a hindrance to success in engineering programs that disproportionately affects women. The removal of such barriers to academic

Citation: Cole, P.; Farrell, S. An online intervention to improve spatial skills, World Engineering Education Forum, Seoul, Seoul, 2016.

success is of particular interest in the context of current efforts to increase the number of engineering graduates entering the workforce and to increase the participation of women in the profession.

Fortunately, there is evidence that spatial skills can be improved in a relatively short time through appropriate instruction and practice. Targeted spatial skills interventions have resulted in substantial gains in spatial skills test scores, eliminate the gender gap in spatial skills test scores, improved student academic performance in engineering courses, and increased retention of students at the university [6, 17].

A variety of validated test instruments are used to measure spatial ability. Tests of three-dimensional spatial ability are of particular interest in engineering education and have been most widely used in educational and psychological research related to STEM fields.

- The Mental Cutting Test (MCT) [18] is a twenty-minute timed test comprising 25 items. This test measures both spatial relations and spatial visualization ability.

- The Purdue Spatial Visualization Test: Rotations (PVST:R) [14] is a 30-item speeded test. Each question presents the subject with a depiction of a 3-dimensional reference object and a picture of the object after it has been rotated about one or more axes. A picture of a second object is shown, and the subject must indicate which of five choices depict the object after it has undergone the same rotation as the first object. This test requires a higher level of spatial visualization ability than other tests by maximizing gestalt-type processing and minimizing analytical processing. Gestalt processing is related to the ability to solve tasks often found in STEM disciplines [19].

- Differential Aptitude Test: Spatial Relations (DAT:SR) [20] comprises 50 questions. The learner must mentally fold a two-dimensional pattern and identify the resulting three-dimensional object. The test measures the learner's ability to move from a two-dimensional space to a three-dimensional space.

- The Mental Rotations Test (MRT) [21] consists of 24 questions that ask the learner to compare two-dimensional drawings and three-dimensional geometric figures. The test is timed; there are two sections of four minutes each with a short break between sections. A reference figure is presented, and the subject must choose two pictures (among four choices) that correctly represent the object after it is rotated. This test is geometrically simpler than the PSVT:R due to the use of cubic surfaces in the test questions, rather than inclined, oblique and curved surfaces [22].

2 Objectives

This study examines the effectiveness of a novel, software-only intervention to improve the spatial visualization ability of engineering students.

3 Methods

A pretest-posttest experimental research method with a comparison group was used on a large cohort of students to evaluate the effect of using a software-only teaching module as an intervention for increasing the spatial abilities of first year engineering students. The sample group comprised approximately 350 first year engineering students in their first term at Rowan University in the United States. The Revised Purdue Spatial Visualization Test: Rotations was administered during the first week of class in the fall term and again at the end of the term in December. The training was offered as part of the Freshman Engineering Clinic introductory course, which had 16 sections. The training was optional and was conducted at the discretion of the instructor of the course, with 8 sections completing the training and 8 sections opting out, forming an experimental group and a comparison group. This study focuses on the students who had weak spatial ability initially (a PSVT:R score of 60% or lower). Statistical methods employed to analyze the results included Welch two sample and paired t-tests, two- way Anova, and Cohen's d effect size estimates.

4 Results

A total of 285 students participated in the study. 70 students achieved a pretest score of 60% or less. Of those who failed, 26 were in the experimental group (Population 1). These students completed an average of 127 minutes of software intervention. 44 students who failed the pretest were in the comparison group that received no intervention (Population 2). 81% of the students who failed the pretest and completed the training passed the posttest, in comparison to 50% of the students from the control group.

Students who failed the pretest and were in the experimental group that completed the training achieved a mean pretest score of 14.9 out of 30 in comparison with 15.1/30 correct for the students who failed the pretest and received no training. The difference between pre-test means for these two populations was not significant ($p=0.75$). Students who failed the pretest and received training achieved a mean posttest score of 21/30, in comparison with 18.3/30 for the students who failed the pretest but received no training. This difference between means was significant ($p=0.005$). An effect size (Cohen's d) of 0.735 was computed for the gain between the two groups.

Of all the students who failed the pretest, 24.4% were male and 39.6% were female. Women who failed the pretest and took the intervention had a significant increase in mean test score from 14.7 on the pretest and 21.0/30 on the post test (p=.009). Women who failed the pretest and did not participate in the training showed a smaller gain between pretest and post test. Their mean pretest score was 15.92/30 and the mean posttest score was 18.31. A similar trend was observed with the men who failed the pretest. The experimental group showed a gain in mean test score from 15/30 on the pretest to 21/30 on the posttest. The mean score of the comparison group increased from 14.8/30 to 18.3/30. Of the students who failed the pretest and completed the training, men and women performed equally well on the posttest.

