Implementing Training for Spatial Visualization Skills: 
Research and Best Practices for Engaging Future Engineers

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Introduction

Spatial visualization skills, the ability to visualize and manipulate objects and situations in one’s mind, is a cognitive skill that influences persistence in engineering and technology, course selection, and success in engineering and technology professions. Decades of research demonstrate that strong spatial visualization skills are linked to success in engineering and technology.

A gender disparity exists such that men have stronger skills to mentally rotate 3-D objects. A number of environmental factors play a role in building spatial skills, including childhood play and educational experience, and even the environment for assessing spatial skills. Poor performance on tasks that require spatial visualization skills can negatively influence perceptions of self-efficacy, with a disproportionate effect on women and members of lower socioeconomic groups.

For more than two decades, Sheryl Sorby, Ph.D., has been conducting research aimed at identifying practical methods for improving 3-D rotation skills, which she and others have illustrated, through extensive research, can be learned and improved with practice. This body of research provides strong support for engineering schools to assess students’ spatial skills and provide remediation and training for students with weak spatial skills. This action is further bolstered by the relatively low-time and low-cost interventions required for delivering training. Sorby’s tested curriculum, Developing Spatial Thinking, is an evidence-based, successful intervention for improving spatial visualization skills and closing the performance gap in just 10-14 hours.

Numerous institutions have delivered spatial visualization skills training courses using Sorby’s curriculum, from which successes, challenges, and best practices for implementation have emerged.

Research at Four-Year Institutions

Sorby and Baartmans conducted a six-year longitudinal study funded by the National Science Foundation on a newly developed pre-graphics training course for freshman engineering majors who were weak in 3-D spatial visualization skills at Michigan Technological University. Freshman students were given the Purdue Spatial Visualization Test: Rotations (PSVT:R) to assess the strength of their spatial visualization skills during orientation. Students who received a score below 60 percent (18 or fewer questions) were considered to have weak spatial skills. An
The experimental group of students who did not pass the test was identified to participate in the training course. A control group of students was also identified and was not enrolled in the training course. Following the training course, the PSVT:R was administered again to the students in the experimental group. The course, which was first offered in Fall 1993, was delivered each fall quarter to first year students as a “pre-graphics” course. Students enrolled in the course made statistically significant gains on the average PSVT:R scores. On average, students enrolled in the training course also went on to outperform those in the control group in subsequent graphics courses. These students also had higher rates of persistence, were more likely to pursue an engineering degree, and had higher GPAs than the control group.

ENGAGE (EngageEngineering.org), a National Science Foundation funded project, later engaged additional four-year institutions in delivering spatial visualization skills training courses based on the Developing Spatial Thinking curriculum. The project had a goal of increasing the capacity of engineering schools to retain undergraduate students by facilitating the implementation of three research-based strategies, one of which is to improve students’ spatial skills. Over 41 schools participated in implementing spatial visualization skills testing and training. A variety of implementation practices were used, which enabled ENGAGE to identify both challenges for implementation, and also best practices for a successful course.

Research at Two-Year Institutions

More recently, the focus of the ENGAGE project has been expanded to two-year colleges through an NSF-funded ATE project entitled, “Spatial Skills Instruction Impacts Technology Students.” Adoption of spatial visualization skills training has not been as widespread at the community college level as it has been at the four-year level, yet the need to focus on technical education is supported by a variety of research findings that suggest the critical need for spatial skills in technical education and career success. This project currently includes four community college partners who have administered the PSVT:R test to students in selected technician and certificate courses. Students who do not pass the PSVT:R are encouraged, but not required, to enroll in a spatial visualization skills training course. Sixty-one percent of all students tested were eligible to enroll in the course. While only 10 percent of eligible students completed the training course, those students who did complete the spatial skills course earned higher grades in their technical education courses than students who did not take the training course.

