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Overview: Visual Spatial Skills

Visual spatial skills are essential for success in engineering. Education, experience, and testing environments have been shown to improve visual spatial skills and have improved retention of engineering students. Although some may speculate that women's supposed inability to perform visual spatial tasks is responsible for their disproportionate representation in engineering, actual gender differences on spatial ability tests are small and appear only on certain tests. Consider the following:

- In general, males perform better on tests of spatial perception and mental rotation, and men and women perform equally well on spatial visualization tests. (Linn and Peterson, 1985)
- Evidence is inconsistent regarding the connection between visual-spatial test scores and engineering course grades. (Peters et al. 1994; Sorby and Baartman, 2000; Hisi, Linn and Bell, 1997)
- Emphasis on the tested abilities as useful for male-stereotyped occupations produces a large gender gap in scores. If the abilities are instead described in relation to female-stereotyped occupations, the gender gap is reduced to a small and insignificant difference. (Sharps, Price, & Williams, 1994)
- Educational programs improve women's test scores in greater proportion than for their male peers. (Baartmans & Sorby, 1996)

Considering that gender differences in scores are small when they exist, are related to stereotype-threat, can be improved with education, and are inconsistently related to actual engineering performance, it is unlikely that women have a deficit in visual spatial skills in proportion to their underrepresentation in engineering. It is clear, however, that providing opportunities for all students to learn and practice their visual spatial skills in an encouraging environment leads to greater educational success.

<u>Visual Spatial Skills Sections</u>

Visual Spatial Skills

Gender differences on spatial ability tests are small and appear only on certain tests, despite the pervasive stereotype that women possess poor visual spatial abilities. Visual spatial skills are essential for success in engineering, although the extent to which scores on visual spatial tests predict success in engineering is inconsistent in the research. However, education, experience and testing environments have been shown to improve and, in some cases, to eliminate the gender gap in visual spatial skills, as well as to improve retention of engineering students. While intervention strategies aiming to improve visual spatial skills have been shown to benefit both women and men, such strategies are typically not emphasized by women in engineering programs because of the small return on investment exclusively for women.

Visual Spatial Skills: Definitions

Although spatial skills have been a significant area of research since the 1920's, there is no real consensus on the definition of "spatial visualization skills" (Sorby, Leopold, & Gorska, 1999). Spatial ability may not be a unitary construct, but rather a collection of specific skills (Voyer, Voyer, & Bryden, 1995). Researchers and theorists in the areas of cognitive psychology, art, science, math, and engineering education have used varying combinations of the words "visual" and "spatial" with "cognition", "ability", "skill", "orientation", "perception", "reasoning", "relations", "rotations", and "imagery", among others, in their attempts to more precisely classify and label this set of mental abilities (Miller & Bertoline, 1991). Through meta-analysis of factor analytic, correlational and process-oriented studies between 1974 and 1982, Linn and Peterson (1985) have derived the following definitions:

> **Spatial ability** is the over-arching concept that generally refers to skill in representing, transforming, generating, and recalling symbolic, nonlinguistic information. Spatial ability consists of mental rotation, spatial perception, and spatial visualization.
>
> **Mental rotation** involves the ability to rapidly and accurately rotate a two- or three-dimensional figure. Tests for mental rotation include the Shepard-Metzler Mental Rotation Test, Flags and Cards, Primary Mental Abilities space, Hidden Patterns, Paper Form Board, Progressive Matrices, and the Vandenberg test.
>
> **Spatial perception** is a person's ability to determine spatial relationships with respect to the orientation of his or her own body, in spite of distracting information. Tests for this ability include the Rod and Frame Test (RFT) and the water level task.
>
> **Spatial visualization** involves complicated, multi-step manipulations of spatially presented information. These tasks require analysis of the relationship between different spatial representations, rather than a matching of those representations. Mental rotation and spatial perception may or may not be elements of the analytic strategy required to complete the task. Tests in this category include EFT, Hidden Figures and Paper Folding, Paper Form Board, Surface Development, Differential Aptitude Test (spatial relations subtest), Block Design, and Guilford-Zimmerman spatial visualization.

