



## Information Sheet Spatial Skills: A Focus on Gender and Engineering



By

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### **Introduction**

Strong spatial-visualization skills, particularly the ability to visualize in three dimensions, are cognitive skills that are linked to success in science, technology, engineering, and management (STEM) fields. Well-developed math and verbal skills are recognized as necessary for success in STEM and the National Science Board (2010) maintains that spatial skills should be added to this list. Unfortunately, significant gender disparities exist on spatial-skills test performance and are most evident in mental rotation, an important skill in engineering.

Poor performance on spatial-visualization tasks can directly affect perceptions of self-efficacy, especially in women and individuals from lower socioeconomic groups (Hsi, Linn, & Bell, 1997; Rafi & Samsudin, 2007; Sorby, 2009; Towle et al., 2005). Students who have the opportunity to improve their spatial-visualization skills demonstrate greater self-efficacy and are more likely to persist in engineering (Hsi et al., 1997). Research has demonstrated that training is an effective way to improve spatial-visualization skills, and gender differences are eliminated as a result of interventions using both technology and manual strategies (Hand, Uttal, Marulis, & Newcombe, 2008; Hsi et al., 1997; Newcombe, 2006; Onyancha, Derov, & Kinsey, 2009; Sorby, 2009; Sorby & Baartmans 2000; Terlecki, Newcombe, & Little, 2008).

The literature overview covers the following topics:

- Definition of spatial skills
- Gender differences
- Spatial-skill ability and success in engineering
- Methods for assessing spatial skills
- Enhancing spatial-skills development: Recommendations for engineering schools
- Enhancing spatial-skills development: Recommendations for practitioners

### **Definition of Spatial Skills**

Sorby (1999) discusses the difference between “spatial abilities” and “spatial skills.” Although the terms are often used interchangeably, *abilities* refers to innate characteristics, implying that someone is born with the ability or inability and cannot learn it, while *skills* connotes learned characteristics, implying that the skill can be improved with practice. Since extensive research supports the latter, the term “skills” will be used throughout this document.

To assess and research spatial-skills proficiency, a number of researchers have collapsed the core spatial skills into two classifications, which Martín-Dorta, Saorin, and Contero (2008) define as “spatial

visualization” (the ability to imagine rotations of objects or their parts in three-dimensional space by folding and unfolding) and “spatial relations” (the ability to imagine rotations of 2-D and 3-D objects as a whole body, which includes mental rotation and spatial perception).

### **Gender Differences**

Linn and Peterson’s meta-analysis (1985) of studies conducted between 1974 and 1982 determined that men perform better than women on tests of spatial perception and mental rotation, and men and women perform equally well on spatial-visualization tests. Masters and Sanders (1993) confirmed the strong difference by gender on performance of mental rotation. The ability to mentally rotate 3-D objects is especially important in engineering, and this skill has the greatest gender disparity in spatial-skills performance, favoring males (Sorby, 2009).

Environmental influences affect spatial skills ability. Research shows that manipulation of environmental factors, such as childhood play and educational experience, can increase scores for both genders and reduce the score gap between genders. Vasta, Knott, and Gaze (1996, p. 550) postulate, “If the gender differences on the spatial tasks can be substantially reduced or eliminated through programmed experiences such as training, it becomes theoretically more likely that the performance differences derive primarily from socialization and, even more so, that they do not reflect fundamental differences in competencies between males and females.”

Test scores may also be improved, and gender differences reduced, through manipulating the testing environment. Sharps, Welton and Price (1993) and later Sharps, Price and Williams (1994) identified the importance of instructions for testing outcomes. In their experiments, when subjects were told simply to solve the problems on the test, as opposed to using their various spatial-skills abilities to solve problems that required rotating objects, no sex differences in performing mental image rotation tasks appeared. These studies indicate the presence of stereotype threat. According to stereotype threat theory, a person’s performance on a task may be compromised if there is the potential to confirm a negative stereotype about the group with whom she or he identifies (for example, women have low ability in spatial skills; Steele & Aronson, 1995).