Training Course Curriculum

The Developing Spatial Thinking curriculum consists of 10, 1-1/2 hour modules. These modules include, (1) Surfaces and Solids of Revolution, (2) Combining Solids, (3) Isometric Sketching, (4) Orthographic Projection, (5) Orthographic Projection of Inclined and Curved Surfaces, (6) Flat Patterns, (7) Rotation of Objects about 1 Axis, (8) Rotation of Objects about 2 or More Axes, (9) Object Reflections and Symmetry, and (10) Cutting Planes and Cross Sections. These modules include a mixture of mini-lectures, sketching exercises, and computer exercises.
Taking Action: Implementing Training for Spatial Visualization Skills

Based on decades of experience at Michigan Tech and the schools who have implemented spatial visualization skills training through ENGAGE, the following steps and considerations when implementing a training course are recommended:

1. Assess student’s spatial visualization skills and deliver a spatial visualization skills assessment to students.
   - The Purdue Spatial Visualization Test: Rotations, or PSVT:R, has been widely used to test spatial visualization skills for over 30 years.
   - It is a 30 question multiple-choice timed test (20 minutes).
   - The test can be delivered to students as a paper and pencil test, as a quiz deployed through a school's Learning Management System (e.g. Moodle, Blackboard, Canvas), or through a survey tool (e.g. SurveyMonkey, Qualtrics).
   - Students can take the test during on-campus orientation and/or remotely—at their convenience—during a time frame that you specify (e.g. the summer before Fall semester begins).

2. Determine which students need training.
   - Review the PSVT:R spatial test scores for your incoming students. Determine a threshold score below which tested students would most benefit from training. Typically, schools use a test score somewhere between 60%-70% (out of 100%) as the threshold.

3. Offer a training course to your students.
   - The course takes about 15 hours to complete and consists of 10 modules taught in 1.5-hour lab sessions each week.
   - Instructors offer a 10-15 minute mini-lecture at the beginning of each lab session. Students work through each software module, often in teams of two, and complete sketching exercises in the workbook pages for the remainder of class time.
   - Some schools have offered spatial visualization skills modules as part of existing courses, while others have offered a bridge course with a subset of modules. Schedule the spatial visualization skills training so students have time to do the homework and absorb what they learn from each module. Don't try to cram it all into a one-or-two-week session. Materials work best in a supervised lab setting where students have time to practice and a person to whom they can ask questions about the material.

4. Teach the spatial visualization skills training course.
   - Institutions have trained faculty, graduate students, and even undergraduates to teach a spatial visualization skills training course. Instructors get access to presentation materials for each module and workbook answer keys. Instructors must have the ability to demonstrate each concept and guide students through the steps they must learn to solve spatial problems.
5. Engage students and structure a spatial visualization skills training course. SVS training should be offered in one of the following formats:
   - Require a course for students who fall below 60% on the PSVT:R. Offer the course as a graded for-credit course to increase the likelihood that students will attend. Involve academic advisers in supporting each student's efforts to enroll in the SVS training course.
   - Automatically enroll students who fall below 60% into a voluntary, graded for-credit SVS course in their first semester. Read about the experiences of Virginia Tech and CU Boulder.
   - Require supplemental instruction sessions for students with weak skills; give a grade and/or record attendance. This approach is similar to requiring tutoring sessions for students with weak math skills. Voluntary supplemental instruction sessions are not effective in improving student performance.
   - Provide SVS training as part of a summer bridge program.
   - Integrate SVS training into a required course. Use this approach only if the majority of your students have weak SVS. Do not use this approach if only a small percentage of students require this training. Consider offering required supplemental SVS instruction sessions or small group tutoring sessions.

6. Evaluate students’ spatial visualization skills following the training course.
   - Capture metrics for students enrolling in and completing the SVS training course. Elicit feedback from students during and after the training to help improve your future training programs. Make sure to implement a post-training test following the course to measure improvements in SVS. Comparing students' pre- and post-training SVS will help you see how effective your training is. Finally, integrate spatial testing and training metrics with student retention and GPA metrics. Measure and monitor the retention and GPA of students with and without spatial training.

Challenges

Schools that have implemented spatial visualization skills training, who tried the following methods, encountered a number of challenges:

- Voluntary credit course
- Voluntary credit course with students preregistered
- Voluntary noncredit course
- Mix of voluntary and mandatory credit courses
- Mandatory noncredit course
- Mandatory credit course
- Training included as part of a required course

Schools that require the spatial skills course for students recommended for training (for credit or no credit) or integrate the modules into a required course such as engineering graphics, see significant participation from students. Voluntary, noncredit courses are least effective in recruiting students to participate in the spatial skills training.
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References


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