In addition, (Law, Pellegrino, & Hunt, 1993) explore another set of spatial abilities, "dynamic spatial reasoning tasks." These tasks involve relative velocity and distance judgment tasks. In their work, gender differences were found for relative velocity but not distance judgments. The differences were partially related to prior experience, and both men and women improved their performance with practice and feedback.

Although unanimous agreement does not exist for the categories and definitions provided by Linn and Peterson (see for example, Voyer et al., 1995), these will be used for the purpose of this discussion of the relationship between visual spatial skills and women in engineering. For further reading on specific spatial skills and gender, refer to (Newcombe, Mathason, & Terlecki, 2002), (Kimura, 1999), and (Halpern, 2000).

Gender and Visual Spatial Skills

Linn and Peterson's (1985) meta-analysis of studies conducted between 1974 and 1982 determined that males perform better on tests of spatial perception and mental rotation, and men and women perform equally well on spatial visualization tests. The difference in performance was large only for mental rotation. Masters and Sanders (1993) confirmed the strong difference by gender on performance of mental rotation. Using meta-analytic techniques, they found that males performed significantly higher in all 14 studies that administered the Mental Rotations test to adolescents and young adults between 1975 and 1992. Voyer et.al., (1995) in an analysis of over 50 years of research, again found sex differences in favor of males in tests that assess mental rotation and spatial perception skills. Though these researchers did not find differences present in young children, differences emerged by age seven. This is consistent with findings from Caldera et al. (1999), who found no sex differences when they tested fifty-one preschoolers' visual-spatial skills. Since spatial aptitude scores frequently do not fall along the normal curve, it may be possible that women in general are not slower on certain tests, but that a yet uninvestigated subgroup of women accounts for the overall differences (Favreau & Everett, 1996). Similar gender differences on spatial ability tests are also found outside the United States, but may be based on certain similarities among the cultures (see, for example, Bergvall, Sorby, & Worthen, 1994; Delgado & Prieto, 504; Peters, Chisholm, & Laeng, 1994).

Various researchers have suggested that gender differences in spatial ability may be transmitted as a recessive characteristic on the X chromosome, that these differences are related to a male sex hormone, or that they are the result of environmental factors (Bergvall et al., 1994). In 1986, these hypotheses were not supported (Linn & Peterson), nor has the present literature overview found support for them. However, empirical support can be found for environmental influences on spatial ability. This is a much more optimistic possibility since research also 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 postulate that "if the gender differences on the spatial tasks can be substantially reduced or eliminated through programmed experiences (i.e., 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" (1996, p. 550). Baenninger & Newcombe's (1989) meta-analysis found spatial activity participation to be related to spatial ability for both sexes, supporting Vasta et. al. Activities that have been found to improve spatial ability include musical experience (Robichaux, 2002), creating artwork (Caldera et al., 1999), play with certain toys, such as such as Legos, Lincoln Logs, and Erector Sets (Sorby & Baartmans, 2000), previous geometry instruction, vocational training, work experience, and participation in certain sports (Sorby et al., 1999).

Research results on spatially related activities are not entirely consistent. For example, Deno (1995) created the Spatial Experience Inventory (SEI) to collect information for 480 spatial activities in three categories (formal academic subjects, nonacademic activities, and sports) spanning elementary through postsecondary education. When the sum of all 480 activities were taken into account without considering gender, the relationship between mental rotations scores and visual spatial activities was significant. When the 480 activities were broken down, the only activities that were found to be significantly related to mental rotations skills for women were: watching "Sesame Street" and other educational TV, manufacturing coursework, building train sets, navigating a car, and playing video games.

