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TPS Test Development and Application into Research on Spatial Abilities

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Abstract. TPS has been developed to provide a modern tool for measuring spatial skills of engineering students. The genesis and development of the subsequent versions of the test, starting from the TPP, through TPS1 to TPS2, will be described in this publication. The test has been administered on a representative group of students ($n > 1270$ subjects) at various types of schools and universities in Slovak and Czech Republics, Poland and Austria. In order to provide a reference measure between the TPS and the other tests used by psychologists as a measure of spatial abilities, standardized psychometric tests such as IST, ISA, OTRS, and MRT have been administered in the researched groups. High correlation coefficients between the listed tests and the TPS have been received. The aim for this part of the research was to validate a new tool for being able to measure spatial ability, namely the TPS, and to provide a comparative study of the test validity.

Key Words: Spatial visualization abilities, tests of space imagination, conditions of tests of abilities, measurement of space abilities, gender differences

MSC 2000: 51N05

1. Introduction

A technical mind and visualization skills are very important traits. Not only in a professional engineering practice, but also in terms of studying engineering subjects. Engineering students who may have limited practical contact with technology and production, are now able to strengthen their skills by a teaching specialist within a modern higher-education school system. The wide consensus amongst the researchers participating in international studies

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is that the problem arises mainly with engineering students at technical universities. Teaching techniques becomes a point of special interest among the educators of technical subjects, because so called "technical thinking" directly relates to the levels of individual spatial ability.

There are some people who can visualize and who cannot. Creation of three-dimensional objects from two or more views becomes more challenging to those individuals, who present a lower level of spatial skills. Spatial imagination is considered to be the basic condition for developing technical skills [1]. According to the results of the factorial studies of the structure of human intelligence, spatial ability has been identified to be one of the factors important for general intelligence [14].

Mark McGee [12] identifies five components of spatial skills: *spatial perception, spatial visualization, mental rotations, mental relations and spatial orientation.*

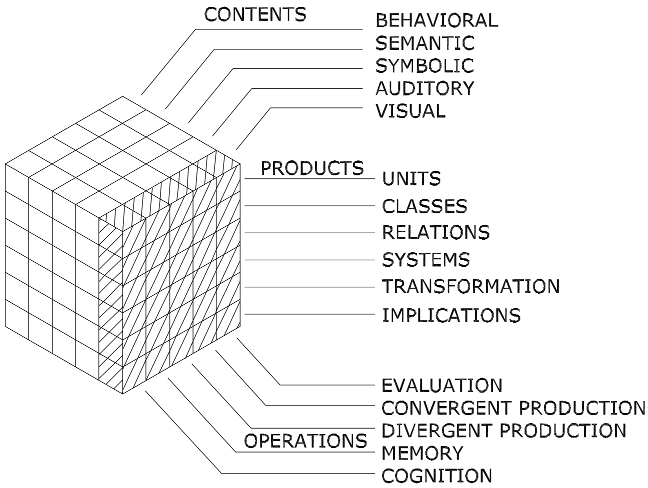

Figure 1: Guilford's model of intellect

Another theory developed by J.P. Guilford [6] provides the hierarchical "Structure of intellect", where intelligence is viewed as comprising "operations", "contents" and "products". There are five kinds of operations (cognition, memory, divergent production, convergent production, evaluation), five kinds of contents (visual, auditory, symbolic, semantic, behavioral) and six kinds of products (units, classes, relations, systems, transformations and implications). A combination of the 5×6 kinds of operations (hatched in Fig. 1) included in visual factor of the "contents" can be taken as a homogenous model of spatial intelligence. Classification for spatial skills based on mental processes that are expected to be used in performing specific tasks in the discussed tests, can be provided based on the described model.

Several spatial factors were isolated in factorial studies carried out by J.P. Guilford [6]. These are as follows [7].

- *Mental manipulations*
  - Orientation abilities,
  - Ability to "feel" three dimensions and ability to read two-dimensional drawings,
  - Ability to understand the complexity of spatial configurations, i.e., ability to visualize and to resist to optical illusion,
  - Ability to remember proportions and the shape and/or to view shape coherence of a 3D object through 2D views in mental rotations or other transformations,
  - Ability to sense the change in the shape of object,

  - Ability to determine the shape or position of the object after manipulation,
- *Manual manipulations (following the mental manipulations)*
  - Ability to draw a 2D image of spatial objects and/or to interpret relations between 3D objects,
  - Ability to determine the function or the composition of the whole when the parts are known,
- *Spatial creativity*
  - Ability to use sketching for finding 3D solutions,
  - Ability to work in 3D space, that is to create spatial constructions according to verbal requirements,
- *Speed of object's manipulation*
  - Speed of reaction, ability to rapidly develop images and interpret them correctly.