Although the performance gap on mental rotation tests, particularly with respect to 3-D objects, persists (Contero, Naya, Company, & Saorín, 2006; Immekus & Maller, 2010; Sutton, Williams, & McBride, 2009), evidence shows that the gender gap in performance on spatial-visualization tests is closing, especially after training. Using longitudinal data from Michigan Tech (1996 to 2009), where all first-year engineering students have taken the Purdue Spatial Visualization Test: Rotations (PSVT:R; Guay, 1977) since 2000, Sorby and Veurink (2010) found that the average test score is increasing for young women and their failure rate is decreasing. While these results are encouraging, there are statistically significant gender differences, favoring males, on the following PSVT:R data: the percentage of students who receive perfect scores, failure rates, and average test scores.

### **Spatial-Skill Ability and Success in Engineering**

Visual-spatial skills are considered necessary and vital for success in engineering and other STEM courses (Hsi et al., 1997; Miller & Bertoline, 1991; Sorby & Baartmans, 2000). Studies also indicate that the addition of spatial skills to traditional predictors for success in engineering—most notably, math and verbal skills—

leads to more robust results in identifying students who are more likely to succeed in undergraduate engineering studies, and who would benefit from remedial activities. Humphreys, Lubinski, and Yao (1993) reported success in predicting membership in various educational and occupational groups by considering spatial-math and verbal-math abilities in their longitudinal study of 400,000 high school students. Webb, Lubinski, and Benbow (2007) found that considering spatial abilities along with SAT math scores in talent searches resulted in an enlarged pool of students with the potential for succeeding in math and science studies.

### ***Methods for Assessing Spatial Skills***

Practitioners need to be able to assess spatial skill levels using appropriate instruments and identify and implement appropriate interventions to effectively encourage the development and enhancement of spatial skills. Voyer, Voyer, and Bryden (1995) discuss the efficacy of various assessment methods.

From a practical standpoint, the following questions should be considered when evaluating the type of test to use:

- Has the test been validated for a sufficiently long enough time?
- Is the test at the right level for my target audience?
- Is the content general enough for my target audience or too restrictive?
- Can more than one topic or theme be tested?
- Can the data be analyzed easily?
- Is cost and availability reasonable?

### ***Enhancing Spatial-Skills Development: Recommendations for Engineering Schools***

Research shows (Contero et al., 2006; Ferguson et al., 2008; Hsi et al., 1997; Martín-Dorta et al., 2008; Onyancha, Derov, et al., 2009; Onyancha, Towle, & Kinsey, 2007) that spatial skills can be improved through training, including research in the area of mental rotation (Sorby & Baartmans 2000; Sorby, Drummer, Hungwe, Parolini, & Molzan, 2006), the skill for which the largest gender gap in performance exists. These studies serve as a reminder that effective interventions can also be low-cost and accessible, an important point for educators operating in resource-challenged environments.

The preponderance of evidence asserting the connection between spatial-skills development and success in engineering provides strong support for engineering schools to assess students' spatial skills and remediate accordingly. Recent research results provide faculty and other practitioners with strong evidence to counter arguments of overcrowded curricula and limited resources.

### ***Enhancing Spatial-Skills Development: Recommendations for Practitioners***

Identifying factors that affect the development and exercise of spatial skills has traditionally focused on gender differences in performance. Recent research efforts, however, indicate that other characteristics, such as working-memory capacity and socioeconomic status may be involved (Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005). Activities that have been found to improve spatial skills include the following:

- Playing video games (Feng, Spence, & Pratt, 2007; Sorby & Veurink, 2010)
- Having musical experiences (Robichaux, 2002)
- Creating artwork (Caldera et al., 1999)
- Playing with certain toys, such as Legos, Lincoln Logs, and Erector Sets (Sorby & Baartmans, 2000)

Precollege participation in the following activities relying on hand-eye coordination tends to be high among postsecondary students with good to excellent spatial skills. Men are more likely than women to participate in these activities:

- Certain sports, such as basketball (Lord & Garrison, 1998)
- Technical education/industrial arts classes (Sorby, 1999, 2007)

Hill, Corbett and St. Rose (2010) recommend that parents, teachers, and volunteers of professional organizations do the following:

- Explain to all young people that spatial skills are not innate but developed.
- Encourage all children and students to play with construction toys, take things apart and put them back together again, play games that involve fitting objects into different places, draw, and work with their hands.
- Use handheld models when possible (rather than computer models) to help students visualize what they see on paper in front of them.

Operating under the premise that spatial skills are malleable, and, therefore, affected by education or life experience, Hand et al. (2008) conducted a systematic meta-analysis. They included 200 studies and found that spatial skills respond very well to training and endure over time in both children and adults, although starting before age 13 has an even greater impact.

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