Gender Differences in Visualization Skills - An International Perspective

*Renata Gorska**
Cracow University of Technology
Sheryl A. Sorby
Michigan Technological University
Cornelie Leopold
University of Kaiserslautern
* *On sabbatical to MTU 1997-98*

ABSTRACT

Three-dimensional visualization skills are critically important for success in engineering careers. A variety of strategies have been implemented to enhance the spatial visualization skills of engineering students. Along with these strategies, standardized tests such as the MCT (Mental Cutting Test), the MRT (Mental Rotations Test) and the PSVT:R (Purdue Spatial Visualization Test: Rotations) have been utilized as a means for measuring spatial ability. This paper examines the factors which seem to be significant in the development of visualization skills and also examines gender differences in background and in visualization ability for students enrolled in U.S., German and Polish technical universities. Thus, gender differences in visualization skills which cross international boundaries can be studied.

Introduction

From previous research conducted by Smith (1964) and Maier (1994), it was found that the ability to visualize 3-D objects and to think in three dimensions is an essential skill for those in technical professions. Five components of spatial skills were considered: spatial perception, spatial visualization, mental rotations, spatial relations, and spatial orientation.

For engineering, and especially for engineering graphics, it is important that a person's spatial abilities be well developed. However, since many of the objects described by engineering drawings are unfamiliar to entering freshmen, it is likely that there will be a portion of engineering graphics students who have difficulty visualizing the objects portrayed in sketches or drawings. In fact, many graphics educators report that there is a significant percentage of their students who have a great deal of trouble with visualization (Kajiyama, 1990).

Assessment of Spatial Skills

Several standardized tests have been developed to assess a person's spatial skills. The Purdue Spatial Visualization Test: Rotations (PSVT:R) was developed by Guay (1976) to assess a person's ability to visualize rotated solids. In a previous study, Gimmestad (now Baartmans) (1990) found that a student's score on the PSVT:R was the most significant predictor of success in an engineering design graphics course. The test has 30 items and is scored as the percent correct. In this test, the top line of the problem shows an object and a rotated view of the object. In the second line, a different object is shown and the student is to select from five choices what this second object would look like if it