In the past years, there have been several international research studies about spatial visualization abilities from different points of views. The overall interest in this field arises largely from the estimation of spatial visualization abilities as necessary and until now not well enough developed traits for visual communications [3]. The belief that visualizing objects is a systematic process which can be taught and learnt by all engineering students indicates that the tools for measuring these skills should be developed. The aim of this paper is to present research and development of the test TPS (Test Priestorových Schopnosti) [7, 8, 9] together with the procedure of its validation and implementation into research on spatial abilities [3, 5]. Standardized tests typically used in the research on spatial ability will be described below.

2. Psycho-diagnostic methods

"A test is a tool for measuring the levels of knowledge, intelligence or ability. It usually comprises a set of questions or problems intended to be solved by a tested person (called as a subject). It can be defined as a procedure for critical evaluation in which the tested person is subjected to a set of impulses to react to. These reactions allow the examiner to asses the tested person" [10].

Various tests have been used to evaluate the students' visualization skill-levels. The spatial visualization tests usually measure various spatial factors of the visualization ability by a geometrical medium.

The ability to perceive a three-dimensional space is a substantial quality of a person's general cognitive power. It is an independent factor, which has been described both in old and new concepts of intelligence. Spatial intelligence is used to master, manipulate and manage the physical environment. It is manifested by the ability to form images of spatial arrangements of 3D objects in a 3D space, or to comprehend the arrangement of elements within a visual stimulus pattern" [17].

2.1. Psycho-diagnostic tests

Standardized tests, such as *Mental Rotations Test* [15], the *ISA-RK* test and specifically its part of the *Analysis of Intelligence Structures, Subtest Cube Recognition* [1] and the test called *OTRS-VK*, which is the *Orientation Test of Cognitive Skills, Subtest Cube Selection*

[16] have been used to provide comparative analysis of the spatial visualization skill-levels of engineering students in the research study.

- *Mental Rotations Test* (MRT) [15]:
  The test consists of 20 items. Each problem contains a criterion figure and four alternative views of a rotated criterion figure. There are two correct alternatives and two incorrect alternatives. The subjects are asked to identify these two correct views. The test together with the problem's example has been presented in previous works [4].
- *Analysis of Intelligence Structures, Subtest Cube Recognition* (ISA–RK) [1]:
  In this test the subject must decide whether any of the seven three-dimensional cubes is identical with the pattern cube. In seven pictorials the cubes are depicted as they are observed from different view-points. The drawings attached to the cube faces help recognizing the views. The subject has to perform an imaginary rotation in order to choose the correct answer. The test consists of 12 problems.
- *Orientation Test of Cognitive Skills, Subtetst Cube Selection* (OTRS–VK) [16]:
  The task is to determine the number of cubes, which have a hole inside but are not damaged. This number must be recorded in an answer sheet. A circle drawn on the face of a particular cube denotes a hole which applies to all the cubes standing in a row behind it. A cross on the top face or on the side face of a cube denotes a cube, which is damaged. The symbol applies to all cubes standing in a row behind it or in a column below it. The test consists of 20 problems.

In Europe, we can still observe a lack of such a diagnostic tool, which would be widely used for testing spatial abilities among applicants to technical universities. Spatial constructions in a technical subject requires spatial imagination. Each person applying for technical study should become a subject of this type of examination by solving a test of spatial skills before he/she decides what type and specialty of the future study and profession he/she chooses. The new test TPS has been developed by the first named author to fill the gap. The test TPS undergoes a standardization process both in a domestic environment in Slovak Republic, and in the international co–operation with the scientists from Poland, Austria and Czech Republic [3, 4, 7, 8, 9, 11, 13, 17].

2.2. Principles of a test construction

The conditions of a test's quality are given by basic methodological requirements expressed by psychometric characteristics of the test.

2.2.1. Objectivity and standard

A correctly constructed test should contain:

- A uniform verbal instruction for administrators,
- Exact set timing,
- A uniform grading scale with no subjective evaluation,
- Fixed standard, which is formed based on the results received in the research, conducted in correctly stratified group of a representative statistic set of subjects.

