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Spatial Imagination — an Overview of the Longitudinal Research at Cracow University of Technology

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Abstract. Spatial ability of engineering students is a critically important trait, which decides of the future career and success in the engineering professional life. In the paper the results of a longitudinal research of the levels of spatial abilities and the methods used for the development of these abilities will be presented. The study described in this paper was conducted with the use of the Mental Cutting Test (MCT) and the Mental Rotations Test (MRT) in an experimental and a control groups. The means for enhancement of the spatial ability levels, especially for female students who lag significantly behind the men, will be discussed.

Key Words: spatial ability, MCT, MRT, engineering education
MSC 2000: 51N05

1. Introduction

The research study on spatial abilities has been conducted at the Civil Engineering Faculty, Cracow University of Technology throughout several subsequent years. The study of the spatial abilities levels during the years was evaluated by the use of various standardized tests, specifically by the Mental Cutting Test (MCT) 1939 [1], the Mental Rotations Test (MRT) 1978 [10], the Differential Aptitude Test, and/or the TPP - Spatial Imagination test 2003 [4]. Various aspects of the problem were tested. The interest in this research topic stems largely from the estimation, that spatial visualization abilities are critical important to success in scientific and technical fields, and that, up until this time, the spatial abilities of some individuals were not developed well enough for effective visual communication.

2. The levels of the spatial abilities

At the beginning of the semester, several tests designed to ascertain spatial visualization abilities were administered to the students of the Civil Engineering Faculty. In the research

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study participated various groups of students. Basically, the experimental research group consisted of the Civil Engineering Faculty students, specialty of building and construction theory. In this group descriptive geometry was a typical mode of instruction. The subjects participating in the study were required to take a course in descriptive geometry (45 teaching hours: 30 hours of lecture and 15 hours devoted to practice) over a 15 week semester. The lectures are given in the group of approximately 120-150 students, while the practice hours consist of about 40 students. The course ends up with the final exam.

The topics covered during the descriptive geometry course include: a general overview and classification of projection methods, the Mongean projection method with complicated problems of solid-plane and solid- solid intersections, the theory of second degree surfaces and their intersections, oblique and normal axonometric projections, coted projection and its application into road design (cuts and fills around a road, roofs determining) and 2-point perspective.

Usually, a control group of students was chosen to be tested simultaneously on the same tests in order to provide basis for comparisons. Typically, the control group consisted either of the Management and Marketing in Civil Engineering students (1999/2000) or of the students of Transportation. The students of Management and Marketing were only required to take an Engineering Computer Graphics course (with no descriptive geometry elements at all). This course consisted of 30 computer lab hours and lasted 2 semesters. The content covered the topics: 2D constructions in AutoCAD (entity drawing, modifying with or without change of an object, 2D rotations, mirroring, etc.); 3D modeling: surface and solid modeling, rendering with lights, background, materials application; ArchiCAD and 3D objects modeling, animation and rendering, sectioning and visualization. The students from Transportation had completed a descriptive geometry course half a year earlier (2002/03, 2003/04) and at the time of the research have been enrolled in the course of Computer Graphics and Multimedia. The course covered 2D and 3D designing aided with AutoCAD, html coding and web design, graphical design of a poster, presentation of works. This course covers 45 teaching hours over one semester: 15 hours of a lecture and 30 hours in the computer lab. The lectures were given in a group of about 30 students, while laboratory groups count up to 10 student per group.

In all cases the control group was smaller than the research group. The detailed numbers of subjects participating in the research in particular years are shown in Table 1 and Table 2. To examine the levels of spatial abilities of the students, the specific test was administered at the beginning of the semester, and called a pre-test, while the test administered at the end of the semester was called a post-test.