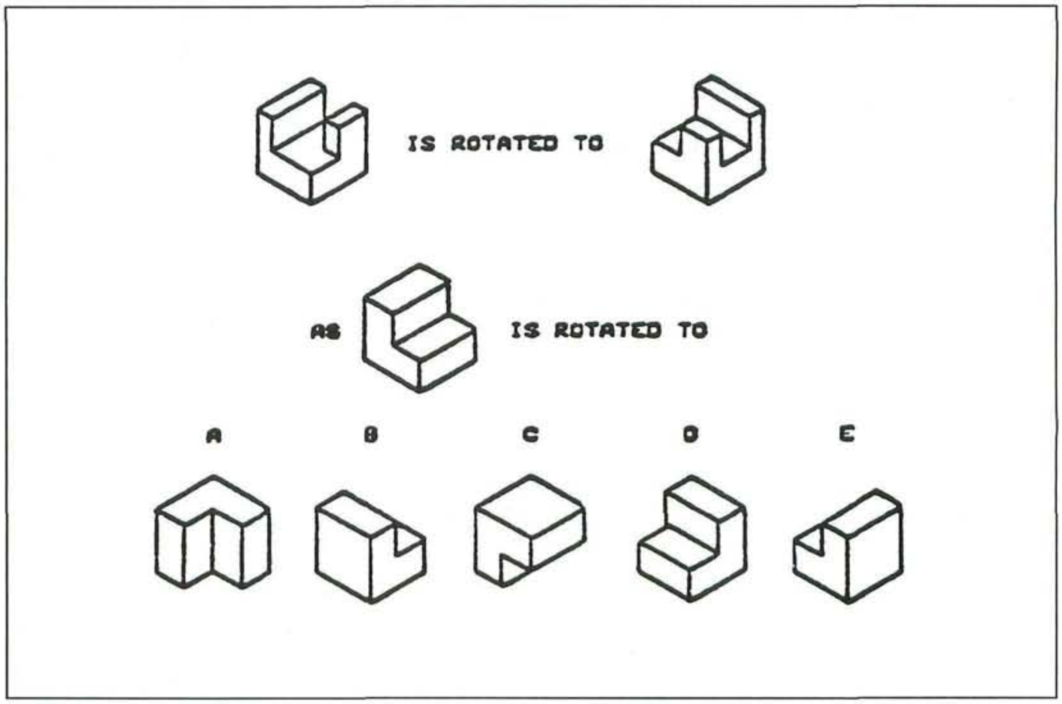


Figure 1 - *Sample problem from PSVT:R.*

were rotated by the same amount as the first object. A sample problem from the PSVT:R is shown in *Figure 1*.

The Mental Rotation Test (MRT) (Vandenberg, & Kuse, 1978) is another standardized exam used to assess a person's spatial skills. The MRT was developed by Vandenberg and Kuse and it consists of 20 items. Each problem contains a criterion figure with two correct alternatives and two incorrect alternatives. Students are asked to identify which two of the alternatives are rotated images of the criterion figure. Thus, in both the PSVT:R and the MRT the components of spatial visualization and mental rotation are tested. A sample problem from the MRT is shown in *Figure 2*.

A third test used to assess a person's spatial visualization ability is the Mental Cutting Test (MCT) (1939). The MCT was first developed for a university entrance exam in the USA and later applied as a testing method in Japan and Australia (Magin, 1994) (Suzuki et al., 1992). The test consists of 25 items. For each problem on the exam, students are shown a criterion figure which is to be cut with an assumed plane. They must then choose the correct resulting cross-

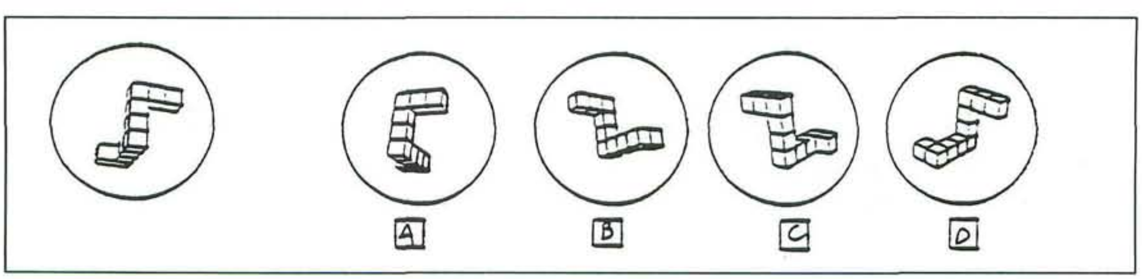


Figure 2 - *Sample problem from MRT.*

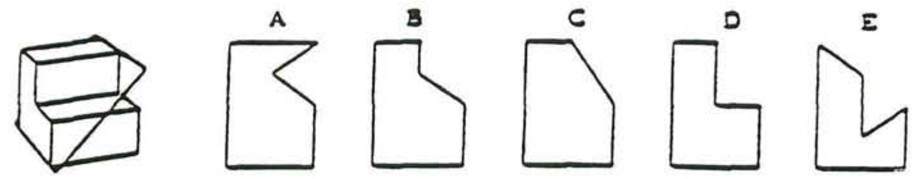


***Figure 3** - Sample problem from MCT.*

section from among five choices. With the MCT, the components of spatial visualization and spatial relations are tested. A sample problem from the MCT is shown in *Figure 3*.

Present Study

In this study, the PSVT:R was administered to 535 (418 males and 117 females) engineering freshmen at Michigan Technological University (MTU) in the USA in the Fall of 1993. The PSVT:R and the MCT were both administered to 319 (212 men and 107 women) students in the winter semester of 1994/95 and to 309 (216 men and 93 women) in the winter semester of 1995/96 at the University of Kaiserslautern (UKL) in Germany. The MRT was administered to 99 students and the MCT was administered to 88 students at the Cracow University of Technology (CUT) in Poland in the 1994/95 winter semester. Student scores on these tests were then analyzed for gender differences. Students were also post-tested to assess the impact of graphics instruction on their spatial skills as measured by these testing instruments.