2.2.2. Validity

Selection of particular problems, tasks, items and their parts, is a subject to this type of activity, which in the process of the test elaboration, will be referred to by the term as "construction". The tasks should activate nothing but spatial imagination and therefore during the preparation of the test, we have thus eliminated the items which would be the following:

- Evoke knowledge obtained at school,
- Require verbal activities,
- Require difficult graphical drawings,
- Interfere with concentration,
- Bear the characters of optical discrimination.

The test's items and their parts should use and activate spatial imagination as thoroughly as possible. It is expected that the test will thouroughly explore a certain trait of spatial imagination. The following conditions must be fulfilled:

- Particular test items must be self-coherent and unique,
- The difficulty of the test items must gradually rise,
- It is necessary to ensure diversity of the answer types.

2.2.3. Reliability

The condition of the test quality has been provided by:

- Creating two equivalent forms of the test: Form A and Form B,
- Creating a relevant number of items,
- Eliminating "dichotomy" and "type testing",
- Diversification of items without repeating an algorithm of solution.

2.2.4. Differentiability

The correctly constructed test "sorts appropriately" the population and ranks the subjects into certain performance categories. Following good experience with the application of the test and precisely set measurements, an exactly defined spectrum of a specific type of ability can be assigned to this category.

3. Genesis of TPS

The project *Space imagination and the future construction VEGA 1/7319/20*, which took place in the years 2000–03, represents the beginning of our research of space imagination. At that time the bank of tasks, which examine spatial imagination, has been created. The first formulations of these tasks resulted in creation of the TPP test. The next project *Measurement of space abilities VEGA 1/1407/04* conducted in the years 2004–06 aimed at modification of the TPP test and its objective was to formulate a modern psycho-diagnostic tool for measuring space abilities. As a result, we created a new versions of the test, which was called the TPS test.

3.1. First version: TPP

Test of space imagination *Test Priestorovej Predstavivosti TPP* was described in [3]. The first version of the test consisted of four independent parts, each called a "Subtest". The research was conducted in various types of schools in international co-operation. In Fig. 2 we can see the proportions between the researched groups, where SPŠ and SOU denote technical schools, G is used for a general type of a high school and INÁ denotes other types of schools, such as music, art or economics schools.

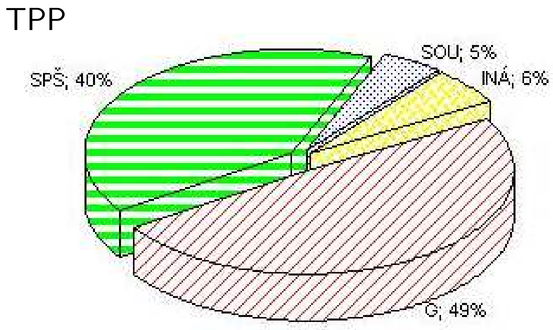

Figure 2: Pie chart of various types of schools for TPP in the Slovak and the Czech Republic

The parallel validity for $n = 844$ (n denotes the number of cases) has been determined by the criteria of the IST and OTRS tests. The test IST (Intelligenz Struktur Test), developed by R. Amthauer, consists of 20 items and it contains the problems similar to those included in the ISA test. The Pearson's product moment of correlation between the TPP and IST or OTRS were respectively equal to

$$r_{\text{TPP-IST}} = 0.41,\ r_{\text{TPP-OTRS}} = 0.49, \text{ while } r_{\text{IST-OTRS}} = 0.37.$$

These results have been calculated based on the data received in research conducted in the Slovak and the Czech Republic and in Poland. The differentiation has been measured and presented in Fig. 3, where frequency of distribution of the results in percentage values is graphically displayed (x-axis: the score received on the test in percentage values; y-axis: the number of a specific result occurence).