Fig. 1 presents the spatial abilities levels at the Cracow University of Technology (CUT), as measured by MRT, while Fig. 2 presents the levels of spatial abilities as measured by the MCT over the several years. The levels of spatial abilities, as measured by the MCT and the MRT during the several years at our university, are at the comparable levels over the years. As it has been proved in a solid body of research carried out primarily in North America (Sorby [7]), in Japan (Suzuki et al. [9], in Germany (Leopold et al. [6]) men, on average, excel on spatial tasks (particularly those tapping ability to rotate a figure in mind as in MRT problems), perception of the vertical and horizontal, mathematical reasoning, and spatio-motor targeting ability [5]. Women, on average, excel on tasks of verbal fluency, perceptual speed, in which rapid pattern-identity matches are made, verbal and item memory, and some fine motor skills. These statements found confirmation in Polish research.

In the research conducted at our university the mean score for both MRT (Fig. 1) and MCT (Fig. 2) on pre-tests was higher for men than for women in each year of the research.

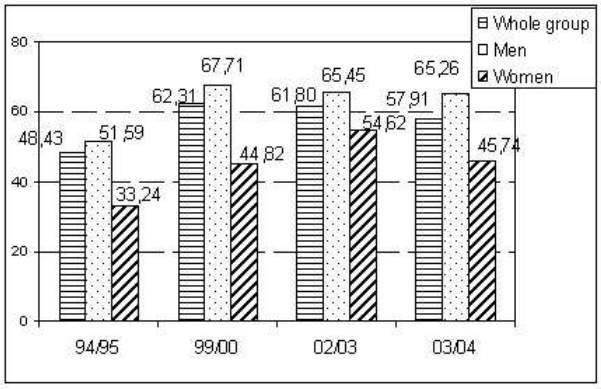


Figure 1: Mean MRT pre-test scores in percentage values for a) the whole group, b) men, c) women

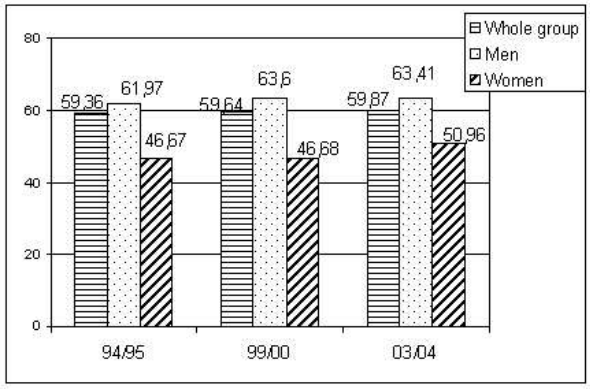


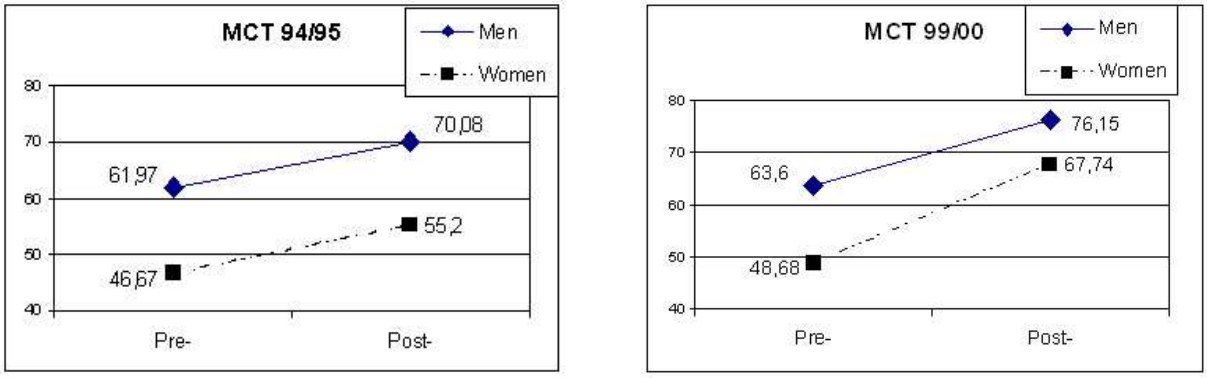
Figure 2: Mean MCT pre-test scores in percentage values for a) the whole group, b) men, c) women