The strongest evidence for improving spatial skills comes from research on practice, training, and education (Bergvall et al., 1994; Sorby et al., 1999; Baenninger & Newcombe, 1989). In their results from a six-year longitudinal assessment of a course to help engineering students overcome deficiencies in 3-D spatial visualization, Sorby and Baartmans (2000) show that participating students scored better on several tests of spatial ability. Retention rates were improved for both male and female students, but more so for women. Factors that make educational efforts effective include administering at least three or four sessions referring directly to a single spatial measure (Baenninger & Newcombe, 1989), allowing for practice and providing feedback (Law et al., 1993), or simply allowing for self-discovery (Vasta et al., 1996). The underlying reason for success in these educational approaches may be that they increase the number of strategies from which students may both choose and implement efficient, effective problem-solving processes. This increase may be especially beneficial to women whose life experiences have not provided them with as many strategies for solving the test questions as their male counterparts (Linn & Peterson, 1985).

Scores may also be improved 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, they found that highly spatial instructions decreased scores for women, but not for men. When the spatial characteristics of the tests were minimized in the instructions, no significant differences were found between men and women on spatial memory or mental image rotation. Furthermore, emphasis on the tested abilities as useful for male-stereotyped occupations produced a large gender gap in scores. If the abilities were instead described in relation to female-stereotyped occupations, the gender gap was reduced to a small and insignificant difference. Evidence that women rate their mechanical and visualization abilities lower than male students (Jagacinski & LeBold, 1981) suggests that these results could be related to self-efficacy.

Interested readers may refer to the following recent literature for a more nuanced explanation of visual spatial skills and gender differences:

- Newcombe, N. S., Mathason, L., & Terlecki, M. (2002). Maximization of spatial competence: more important than finding the cause of sex differences. In A. McGillicuddy-De Lisi & R. De Lisi (Eds.), *Biology, Society, and Behavior: The Development of Sex Differences in Cognition*. Westport, Connecticut: Ablex.
- Kimura, D. (1999). *Sex and Cognition*. Cambridge, MA: The MIT Press.
- Halpern, D. F. (2000). *Sex Differences in Cognitive Abilities* (3rd ed.). Mahway, NJ: Lawrence Erlbaum Associates.

Visual Spatial Skills, Gender, and Engineering

Visual spatial skills are considered necessary and vital for success in engineering courses and technical professions (Hsi, Linn, & Bell, 1997; Miller & Bertoline, 1991; Sorby & Baartmans, 2000). Peters et al. (1994) found in one sample that engineering students performed better on the Mental Rotations Test than students pursuing Bachelor of Arts degrees, and that male engineering students also outperformed female engineering students In Peters et al.'s study, the difference in scores did not translate into better course grades. Other studies, such as those by Sorby and Baartman (2000) and Hisi, Linn and Bell (1997), do show a connection between grades and visual spatial scores. In their six-year longitudinal study of spatial visualization education, Sorby and Baartmans (2000) found that the single most significant predictor of success in the first year graphics course at Michigan Technological University (MTU) was the Purdue Spatial Visualization Test: Rotations (PSVT:R) – a test which consistently produced gender differences in their samples. The two other significant factors they found were the math ACT subtest score and a combination of prior experiences in shop, drafting, and solid geometry (experiences more males than females had). Success in the graphics course was crucial for engineering students at MTU. Eighty percent of those who struggled with their engineering graphics courses did not persist in engineering.

Gender differences in visual spatial skills may also affect the way that women engineering students perceive themselves. It is possible that score differences are accepted (by female students and those around them) as an unchangeable phenomenon of natural ability, a phenomenon permanently disabling female students and providing evidence that women just do not belong in engineering classrooms. Such interpretations may result in a downward spiral of lost self-confidence, lowered test scores, and a decrease in sense of belonging for female students. Support for this possibility is found in women's reduced test scores when visual spatial skills are introduced as abilities in which men excel but women do not (Sharps et al., 1994), (Jagacinski & LeBold, 1981). Although research addressing women's perceptions of their own visual spatial self-efficacy and subsequent feelings of belonging in the engineering program has not been conducted, personal accounts reveal this may be a factor in engineering persistence (Sorby, 2001; Deno, 1995).