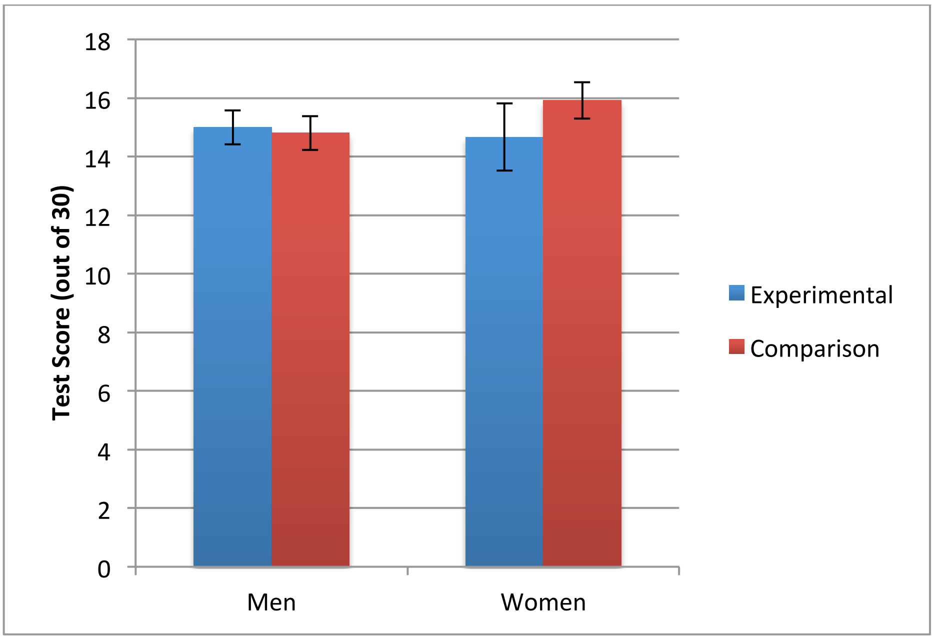

Figure 1. Pre-test scores for men and women in the experimental group and the control group. Total test score is out of 30 points maximum.

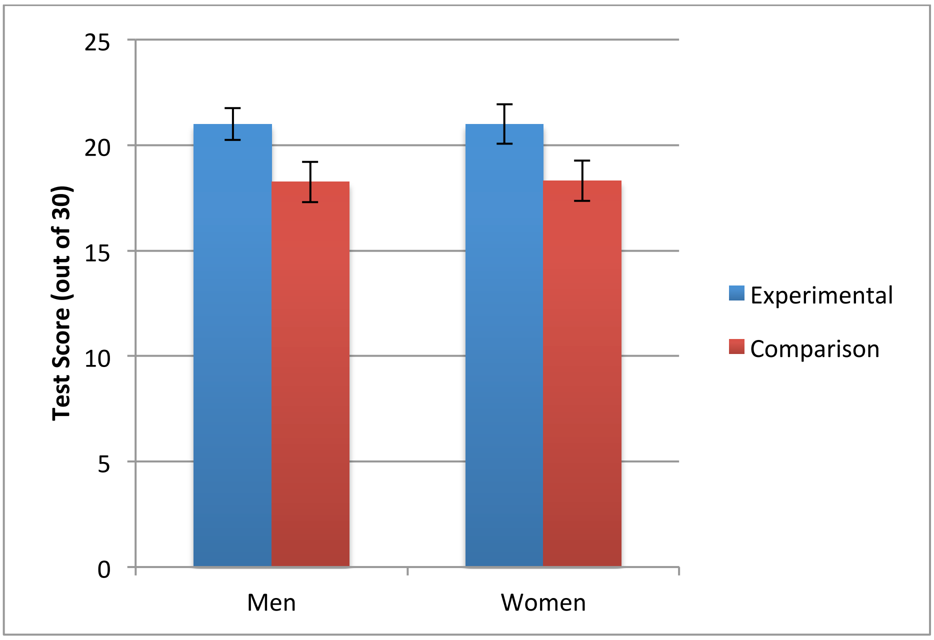

Figure 2. Post-test scores for men and women in the experimental group and the control group. Total test score is out of 30 points maximum.

5 Conclusions

A software-only intervention successfully increased the spatial visualization ability of first year engineering students as measured by the Revised Purdue Spatial Visualization Test: Rotations. Students who failed the pretest and completed about two hours of software-based intervention using an online training program showed significant gains in spatial skills test scores. There was no difference between the mean posttest scores of men and women in this group.