Whats more, the statistical analysis provided in each year showed that there is a statistically significant difference between male and female students [2, 4, 6, 3, 8, 7]. The question remains still open which one among the courses such as descriptive geometry, engineering graphics with sketching, or computer graphics is the best means for enhancing spatial abilities. The research on the last issue has been conducted by Sorby and Górska [2]. The described research study provided the evidence that the course, which contains a lot of hand-made sketching together with the work on the hand-on models has enhanced spatial abilities better than the course with only computer graphics elements.

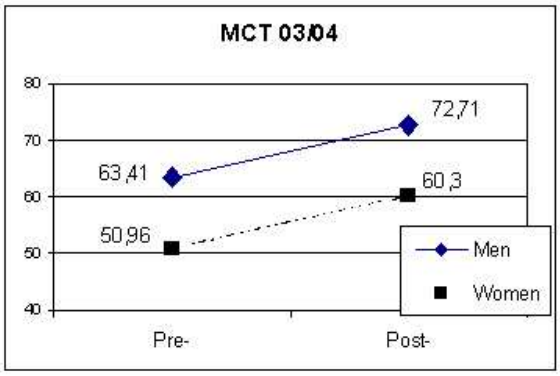
3. MCT – discussion on the results

Suzuki et al. [9] discusses correlation between spatial ability and general intelligence in his work. The research results provide evidence that the ability to mentally construct visual images of three- dimensional objects based on their two-dimensional representations, has a high correlation with general intelligence, which was tested with the use of the Advanced Progressive Matrices Test (APM.) In conclusion it is stated that the MCT reflects the SVF (spatial visualization factor). The results of MCT, as used as a testing instrument at the Faculty of Civil Engineering in Poland, show that a "practice effect" might possibly be influencing the post-test results and gains. Fig. 3 shows the pre- and post-MCT values in particular years on MCT. The numbers of subjects participating in the research will be shown in Table 1. Results were calculated fort the students who took both MCT and MRT test. In all experimental groups and control groups but the group of 99/00 the gain scores on pre- and post-tests are similar in groups of men and women. Although it was proved that the gain scores are statistically significant, only in the 99/00 year the trend lines are not parallel in the groups of men and women. In practice, there is no difference in gains on MCT in relation to the type of instruction; descriptive geometry or computer graphics.

In Fig. 4 the MCT test results are presented for the control groups. One control group, which was chosen with no previous descriptive geometry instruction, was in the Management and Marketing in Civil Engineering specialty (99/00), where the basic instruction was only the computer graphics. This group consisted of the students who were in the sophomore level. There was a significant gain of the mean score in the groups of men and women. If we compare the gain scores for women in the experimental group to men and to both groups in

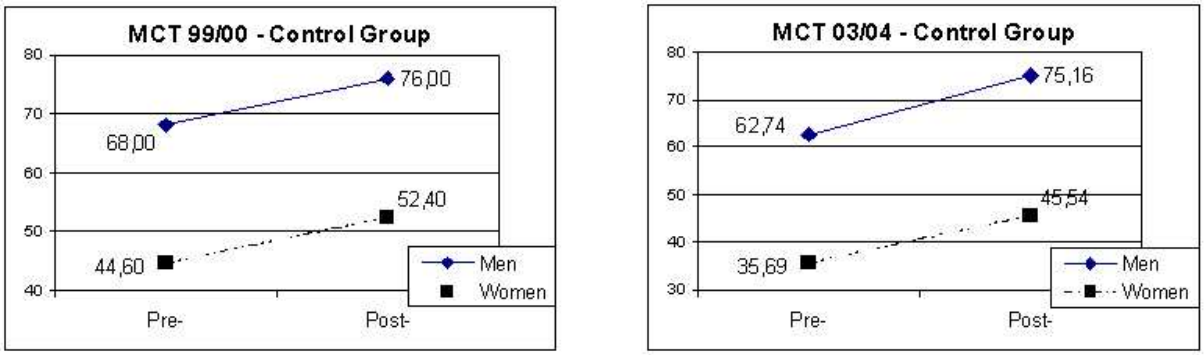


a) b)



c)