Along with these tests, background questionnaires were filled out by the students. The questions asked of the students were all related to those types of activities which are thought to develop spatial skills including: age, handedness, play with certain types of toys, previous geometry instruction, vocational training, work experience and participation in certain sports. In addition, at the UKL, in the 1995/96 version of the questionnaire, students were also asked about their math scores, their motivation for selecting their study field and more detailed questions were included about their play as children with certain toys. The questionnaires administered in this study closely parallel those on the Spatial Experience Inventory administered by Deno (1995).

Student responses were assigned values according to the number of choices available on each particular question. Variables were treated qualitatively rather than quantitatively for the most part (exceptions included the age of the subject and the number of years of previous drafting experience, etc.). For example, gender was assigned a value of either "M" or "F," however, participation in previous drafting was assigned a value according to the number of years a student participated in such a course (i.e., "0" for no previous experience, "1" for one year of experience, "2" for two years experience and so on). Some variables were assigned values according to responses on a 4-point scale of Never, Rarely, Often, and Intensively. An ANOVA analysis was performed with the dependent variable being the score on the particular spatial visualization test and the factors being gender, previous experiences, etc. The responses were individually screened to determine their significance in the development of spatial skills as measured by the respective testing instruments. Means and standard deviations were computed for each of the variables. Based on the results of F tests, insignificant ($p>0.05$) factors were removed from the model one at a time until only significant factors (1% level of significance at MTU and 5% level of significance at CUT and UKL) remained. Those variables which were deemed significant were then tested for gender bias.

Results

The results of this study are summarized in the following. Although different testing instruments were used at the universities participating in this study, we believe that interesting gender-based differences can be reported and that a certain amount of correlation exists between the data collected regardless of the testing instrument chosen.

Gender Differences in Pre-Test Scores

Student test scores were analyzed to determine if there were significant gender difference in visualization skills as measured by these testing instruments. Significant gender differences ($p<0.05$) were found at each of the three universities participating in this study. *Table 1* summarizes the gender differences in student performance on these tests. At MTU, of the 79 students who received perfect scores (100%) on the PSVT:R, only 4 were female (3.4% of the female population) and 75 were male (17.9% of the male population). On the other hand, women were much more likely to fail (score of 60% or lower) the spatial visualization tests than were their male counterparts. Failure rates for the various tests are presented in *Table 2*.

	MTU(93)	UKL(95/96)		CUT(94/95)	
	PSVT:R	PSVT:R	MCT	MRT	MCT
Men	12.0%	13.5%	38.6%	64.0%	35.6%
Women	39.3%	45.0%	68.6%	100.0%	73.0%

Table 2 *- Failure rates (percentage of students who failed the exam.)*

Significant and Non-significant Factors for Spatial Skills

Several factors were analyzed to determine their statistical significance in the development of 3-D spatial skills as measured by these testing instruments. A significance level of 5% ($p<0.05$) was applied at both UKL and CUT, however, at MTU, a significance level of 1% ($p<0.01$) was used in the analysis.The p-values for each of the variables deemed significant are shown in *Table 3* (X denotes not significant, NA denotes not questioned, W denotes significant for women only, and M denotes significant for men only).