The software intervention offers several advantages over conventional classroom interventions. Because the training is available online, it may be completed independently by students at their own pace. This mitigates many of the logistical difficulties of offering a conventional for-credit classroom intervention, such as instructor time, classroom scheduling, and student scheduling. The intervention required an average of only two hours of student time, in comparison with a full semester of class time and homework time required for a conventional course-based intervention.

6 References

1. Humphreys, L. G., Lubinski, D., and Yao, G.: Utility of Predicting Group Membership and the Role of Spatial Visualization in Becoming an Engineer, Physical Scientist, or Artist. Journal of applied psychology, 78, 250-261 (1993).
2. Shea, D. L., Lubinski, D., and Benbow, C. P.: Importance of Assessing Spatial Ability in Intellectually Talented Young Adolescents: A 20-Year Longitudinal Study. Journal of Educational Psychology, 93, 604-614 (2001).
3. Sorby, S. A.: Educational Research in Developing 3-D Spatial Skills for Engineering Students. International Journal of Science Education, 31, 459-480 (2009).
4. Wai, J., Lubinski, D., and Benbow, C. P.: Spatial Ability for Stem Domains: Aligning over 50 Years of Cumulative Psychological Knowledge Solidifies Its Importance. Journal of Educational Psychology, 101, (2009).
5. Wai, J., Lubinski, D., Benbow, C. P., and Steiger, J. H.: Accomplishment in Science, Technology, Engineering, and Mathematics (Stem) and Its Relation to Stem Educational Dose: A 25-Year Longitudinal Study. Journal of Educational Psychology, 102, (2010).
6. Sorby, S. A.: Developing Spatial Cognitive Skills among Middle School Students. Cognitive Processing, 10, S312-S315 (2009).
7. Benbow, C. P., Lubinski, D., Shea, D. L., and Eftekhari-Sanjani, H.: Sex Differences in Mathematical Reasoning Ability at Age 13: Their Status 20 Years Later. Psychological Science, 11, 474-480 (2000).
8. Debelak, R., Gettler, G., and Arendasy, M.: On Gender Differences in Mental Rotation Processing Speed. Learning and Individual Differences, 29, 8-17 (2014).
9. Halpern, D., Benbow, C. P., Geary, D. C., Gur, R. C., Hyde, J. S., and Gernsbacher, M. A.: The Science of Sex Differences in Science and Mathematics. Psychological Science in the Public Interest, 8, 1-51 (2007).
10. Maeda, Y. and Yoon, S. Y.: A Meta-Analysis on Gender Differences in Mental Rotation Ability Measured by the Purdue Spatial Visualization Tests: Visualization of Rotations (Psvt:R). Educational Psychology Review, 25, 69-94 (2013).
11. Voyer, D., Voyer, S., and Bryden, M.: Magnitude of Sex Differences in Spatial Abilities: A Meta-Analysis and Consideration of Critical Variables. Psychological Bulletin, 117, 250-270 (1995).
12. Johnson, W. and Bouchard, T. J.: The Structure of Human Intelligence: It Is Verbal, Perceptual, and Image Rotation (Vpr), Not Fluid and Crystallized. Intelligence, 33, 395-416 (2005).
13. Kozhenikov, M., Motes, M. A., and Hegarty, M.: Spatial Visualization in Physics Problem Solving. Cognitive Science, 31, 549-579 (2005).
14. Guay, R. B., "Purdue Spatial Visualization Test: Visualization of Rotations.," ed. West Lafayette, IN: Purdue Research Foundation, 1976.
15. Sorby, S. A.: Improving the Spatial Skills of Engineering Students: Impact on Graphics Performance and Retention. Engineering Design Graphics Journal, 65, 31-36 (2001).
16. Sorby, S. A.: Developing 3-D Spatial Visualization Skills. Engineering Design Graphics Journal, 63, 21-32 03/01/ (1999).
17. Hsi, S., Linn, M. C., and Bell, J. E.: The Role of Spatial Reasoning in Engineering and the Design of Spatial Instruction. (1997).
18. CEEB, "Special Aptitude Test in Spatial Relations," ed: developed by the College Entrance Examination Board, USA, 1939.
19. Bodner, G. and Guay, R.: The Purdue Visualization of Rotations Test. The Chemical Educator, 2, (1997).
20. Bennett, G. K., Seashore, H. G., and Wesman, A. G., "Differential Aptitudt Test: Forms S and T," The Psychological Corporation, New York1973.

21. Vandenberg, S. G. and Kuse, A. R.: Mental Rotations, a Group Test of Three-Dimensional Spatial Visualization. Perceptual and Motor Skills, 47, 599-6-4 (1978).
22. Yue, J., "Spatial Visualization by Orthogonal Rotations," in *ASEE Annual Conference and Exposition*, Salt Lake City, UT, 2004.