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JUNE 22 - 26, 2020 #ASEEVC
Paper ID #30736

Work in Progress: Spatial Visualization Intervention in First Semester Engineering Course

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Introduction

Spatial visualization skills are linked to success in chemistry, computer science, engineering, and mathematics [1,2]. Studies found that females, independent of racial and ethnic background, consistently lag behind males in measures of spatial skills[3]. Brus et al. found that female students entering an engineering program report less confidence than male students in three categories: career choice, scientific preparation, and their preparation of using graphical tools[1]. The combination of a lack of confidence upon entry into an engineering program and low spatial visualization skills, in comparison to male peers, may hurt retention efforts in the case of female engineering students[1,2]. Studies also found that students can improve their spatial skills in a short amount of time through specialized training[4]. Various training approaches, including the use of pencil and paper exercises and specific computer applications or mobile apps, demonstrate similar improvements in spatial visualization[4,5].

Spatial skills comprise a broad category of subabilities whose definitions and associated mental processes require their own line of research[3,6]. Spatial ability subcategories, identified from cognitive studies, include: spatial perception, mental rotation, and spatial visualization[6]. Spatial perception refers to an individual's ability to determine the orientation of object's in relation to themselves, in spite of distractions. Mental rotation skills allow individuals to rotate two- or three-dimensional objects in their minds. The spatial visualization subcategory covers multistep problems involving both mental rotation and spatial perception. In the identification of these three subcategories, the authors found that the only significant discrimination, favoring males, was in tests of mental rotations. Meta-analysis showed the effect size for sex measured using the Vandenberg Mental Rotation Test (MRT) falls within 0.77-1.12 for a 95% confidence interval. The male advantage in mental rotation tasks did not carry over to multi-step spatial visualization tasks. In an attempt to explain the male advantage in mental rotation tasks, Voyer et al. considered visual spatial working memory, or the short-term storage of visual or spatial information[7]. The authors found that significant male advantage in visual spatial working memory does not fully account for the large difference in in mental rotation. Given the male advantage in mental rotations tests, the processes involved in mental rotation and the identification of tasks that require mental rotation demand attention[7,8].

This work considers the impact of a short spatial-skills intervention during a first semester engineering course as part of a new engineering program. The goal of the intervention is to improve mental rotation skills of our first year students. We hope these efforts will help to retain students in the engineering program.

Methods

Our Engineering Success course runs every fall. The course spans 55 minutes on Mondays, Wednesdays, and Fridays. We collected data from 20 students over the first two years of our engineering program: 15 students in the first year and 5 students the following year. Our sample consists of 4 female and 16 male students.

Table 1. Intervention Plan.

Day	Activity	Description
1	Pre-intervention measurements	Students complete the first 12 questions of the Vandenberg MRT and create 3-view sketches of pipefittings.
2	Plexiglass activity	Students create 3-view sketches of pipefittings and work in small groups to trace object edges for front, top, side-view on plexiglass.
3	Building-brick assembly	Students assemble building bricks from front, top, and side-view images.
4	Building-brick sketches	Students create 3-view sketches of building brick structures, and assemble building blocks based off a classmate's sketches.
5	Worksheet	Students complete a worksheet containing orthographic projection exercises.
6	Post-intervention measurements	Students complete the last 12 questions of the Vandenberg MRT and create 3-view sketches of pipefittings.

Table 1 outlines our six-day intervention to improve the mental rotation skills of students in one of our first semester engineering courses, ENGR 112: Engineering Success. The spatial visualization segment of Engineering Success begins and ends with an evaluation in the form of half (12 questions) of the Vandenberg MRT[9] and a three-view sketch of a pipefitting. We allow students as much time as necessary for them to complete the MRT without feeling rushed. The intervention includes several hands-on activities to promote the practice of spatial skills. During the hands-on activities students sketched pipefittings and, in teams, outlined edges of the pipefittings on plexiglass to compare with their sketches. Students also assembled building-brick structures according to 3-view instructions, i.e. pictures of front, top, and side views of the structure. Later, students sketched premade building-brick structures, disassembled the original structures, exchanged disassembled objects and drawings with a classmate, and tried to reproduce the classmate's original structure. In this activity, students check their structures against the original 3-view pictures. Lastly, students worked through a packet of orthographic projection exercises, translating pictorial views to orthographic views and vice versa without a physical model. The mental rotation tests given at the start and conclusion of the lecture series measure changes in mental rotation skills over a two-week, six-class period, time frame.

Results and Discussion

Figure 1 shows improvement in the scores of our lowest scoring students on the MRT. The test scores are out of 12 points with one point awarded for each correctly answered question. Of the 20 students, six students scored below 10 out of 12 on the initial MRT. Of the six lowest scoring students, two improved their score on the second MRT by three points, two improved their score by two points and one improved their score by one point. One student who scored 5 points on the initial mental rotation test scored one point lower on the second test, however this student left the final six questions blank, suggesting the student did not realize the test was double sided.