From the data presented in this table, it is clear that gender is the most significant predictor of success on all spatial visualization tests at all universities. Other significant fac-

	MTU	UKL		CUT	
	PSVT:R	PSVT:R	MCT	MRT	MCT
Men	79.6 (n=418)	79.3 (n=428)	67.4 (n=428)	51.5 (n=82)	62.1 (n=73)
Women	68.1 (n=117)	63.2 (n=200)	52.5 (n=200)	34.7 (n=17)	46.7 (n=15)

Table 1 *- Average test scores (scores in percentages).*

Background Factor	Cracow Univ. of Tech.		Kaiserslauterns Univ.*		MTU
	MRT	MCT	PSVT:R	MCT	PSVT:R
Gender	p=0.0004	p=0.0046	p<0.0001	p<0.0001	p=0.0001
Age	X	X	X	X	X
Field of Study	X	X	p=0.0003	X	X
Left-/Right-Handedness	X	X	X	X	X
Play with Const. toys	X	W	p=0.0015	p=0.0081	p=0.0042
Play with Dolls	NA	NA	X	X	NA
Play with Models	NA	NA	X	p=0.0154	NA
Video Games	X	X	p=0.0003	X	X
Geometry	X	p=0.0055	X	X	X
Math Score	NA	NA	M	p=0.0383	p=0.0002
Drafting Exp.	X	X	p=0.0175	p=0.0499	p=0.0001
Type of Educatio n	p=0.0254	X	W	p=0.0439	NA
Work Experience	X	0.0373	W	p=0.0034	X
** Data for 1995/96 only*					

Table 3 - Significance of background variables in developing spatial skills (p-value).

tors seem to be: 1) play with construction toys, 2) previous drafting experience, 3) the type of secondary education received (in Europe only), and 4) math ability or preparation. These results are similar to those reported by Deno (1995).

Gender Bias in Significant Predictors of Success

After determining those factors which were significant predictors of success on a spatial visualization test, those factors which were deemed significant were tested for gender bias using a Pearson's Chi2-test. The following summarize the findings in the area of gender bias:

- At MTU, and at UKL it was found that male students were significantly more likely to have played with constructiontoys as a young child.

- At MTU and UKL math scores were not significantly different for the men compared to the women students.

- At MTU it was found that significant gender differences existed in the variable of previous experience in design or drafting courses. In other words, men were significantly more likely to have participated in earlier design or drafting related courses.

At CUT, gender differences in previous drafting experience was not a significant factor.

- At UKL men played with video and computer games significantly more than women.

Thus, it is apparent that of the background variables tested,. women were much less likely to have participated in those activities which we believe lead to the development of spatial visualization skills and which are better starting conditions for developing spatial visualization skills.

Improving Spatial Skills

At both CUT and UKL, students were post-tested after attending a semester course in descriptive geometry. The descriptive geometry courses at these two universities are very similar. These courses focus on the fundamentals of Mongean descriptive geometry as well as several advanced topics in projective geometry. Topics such as intersections between solids, theory of surfaces, projective theory of conics, and transformations such as collination and homothety are used as the methods for solving geometric problems. Course topics also include isometric and oblique projections. In the Architecture departments at these universities, special emphasis is placed on central projection theory as well as on shadow construction. These courses are generally 3-4 semester credits with manual construction techniques utilized throughout. A dependent t-test was performed on the gain scores for both men and women on each of the spatial instruments. In each case, statistically significant gains ($p<0.005$) were determined on each test for both men and women students. The