Figure 3: MCT: Pre- and post-test results in experimental groups by gender at CUT: a) 94/95, b) 99/00, c) 03/04



a) b)

Figure 4: MCT: Pre- and post-test results in control groups by gender at CUT: a) 99/00, b) 03/04

the control group in 99/00, it is much higher than the other results.

In the research conducted in the year 03/04, the control group was chosen from the students of Transportation specialty. Descriptive geometry instruction was given to this group, but the instructor for the experimental group and for the control group was not the same person. Gains on MCT were comparable for women in both groups and for men in the experimental group, while the mean gain in the control group of men was significantly higher.

Table 1: Mean gain scores, standard deviation (in percentage values) and number of cases on MCT

Year	*Men*	*Women*
94/95		
Ex.group	8,11 s.d.=11.96 (n=73)	8,53 s.d.=10.24 (n=15)
99/00		
Ex.group	12,55 s.d.=16.68 (n=130)	19,06 s.d.=18.54 (n=47)
Control group	8,0 s.d.=17.74 (n=7)	7,8 s.d.=14.42 (n=20)
03/04		
Ex.group	9,3 s.d.=11.74 (n=68)	9,34 s.d.=12.10 (n=27)
Control group	12,42 s.d.=9.97 (n=19)	9,85 s.d.=19.02 (n=13)

Table 2: Mean gain scores, standard deviation (in percentage values) and number of cases on MRT

Year	*Men*	*Women*
94/95		
Ex.group	9,45 s.d.=15.21 (n=82)	11,61 s.d.=15.74 (n=17)
99/00		
Ex.group	23,89 s.d.=15.69 (n=133)	29,39 s.d.=21.00 (n=41)
Control group	16,79 s.d.=11.61 (n=7)	14,37 s.d.=14.14 (n=20)
02/03		
Ex.group	14,81 s.d.=16.13 (n=77)	15,44 s.d.=13.40 (n=39)
Control group	8,38 s.d.=11.45 (n=17)	21,92 s.d.=11.23 (n=13)
03/04		
Ex.group	17,02 s.d.=12.56 (n=68)	14,81 s.d.=15.57 (n=27)
Control group	13,16 s.d.=13.04 (n=19)	23,84 s.d.=13.91 (n=13)

The mean gain on MCT in the control group of women was statistically significant though the final result was still much lower than that of the women in the experimental group.

4. MRT – the measure of spatial ability

Analogically as the MCT test, MRT test was administered in the same groups in subsequent years. The tests results were statistically analyzed. T-tests were performed to determine the significance of differences in mean gains between men and women. There were significant differences on MRT in the years 94/95 ($p < 0.0001$), 99/00 ($p < 0.0001$), 02/03 ($p < 0.005$) favoring the males. In general, the students in the control group had lower mean gains when compared to the students in the experimental group in 99/00, while it was not the case for women in a control group of 02/03 and of 03/04 (Table 2). The reason for this result may be due to the fact that female students in these groups performed on pre-tests very low and there was a big gap to be narrowed.