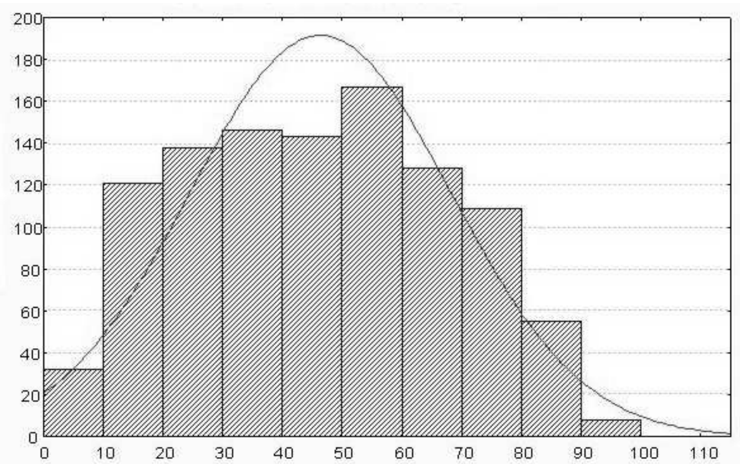

Figure 3: Normal distribution of TPP; $n = 1047$

3.2. Second version of TPP: TPS

Analysis of the results measured by TPP test has shown several imperfections. Changes in the formulation of instructions in each subtest, fixation of the numbers of problems in each subtest, cancellation of one of the subtests and exchange of the problems in one of the subtests gave rise from the TPP to a new version of the TPS1 test (Test Priestorových Schopností). The test was administered to $n = 400$ subjects.

Following further analyses, the author selected 10 problems in each of the three subtetsts and included them into the second version of the TPS. This second version, called TPS2, was administered to more than 1270 subjects in Slovak and Czech Republics, Poland and Austria. The test consists of three parts: Subtest1, Subtest2 and Subtest3, while each of the Subtest comprises 10 problems.

Subtest1 – Mutual position (Fig. 4). The subject draws a mental line and a geometrical plane respectively between two and three given points. The points are chosen either on the faces or on the edges of one of the regular solids (a cube, a tetrahedron or an octahedron). The subject has to mentally fix the mutual position between the line and the plane, while the line and the plane can be either parallel or intersecting. There are 4 exemplary drawings included in each problem. The task is to identify this single item out of four possibilities, in which the relation between the line and the plane is different from the the relations existing in the other options. Solution time: 13 minutes.

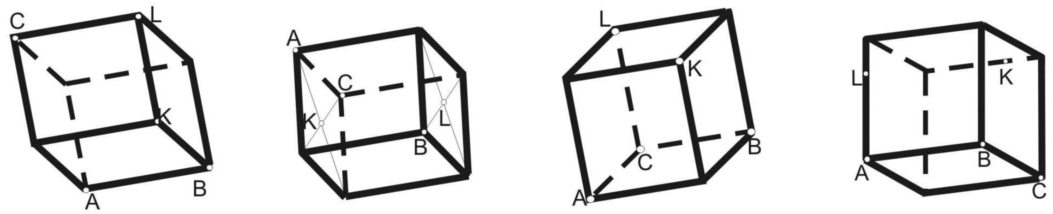

Figure 4: Subtest1 – Parallel or intersecting ?

Subtest2 – A snake in a cube (Fig. 5). The subject draws an axonometric view of a snake twisting along the edges or faces in a cube. There are given three views of the snake depicted in the third-angle projection. Solution time: 13 minutes.

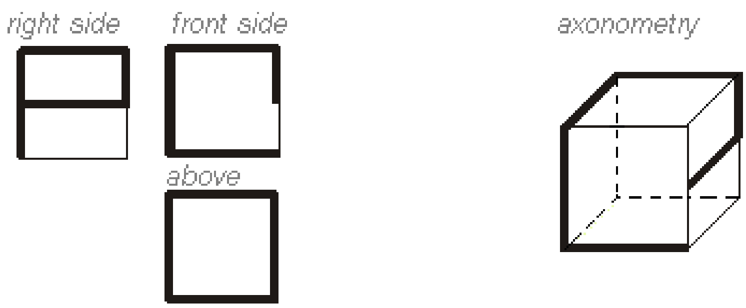

Figure 5: Subtest2 – A snake in a cube

Subtest3 – Two parts of a cube (Fig. 6). A cube has been cut into two pieces and displayed with one marked part K. The task is to choose a complimentary part of a cube out of four options a, b, c or d to make a perfect cube with the given piece K. Solution time: 8 minutes.