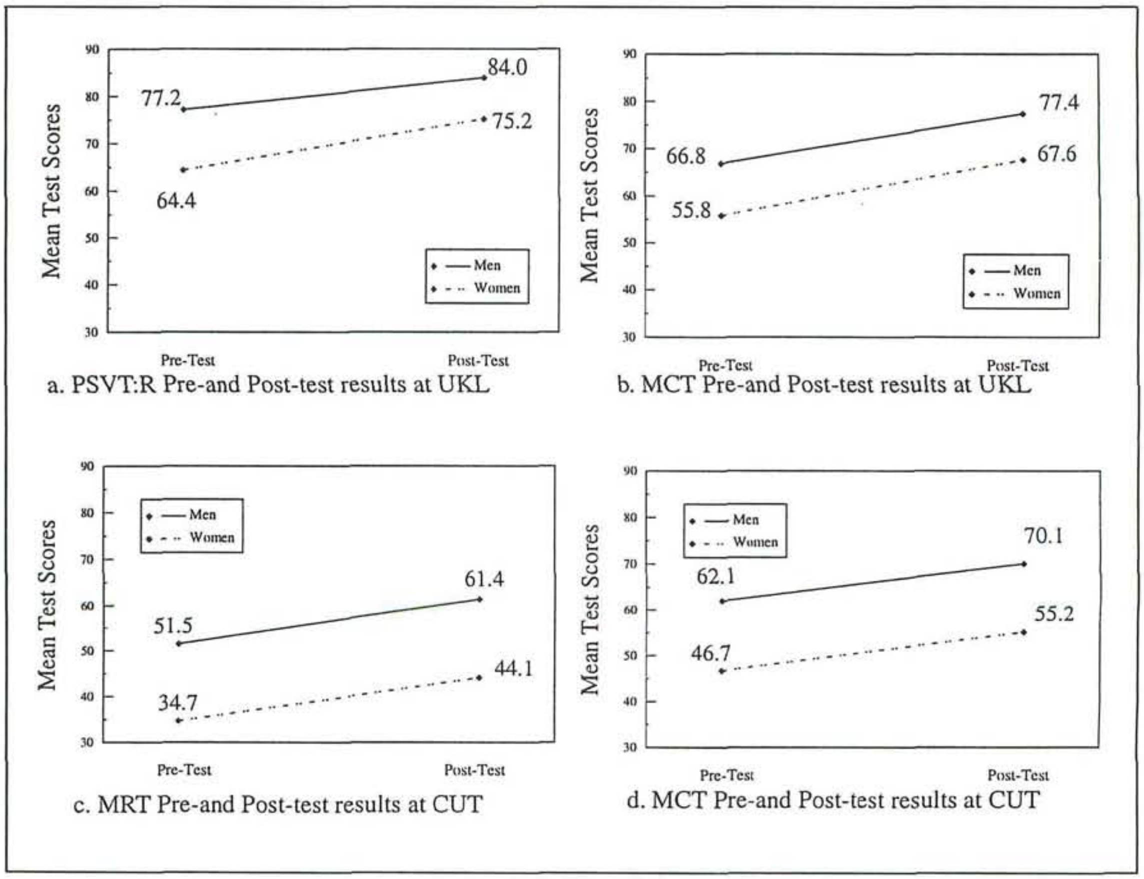


***Figure 4** - Pre- and Post-test results for CUT and UKL.*

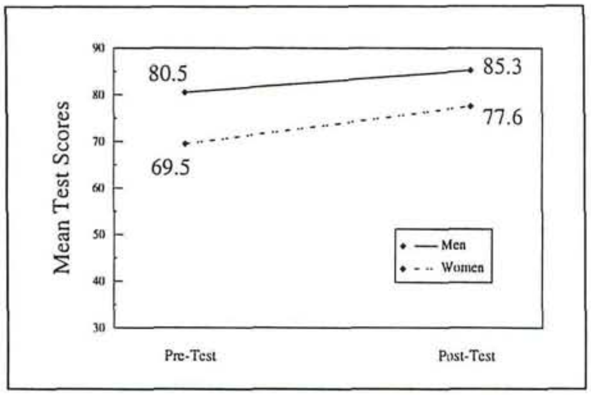
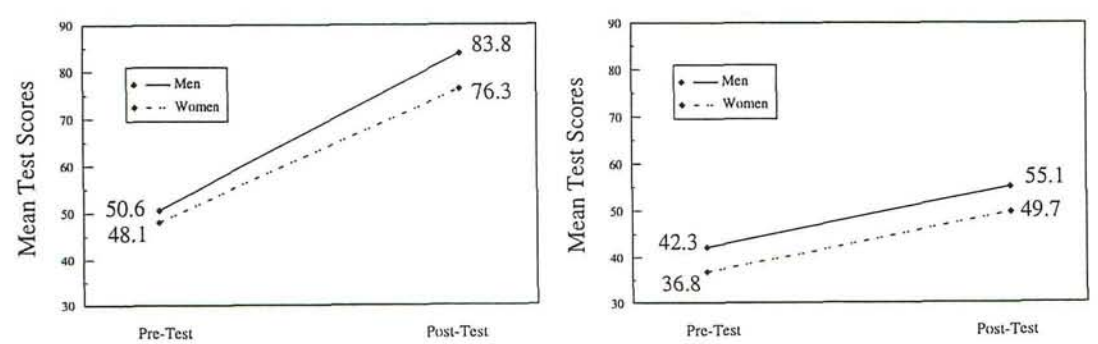