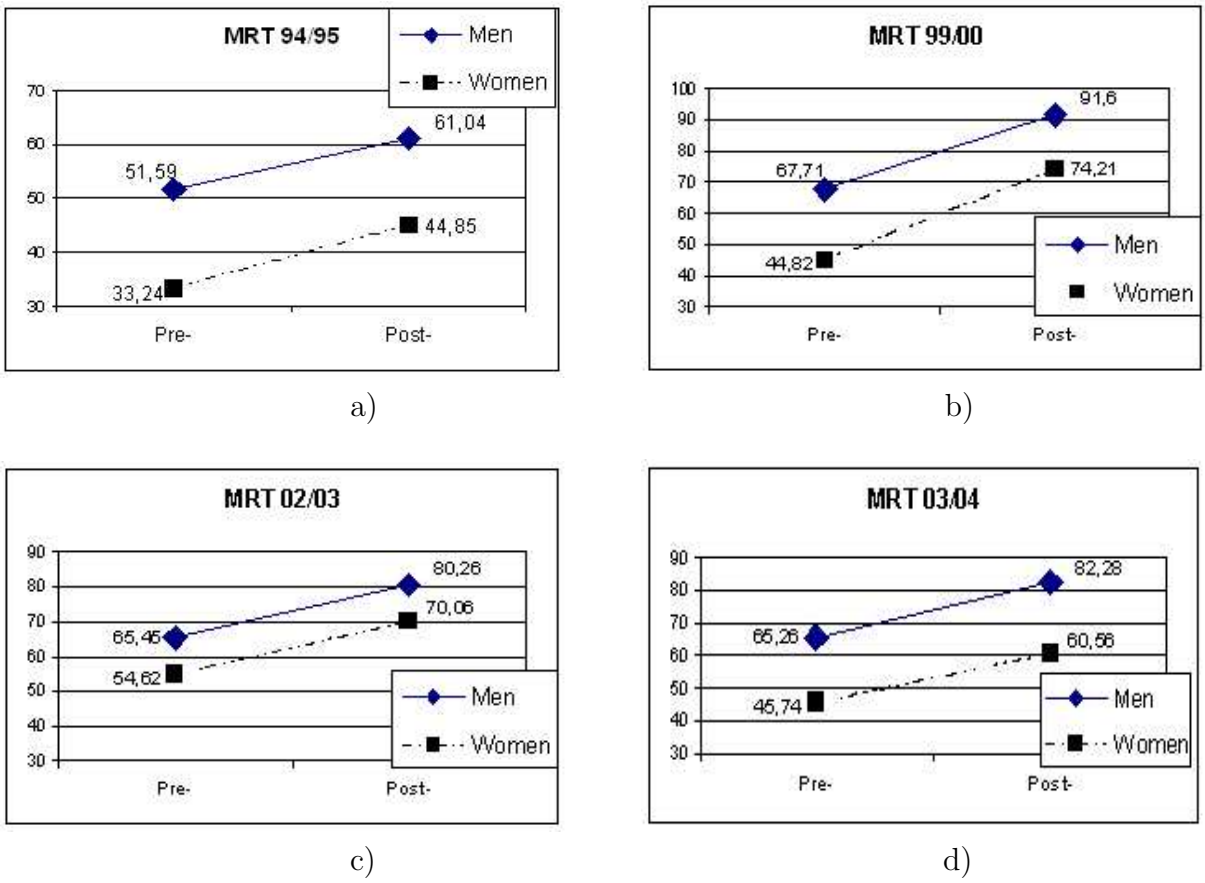


Figure 5: MRT: Pre- and post-test results in control groups by gender at CUT: a) 94/95, b) 99/00, c) 02/03, d) 03/04

5. Conclusions

The main issue of this research was to provide data for comparison of the spatial abilities testing results, as measured by various testing instruments, specifically by MRT and MCT tests in a longitudinal research conducted at one university.

- As students enter technical university with different levels of spatial abilities it is necessary to measure this level by the use of standardized tests and then to propose the best teaching methodology and tactics to improve these skills. Specifically, as women usually score lower than men, it is especially important to "narrow" the gender gap between women and men.
- MRT test results provide evidence that the "practice effect" will be eliminated as there is strong time limitation for solving the test problems (see Figures 1-6).
- Gain scores on MRT test in the groups with descriptive geometry instruction are typically higher than those in a group with pure computer instruction except from the women who started with the lowest pre-test scores.
- Gain scores on MCT test in the groups with descriptive geometry instruction are similar to these in groups with pure computer instruction.
- Female students should be prepared in advance to take their descriptive or engineering graphics course by getting enrolled in special visualization courses as it is already done in some developed countries (Sorby [8]).