3.2.1. Objectivity and standardization of TPS2

During the administration of the TPS test we used the written instructions, kept the timing and the single valued answer key. Correct stratification of the analyzed sample of students

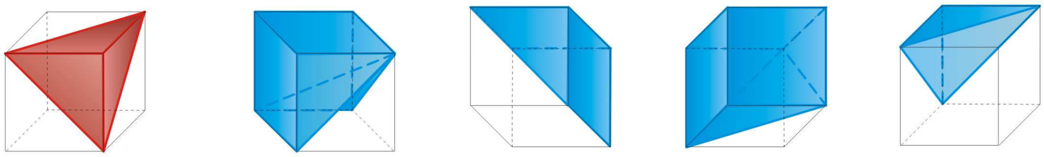

Figure 6: Subtest3 – Cube's complement

who participated in the research study was ensured by conducting it at various types of universities. Specifically, we administered the test at technical study faculties in Slovak and Czech Republics, in Poland and Austria, at faculties of natural sciences and at pedagogical faculties in Slovak and Czech Republics.

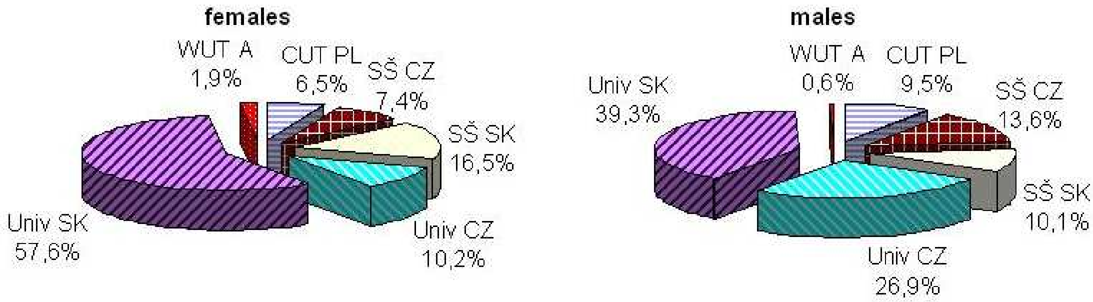

Figure 7: Demographics by gender (males/females) for the groups tested with TPS2

The data was acquired from $n = 1265$ students of secondary schools and universities from Slovakia (BERG and SjF in Košice, SvF and MTF STU in Bratislava), Czech Republic (ČVUT in Prague), Poland (CUT in Kraków), and Austria (VUT in Vienna). The average age of the subjects was 19.6. The percentage distribution between the researched groups divided by gender (males/females) and type of schools (secondary schools / universities) has been presented in Fig. 7.

Differentiation of the results on particular Subtests of the TPS, namely on Subtest1, Subtest2, Subtest3, has been presented in Fig. 8. In the chart the x-axis displays the scores received on testing in absolute values, while the y-axis displays the numbers of a specific result occurence.

3.2.2. Validity of TPS2

The results of the first tuning of the TPS have been presented in [5] and [9]. To answer the question whether the content of the TPS2 test corresponds to the measured characteristics we are using the Content Validity Ratio CVR (1) index defined in [2]. An equation for the CVR ratio will be expressed by a formulae

$$CVR = \frac{n - \frac{N}{2}}{\frac{N}{2}} \tag{1}$$

where
n – denotes the number of experts who indicated the answer No. 1 of the inquiry,
N – indicates the number of all experts participating in the inquiry.

After J. Ferjenčik [2] we read the following: "When the CVR index equals to or is larger than zero, then it means that the test is a good representative of the researched quality".