Figure 5 - PSVT:R Pre- and Post-test results at MTU.

gender differences in mean scores were analyzed using an independent t-test and found to be statistically significant ($p<0.0001$ at UKL and $p<0.005$ at CUT) for all tests at both the pre- and the post-test. The results of the pre- and post-testing are shown in *Figures 4a-d.*

Similar results were obtained at MTU in a study conducted in 1985 (Gimmestad, 1990) on the improvements of student scores on the PSVT:R after enrolling in an engineering design graphics course. In this previous study, the mean score on the pre-test for women (69.5%) was significantly lower ($p<0.001$) than for men (80.5%). Both men and women made statistically significant gains ($p<0.001$) as a result of their graphics instruction, however, the average post-test score for women (77.6%) was still significantly lower ($p<0.001$) than that for men (83.3%). Independent and dependent t-tests were also used in this analysis. Results from this previous study are shown in *Figure 5.*

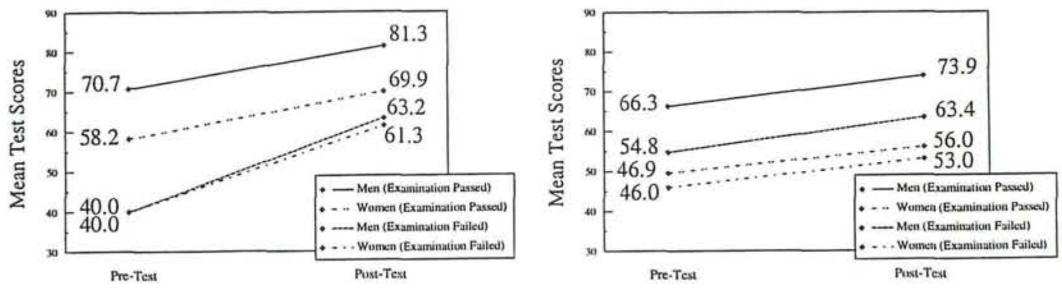
Furthermore, since 1993, MTU has had an introductory course aimed specifically at the development of spatial visualization ability in freshman engineering students. The students who enroll in this course failed (scores of 60% or lower) the PSVT:R pre-test. A dependent t-test was performed on the gain scores for both men and women on the PSVT:R and the MCT. In each case, statistically significant gains ($p<0.005$) were determined on each test for both men and women students. However, an independent t-test showed that the gender differences on spatial tests for students in this course generally were not statistically significant ($p>0.05$) at either the pre- or the post-test. The exception to this is that for the PSVT:R post-test, gender differences were statistically significant ($p<0.005$). We suspect that the reason that the gender differences were not significant on these tests was due to either a) the small sample size, or b) the fact that this sample is



a. PSVT:R Pre-and Post-test results at MTU after participation in special course

b. MCT Pre-and Post-test results at MTU after participation in special course

Figure 6 - Pre- and Post-test results at MTU.



a. MCT Pre-and Post-test results at UKL

b MCT Pre-and Post-test results at CUT

***Figure** 7 - Pre- and Post-test results at UKL and CUT.*

not truly representative of the population as a whole (i.e., students enrolled in this course because they scored lower than 60% on the PSVT:R pre-test). The results from student participation in this special course for 1996 and 1997 are presented in *Figure 6.*

At the UKL and CUT, a connection was found between pre- and post-test scores and whether or not a student passed or failed the examination in descriptive geometry. *Figure 7* shows these results for the MCT at the two universities. Similar results were obtained at both universities for the MRT and PSVT:R.