Examples of Successful Interventions

Since visual spatial skills are important for all engineering students but do not account for the large degree of underrepresentation of women in engineering, there are only a limited number of examples to draw upon. Of those for which published material is available, the following two are prominent and have proved successful. One example of an intervention that benefits male and female students (but in which females find disproportionate benefits, reducing the gender gap in scores) can be found at Michigan Technological University, where Baartmans and Sorby designed a successful course to improve spatial abilities of engineering students (Sorby & Baartmans, 2000). This three-credit course consists or 2 hours of lecture and 2 hours of computer lab per week during a quarter term. Details about the class and resources used can be found in the author's publications about the project and in their book, *Introduction to 3-D Spatial Visualization* (Baartmans & Sorby, 1996).

Another example is found in Hsi, Linn and Bell's (1997) three-hour workshop. Based on the "Scaffolded Knowledge Integration" framework, their spatial strategy instruction includes teaching a repertoire of spatial strategies, making the process of distinguishing strategies and thinking about spatial problems visible, encouraging students to monitor their own progress and recognize their spatial reasoning strengths and weaknesses as independent learners, and taking advantage of social support for learning. Provided during the semester for low scoring students in their introductory engineering graphics course at the University of California at Berkeley, the workshop effectively eliminated previously established gender differences in spatial reasoning task scores. More details about this intervention are provided in their article (Hsi et al., 1997).

Assessing Spatial Abilities

A considerable amount of research has been devoted to assessing visual spatial abilities. Most journal articles provide extensive information on the types of tests used and on books, such as *A Handbook Of Spatial Research Paradigms And Methodologies, Vol. 2: Clinical And Comparative Studies* (Foreman & Gillett, 1998) are available. An online search of ETS' test collection at www.ets.org using the keywords "spatial ability" and/or "visualization" will also provide assessment instruments. The Buros Institute's *Mental Measures Yearbook* (Buros, 1938) provides test reviews to assist in choosing an instrument. As various tests measure different components of visual special skills and women perform differently on these different components, it is critical to choose an instrument in line with the component under study. The following list developed by Voyer et al. (1995, p. 257) provides information on tests and their results by gender.

- Cards Rotation Test (significant) (Ekstrom, French, & Harman, 1976)
- Generic mental rotation tasks (significant) (Shepard & Metzler, 1971)
- Spatial Relations subtest of the Primary Mental Abilities (significant) (Thurston, 1958)
- Paper Form Board (significant) (Likert & Quasha, 1941)
- Spatial Relation subtest of the DAT (homogeneous but not significant) (Bennett, Seashore, & Wesman, 1947)
- Paper Folding (homogeneous but not significant) (Ekstrom et al., 1976)
- Rod-and-frame test (significant for some but not other age groups) (Witkin & Asch, 1948)
- Block Design subtest of the Wechsler Adult Intelligence Scale, the Weschler Adult Intelligence Scale-Revised, and the Weschler Intelligence Scale for Children (significant for some but not other age groups) (Weschler, 1946, 1949, 1955, 1974)
- Mental Rotations Test (scoring and testing influences magnitude of differences) (Vandenberg, Kuse, & Vogler, 1985)
- Water Level Test (scoring and testing influences magnitude of differences) (Piaget & Inhelder, 1956)
- Identical Blocks Test (scoring and testing influences magnitude of differences) (Stafford, 1961)
- Embedded Figures Test (scoring and testing influences magnitude of differences) (Witkin, 1950)

Another tool that may be of interest to researchers is the Spatial Experience Inventory (SEI) developed by Deno (1995), which provides a list of spatial experiences that may contribute to increased skill levels and test scores.

Conclusions

To summarize, a great number of tests are available to measure visual spatial skills (Voyer et al., 1995). Some of them consistently reveal differences by gender, a difference that may be the result of low spatial skills among a selected (but as yet unknown) subset of women, rather than the entire population of women (Favreau & Everett, 1996) and/or differential exposure to various spatially related activities (Baenninger & Newcombe, 1989). Visual spatial skills are essential for engineering, but scores on visual spatial tests sometimes do not (Peters et al., 1994) and sometimes do (Sorby & Baartmans, 2000) predict success in engineering, perhaps depending on the type of skill measured. In the event that interventions have occurred to improve the visual spatial skills of engineering students, these have been successful (Hsi et al., 1997, Sorby, 2001).

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