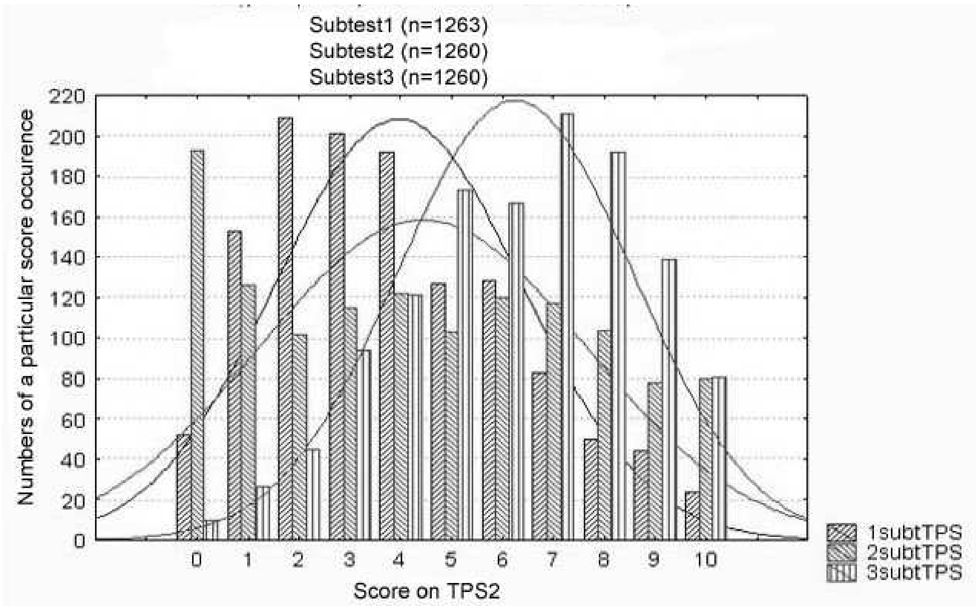

Figure 8: Histograms of results on particular Subtests:
Subtest1, Subtest2 and Subtest3 ($n = 1260$)

The questionnaire was presented to a group of experts who have been chosen among geometry teachers, engineers and psychologists. The hypothetical statement was formulated to sound: "Does the presented test and its parts (Subtest1, Subtest2, Subtest3) measure the desired qualities of spatial abilities?" The choice of answers was between:

1. It is fundamental.
2. It is useful, but not fundamental.
3. It is irrelevant.

The outcome of this inquiry was that only 6–9% of the inquired specialists chose the answer number 3. For the test TPS2 parts we obtained respectively the values:

$$CVR_{\text{Subtest1}} = 0.47;\ CVR_{\text{Subtest2}} = 0.50;\ CVR_{\text{Subtest3}} = 0.53\,.$$

Mutual independence of the subtests is given in Table 1 where the values of partial correlations have been inserted. Unequal difficulty of particular subtests has been signalized by several parameters, as shown in the histogram in Fig. 8. The group score on the Subtest3 showed that this part was the easiest for the students in all researched groups.

Criteria for convergent validation, which we are considering, are ISA [1], OTRS [16], MRT [15]. The data were calculated for $n = 522$ subjects from Slovak and Czech schools and for $n = 76$ subjects in Poland. The correlation coefficients for particular data are respectively equal to

$$r_{\text{TPS2-ISA}} = 0.61,\ r_{\text{TPS2-OTRS}} = 0.51, \text{ and } r_{\text{ISA-OTRS}} = 0.41 \text{ for the Slovak Republic}$$
$$\text{and } r_{\text{TPS2-OTRS}} = 0.41,\ r_{\text{TPS2-MRT}} = 0.56 \text{ for Poland.}$$

3.2.3. Reliability of TPS2

Correctness and precision of measurement was evaluated by the use of a correlation coefficient between the results on the input and output measurements while there was minimum 6 weeks pause between pre- and post-testing. We obtained a high Pearson's coefficient for each subtest (Table 2).

Table 1: Partial correlations between independent subtests ($p < 0.0500$, $n = 973$)

	Subtest1	*Subtest2*	*Subtest3*
Subtest1	1.00	0.33	0.28
Subtest2	0.33	1.00	0.43
Subtest3	0.28	0.43	1.00

Table 2: Pearson's correlation coefficient of reliability for pre- and post-testing in Slovak and Czech Republics ($n = 135$)

Subtest1	*Subtest2*	*Subtest3*	*whole TPS2*
0.59	0.75	0.62	0.82

4. Measurement of some relations between particular results

The next step of the research was to provide a measure of the variability or dispersion of the data. Similarly to TPP, also TPS2 has a normal frequency of distribution. The measure was calculated both in groups by gender and in the whole group and the differences between the universities have been analyzed. In Fig. 9 we have an exemplary chart of the results distribution for the Subtest2, which is presented by gender for all universities and schools where the numbers of cases are respectively $n = 799$ for men and $n = 456$ for women.

Scheffeh's test was used to control conditions of homogeneity and dispersion of variables by the factors "type of university" and "gender". There exists a statistically significant difference ($p < 0.05000$) between most of the universities on TPS2 (Table 3).