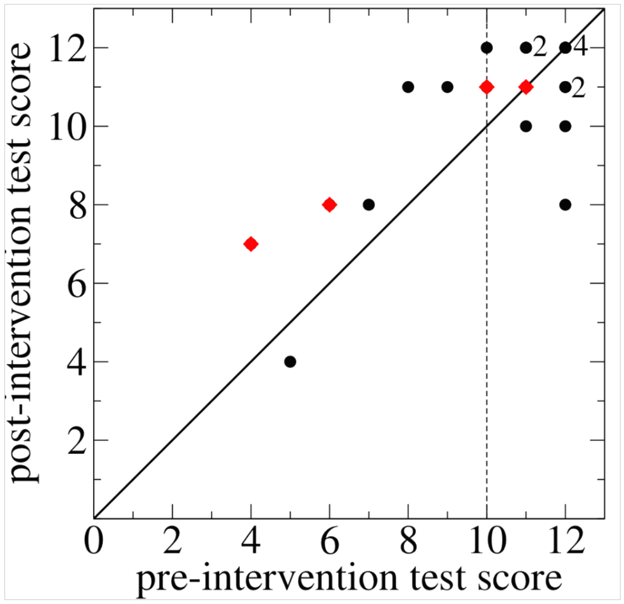

Figure 1. Post-intervention versus pre-intervention MRT scores. Black circles indicate male students' scores, and red diamonds represent female students' scores. Markers representing more than one student's pre- and post-intervention scores are marked with their multiplicity; there were four male students who scored 12 points on both pre- and post-intervention tests, two male students who scored 10 points and 12 points on the pre- and post-intervention tests, and two male students who scored 12 points and 10 points on the pre- and post-intervention tests.

Figure 2 shows a moderate positive correlation between final exam scores and pre-intervention mental rotation test scores. Our spatial visualization intervention takes place near the end of the semester, after exams 1 and 2, but before the final exam. The MRT exam scores do not contribute to the students' overall course grade. The final exam covers the same mathematical content as exams 1 and 2, but we find less correlation of exam 1 and exam 2 scores with pre-intervention mental rotation test scores (correlation coefficient = 0.29 and correlation coefficient = 0.34). We also find less correlation between final exam scores and post-intervention mental rotation test scores (correlation coefficient = 0.31). Despite the established link between spatial skills and cognitive skills[10], improvements in measures of mental rotation skills do not translate into improvements in students' final exam scores. In fact, figure 3 shows a moderate negative correlation between changes in our students' mathematical exam scores and changes in MRT scores.

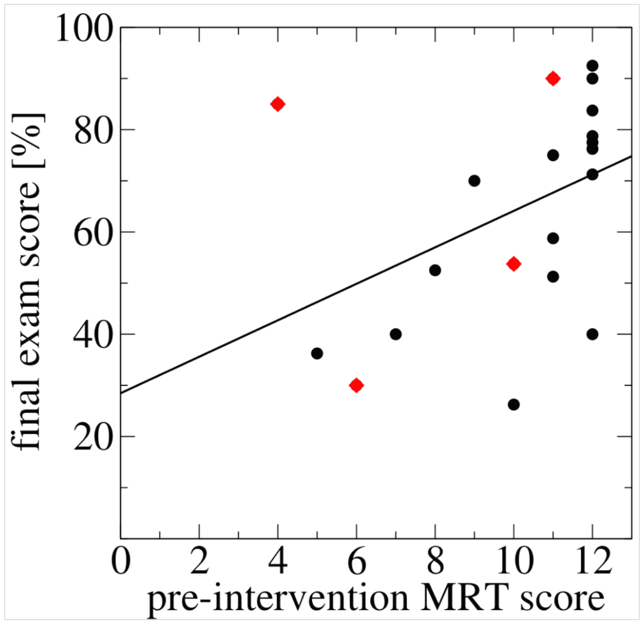

Figure 2. Final exam score versus pre-intervention MRT scores. Black circles indicate male students' scores, and red diamonds represent female students' scores. The best fit line (solid black) has a correlation coefficient of 0.43.

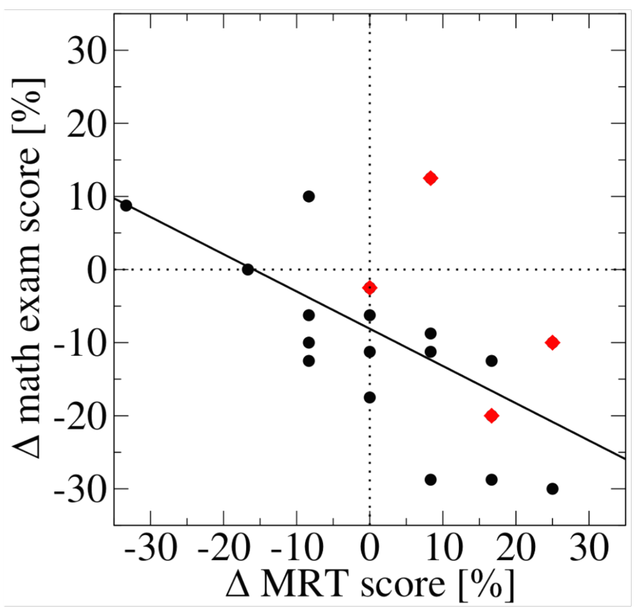

Figure 3. Change in mathematical exam score versus change in MRT score. Black circles indicate male students' scores, and red diamonds represent female students' scores. We calculated change in mathematical exam score by subtracting the average of exam 1 and 2 from the final exam score. The change in MRT score is the student's post-intervention

score minus their pre-intervention MRT score. The best fit line has a correlation coefficient of −0.61.

We improved MRT scores of our lowest scoring students for our first two incoming classes of engineering majors over six-class period timeframe. Of the four female students, two fell in our low-scoring range of less than 10 out of 12 correct answers on the pre-intervention MRT. Four out of 16 male students scored less than 10 points on the pre-intervention MRT. Students expressed in class that they enjoyed the activities involving building bricks. In the future, the tracing-on-plexiglass activity could be improved by either by providing finer tipped dry-erase markers or by using larger objects with at least some straight edges in lieu of pipefittings. Our new engineering program has a small number of students, which limits the size of our sample. We plan to continue gathering data for future classes to accumulate a large enough sample to produce valid and reliable results.

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