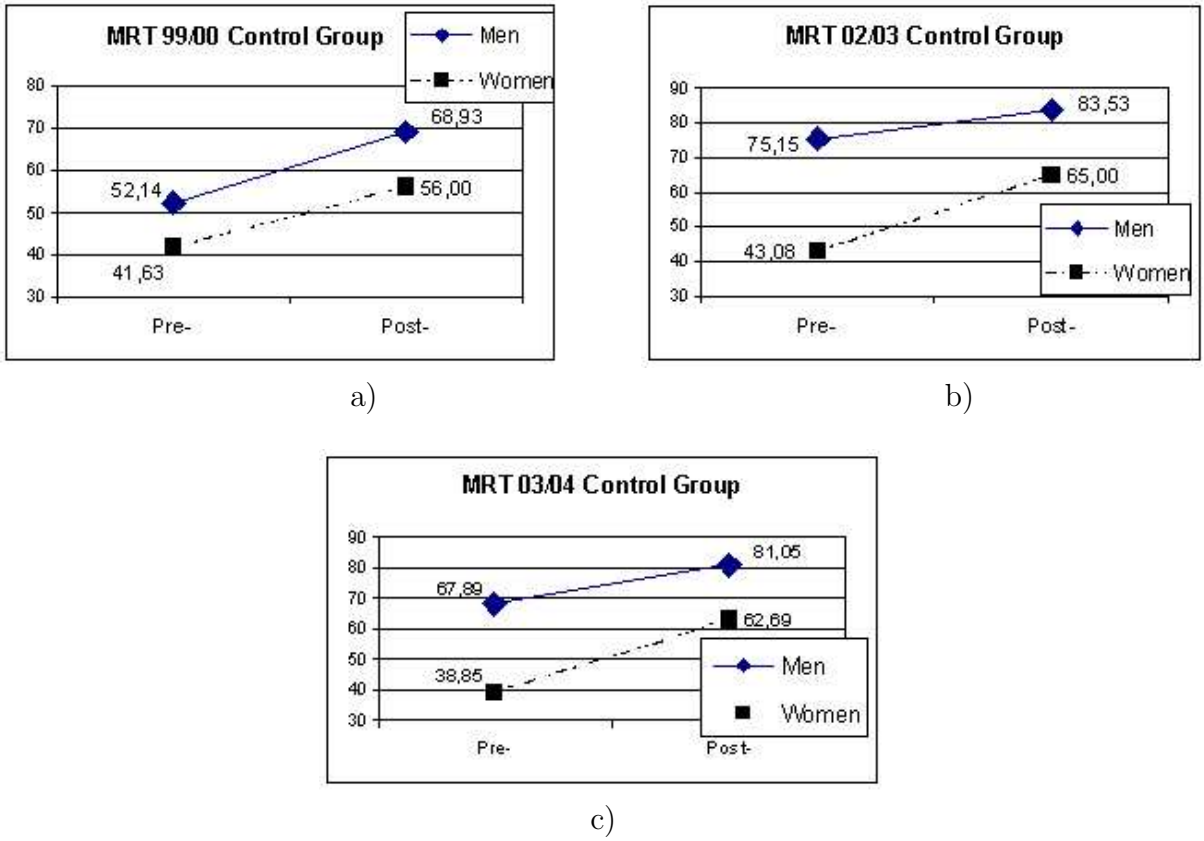


Figure 6: MRT: Pre- and post-test results in control groups by gender at CUT: a) 99/00, b) 02/03, c) 03/04

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