Table 4 presents values obtained in the Levene's, Brown and Forsyth's t-test, which was used to calculate the significance of differences between the particular subtests. Subtest3 does not show a significant difference ($p = 0.40$ for Levene's and 0.28 for Brown and Forsyth's

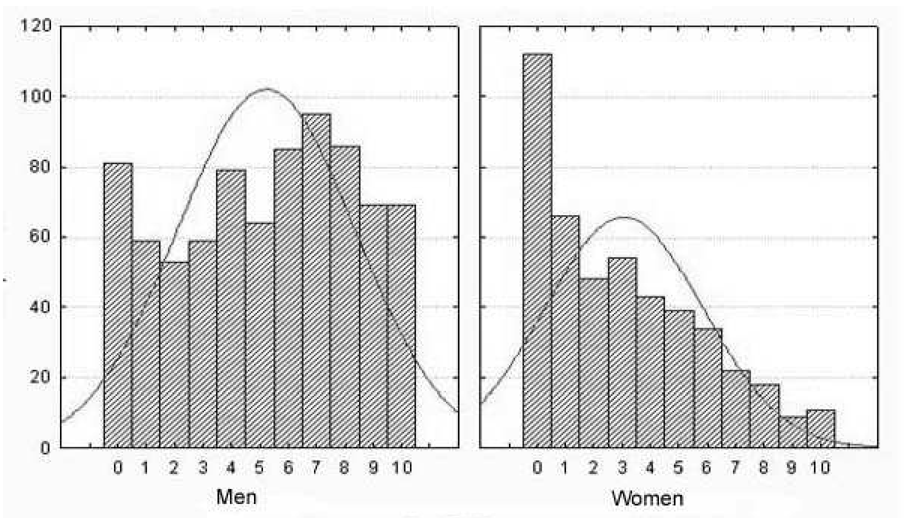

Figure 9: Differences on results between men and women on Subtest2

Table 3: Scheffeh's test of mean scores on TPS2 for measuring the equality of dispersion between the universities

Technical Univ.	{1}	{2}	{3}	{4}	{5}	{6}
ČVUT {1}		0.000000	0.000000	0.289365	0.000000	0.000074
BERG {2}	0.000000		0.000738	0.000000	0.165543	0.000000
SjF TU {3}	0.000000	0.000738		0.031509	0.539993	0.818861
SvF STU {4}	0.289365	0.000000	0.031509		0.000003	0.456249
MTF STU {5}	0.000000	0.165543	0.539993	0.000003		0.016277
CUT {6}	0.000074	0.0000000	0.818861	0.456249	0.016277	

Table 4: T-test of mean scores on TPS2 for men *(Mean M)* and women *(Mean W)* in Levene's, Brown and Forsyth's tests of equal dispersion (n – number of cases)

	Mean M	*Mean W*	*n M*	*n W*	*Levene p*	*Brn–Fors p*
Subtest1	4.28	3.32	801	457	0.01714	0.01
Subtest2	5.20	3.04	799	456	0.00003	0.00
Subtest3	6.86	5.07	798	457	0.39991	0.28

t-tests respectively).

Figure 10 presents a graphical result which was obtained at particular universities. Men showed better power of solwing TPS2 than women. The largest disproportion was shown at ČVUT, while minimal disproportion was at SvF TU and CUT. The best results on TPS2 were in ČVUT for men and in SvF STU for women.

Although the standard deviations calculated in groups by gender have similar values, the correlation between the mean score in each of the groups (men and women) and the standard deviation present the existence of only two values distant from the main trend line (Fig. 11). Homogeneity of the results is slightly disturbed. This shows that the majority of female subjects scored lower than males on TPS2.

5. Conclusions

Our school system has passed through many reforms since the second half of the past century. The results of these reforms will continue to be measured in the future. However, we can still state that the students at our technical universities have neither well developed spatial skills nor sufficient technical talent. This can be observed in such situations when a student has to solve a certain technical problem, to design a specific procedure, to work on partial tasks in teamwork, or to operatively change an initial strategy of solution for real-life constructions of both geometrical and generally technical character. Fantasy, imagination, inquisitiveness and strenuousness, space imagination and creativity are inborn traits of each human being, but in some cases not sufficiently well developed to perform the creative work of a designer. The qantity and the quality of students at design and construction specializations are still