As it can be seen from *Figure 7*, the MCT pre- and post-test scores of those students who failed the descriptive geometry examination lagged behind those who passed the examination at both universities. Interestingly, for male students, the test scores show a better correlation with course performance (i.e., students' who fail the MCT also fail the final examination) than it is for women. At the UKL, it can be seen that those students who started with a lower score on the MCT had a more dramatic improvement in their test scores, but the improvement was insufficient to pass the examination.

At the UKL, the PSVT:R and MCT were administered to a control group of 12 students. These students were administered the tests as both pre- and post-tests in order to assess whether or not the gains measured in test scores reflected true gains in spatial abilities or were merely gains due to the practice effect in taking the test twice. Although this control group was very small, independent t-tests were administered to determine whether gains on the spatial tests were due to descriptive geometry instruction or were due to the practice effect. For the MCT, the students enrolled in the descriptive geometry courses had significantly higher gains ($p=0.0033$) as compared to the students in the control group. A similar conclusion was not possible for the PSVT:R. However, research by Stanley, et. al. (Stanley, 1972) suggests that the average gain due to the practice effect for tests administered approximately 3 months apart is 0.2σ or less. Average gain scores on the tests administered in this study were generally larger than this. Suzuki, et.al., and Tsutsumi and Suzuki (Suzuki et al., 1992), (Tsutsumi & Suzuki, 1991) have also conducted studies with control groups. They found that gains on the MCT are probably due to graphics instruction, whereas gains on the MRT could be due largely to the practice effect.

Conclusions

As measured by the testing instruments described in this paper, there are significant differences in the spatial visualization ability between the men and women who choose engineering or other technical careers. This is true for students in the USA, Germany and Poland. Women also seem to have fewer background experiences in the type of activities which seem to develop spatial ability.

The goal of the research conducted at the technical universities in Poland, Germany and the U.S. was to not only provide a statistical evaluation of the collected data but also to distinguish those factors which are recognized to be significant in the development of spatial ability as measured by standardized tests. In reference to the results obtained in this research and to international discussions, it became apparent that there was a need to modify the background questionnaire. In this context, the background questionnaire filled out by the students during spatial visualization testing has undergone changes. Some of the modifications to the questionnaire include: 1) making a more refined distinction between the types of toys played with as a child, 2) distinguishing between the frequency of activity for play with the various toys, 3) determining the frequency of the activities in which the students took part (e.g., playing computer/video games, sports participation, etc.), 4) distinguishing level of participation between sports which are essentially individual, team or two-person activities, 5) questions about hobbies, 6) asking for information regarding why a student chose his/her major, and 7) omitting questions such as age and left-/right-handedness that have not proven to be statistically significant in previous studies.

Traditional graphics courses in the USA and descriptive geometry courses at UKL and CUT improve the spatial ability of both the men and the women in the course, but it is interesting to note that in most cases, the post-test scores for the women after completing these graphics courses were less than the corresponding pre-test scores for men. Thus, the women started the course with a deficiency and the improvement that they made did not narrow the gap. Thus, women were not supported enough in these courses to compensate for their deficiency in spatial abilities. These deficiencies were brought about largely from differences in socialization conditions. For the special course in spatial visualization, however, much more dramatic improvements in spatial ability were reported and gender differences in post-test scores were not statistically significant for the MCT. Part of the dramatic improvement in test scores for the students in this special course could be due to the smaller, more personal class sizes. Future research should consider the different preferred learning styles of men and women and how to take advantage of these difference in the development of spatial visualization skills.

This study was done in collaboration with:

Leszek Piekarski
Division of Descriptive Geometry and Engineering Graphics, Cracow University of Technology, Cracow, POLAND

Lisa Parolini
Civil and Environmental Engineering, Michigan Technological University, Houghton, Michigan USA

Markus Horst
Architecture, City and Environmental Planning, and Civil Engineering, University of Kaiserslautern, Kaiserslautern, Germany

Kerstin Seidenschwann
Architecture, City and Environmental Planning, and Civil Engineering, University of Kaiserslautern, Kaiserslautern, Germany

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