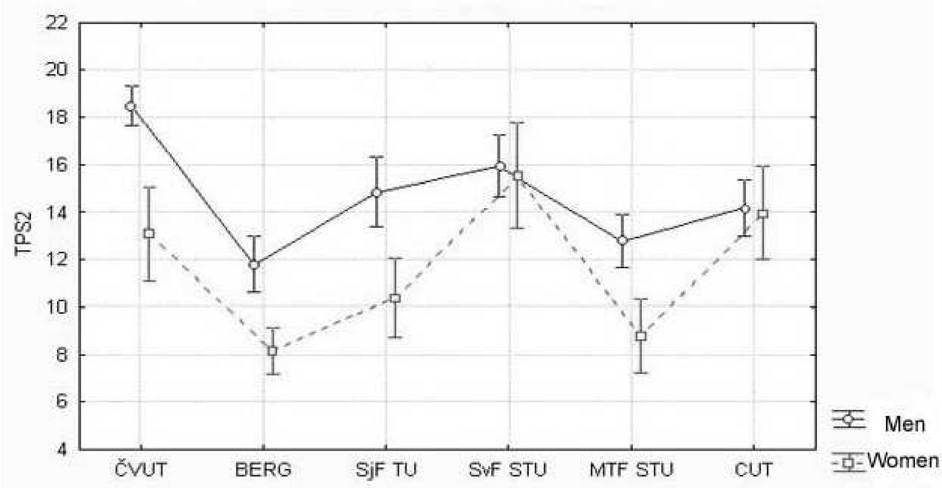

Figure 10: Relation between the mean TPS test score by gender and type of university

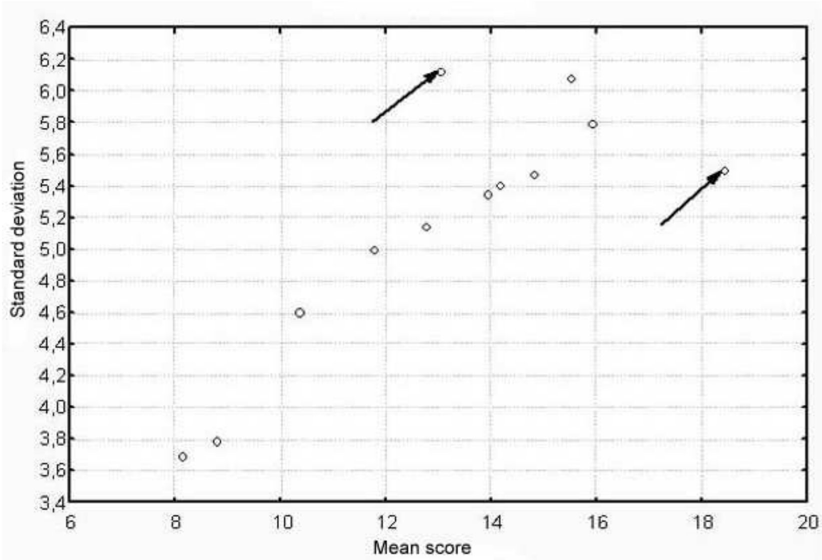

Figure 11: Correlation between a mean score and standard deviation by universities

decreasing.

The test TPS has been developed to provide a modern tool for measuring spatial skills of engineering students. The author of the test Z. Juščáková [7, 8, 9] conducted research on the test standardization in international co–operation [3, 11, 13, 17]. The results obtained in this cooperation led the author to the test modifications from the original version of TPP, through TPS1 to TPS2. At this stage of data analysis, the following conclusions can be made.

- The test has been administered on a representative group of students at various types of schools and universities in Slovak and Czech Republics, Poland and Austria. Statistical analyses showed a significant difference between the mean scores in various types of schools. Both variables, "university" and "gender", have a significant influence on power in TPS.
- The analysis of the results by gender shows that particular subtests (Subtest1, Subtest2, and Subtest3) in particular universities have normal distribution.

- However, more detailed analysis performed with the use of a Shapiro-Wilcoxon's test of normality shows that the results obtained in ČVUT and CUT do not have normal distribution as measured in a whole group. This may have resulted from the inequality of the tested samples of groups.
- The conditions of homogeneity between the researched groups by the "type of university" and "gender" has been observed but there is some discrepancy in it.
- The Levene's and Brown and Forsyth's tests of equal dispersion showed that there is a significant difference on Subtest1 and Subtest2, but no significant difference on Subtest3 in groups by gender.
- The research showed a good correlation between the TPS and the other psychometric tests such as IST, ISA, OTRS and MRT.

In general, the results of the research confirmed the earlier findings on the testing with the use of the other, typically administered spatial tests. However, the goal of this part of research was to validate a new tool for measuring spatial ability, and to provide a comparative study of the test validity.

Based on the results of the research conducted with the use of TPS2, we can also state that we are having at our universities the groups of females with well-developed spatial abilities. The problem is how to recognize those students who have difficulties with thinking in three dimensions.

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