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Development of Spatial Abilities of Architectural and Civil Engineering Students in the Light of the Mental Cutting Test

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Abstract. The present article aims to present the results of a survey conducted at Ybl Miklós Faculty of Architecture and Civil Engineering among architecture and civil engineering students in their first grade with regard to changes in their spatial abilities. We applied the internationally acknowledged Mental Cutting Test (MCT) in the survey. We analysed the impact of one semester-long attendance of the discipline Descriptive Geometry on test results; distribution in different subject groups; signs of considerable differences between genders and majors; improvement of the subjects and indexes to measure improvement; connection between MCT results and end-term marks of the subjects. In the analysis statistical methods were used; the conclusions extracted from data evaluation were submitted to hypothesis testing and the results were interpreted.

Key Words: Mental Cutting Test, Descriptive Geometry, spatial ability

MSC 2010: 97G80, 51N05

1. MCT – Previous researches and results

The standard Mental Cutting Test (MCT) was originally developed in the USA as an entrance examination aptitude test in 1939 [1]. Later the test was used by Suzuki [9] for measuring spatial abilities in relations to graphics curricula. After that the test was used in many international researches and projects from Japan through Germany, Austria, Poland, Croatia, Slovenia to Slovakia etc. [5, 10, 2, 13, 14]. Most of these experiments' goal was to increase the success and efficiency of the test filling subjects by, for example, using stereographic system or drawings of the intersection [11, 12]. Furthermore this test is widely used for measuring students' spatial kills and development.

The classical MCT consists of 25 problems. In each problem a parallel perspective drawing of a solid body is given, which has been cut by a plane. The subjects are asked to choose the correct cut among the 5 given alternatives, always one being correct. Most of the solids in

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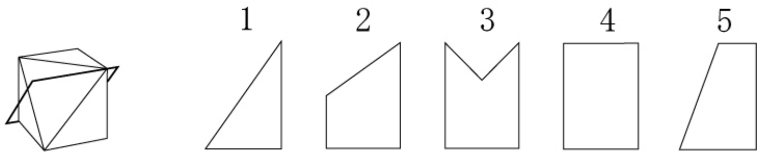

Figure 1: Sample problem from the usual MCT

MCT have relatively complicated, unusual forms, some of them are truncated cubes, others are curved objects, like cylinders etc.

It was shown by Saito et al. [5, 6, 7] that in order to solve the MCT problems, subjects go through 3 phases of information processing, which are:

- recognizing the solid from the parallel perspective drawing as well as the relative location of the cutting plane,
- cutting the solid by the given cutting plane,
- judging the characteristic quantity of the section, if neccessary.

It was pointed out by Tsutsumi et al. [11] that subjects who reached low scores didn't seem to be able to recognize the objects and the cutting planes correctly. She also provided an analysis of the factors of spatial thinking that can be measured by the Mental Cutting Test.

There is another famous result stating that female subjects much less likely to get high scores in the standard MCT [10, 3, 4]. Furthermore Suzuki et al. [8] provide evidence that there is a high correlation between general intelligence and spatial ability that is mentally construct visual images of three-dimensional objects based on their two-dimensional pictures.

A few years ago, Németh and her collegues [4] presented an analysis of MCT results of first year engineering students with emphasis on gender differences and typical mistakes.

2. Conditions of the survey

The present survey was conducted at Ybl Miklós Faculty of Architecture and Civil Engineering of Szent István University in their first semester of 2010. Subjects of the survey were architecture and civil engineering students in the first grade. The Mental Cutting Test was applied in the survey; please find above (Fig. 1) a test problem for illustration. Subjects were required to complete the test twice in the semester, on the first and the last lessons. 167 civil engineering and 168 architecture students participated in the survey, which means, they completed the test in September. At the sampling the subjects were identified by their NEPTUN electronic administration code; they had to answer questions concerning their faculty, gender, hand preference, and previous studies. The completion of the test took altogether 20 minutes, both in September and December.

All students participating in the survey attended Descriptive Geometry in the studied semester. Both trainings consist of a lecture and two seminars per week with constant recitation. Students receive the signature for completing the course for 10 home assignments and two written in-class tests and they also have to take a written or occasionally oral exam at the end of the term. Nevertheless, there are considerable differences between the trainings. Civil engineering students attend Descriptive Geometry for one semester, while students of architecture have to complete a three-semester long study of the discipline. Thematically the curriculum for civil engineers basically covers the following topics: Introduction to Monge projection, relations between spatial elements, problems of incidence. Constructions of intersection points and intersection lines in Monge system. Plane section of polyhedra and intersection between polyhedra in Monge representation. Projections of a circle. Representation, plane section and mutual intersection of surfaces of revolution. Introduction to oblique and orthogonal axonometry: representation of different families of solids (polyhedra) and curved surfaces. Introduction to terrains.

The training for students of architecture follows a considerably different curriculum, as circle problems, curved surfaces and terrains are introduced in the next semesters of the training, while they study parallel perspective image construction and draw shadow constructions of solids in all representational systems already in the first term. They follow a tighter time-scheme, the complexity level and task difficulty are higher than those for civil engineering students.

3. Methods of the survey

The results of full-time architecture and civil engineering students at Ybl Miklós Faculty of Architecture and Civil Engineering of Szent István University were examined separately due to differences in Admission Test scores, syllabi and professional requirements, however, whenever possible, they were compared. On the other hand, we have tried to explore the relations between further data registered at the sampling — gender, hand preference, previous studies in Descriptive Geometry and the end-term mark of students — and their achievement in the test. Statistical methods, relative numbers of distribution as well as indexes were used in the analysis. The conclusions which were drawn from the tendencies that were extracted from the data were submitted to hypothesis testing.

First, in case of all conclusions and results, the applied statistical methods and the results will be presented, and then we will make attempts to find an explanation for the tendencies. The number of students scoring 0, 1, 2, ..., 25 points, joining their classes by two, was grouped into 13 clusters that facilitated statistical processing. In each cluster the reached scores were changed to the mean of the two endpoints of the cluster.

4. Examination of the distribution of the results of architecture and civil engineering students

First, we analysed whether the distribution received by this method could be estimated with normal distribution at certain significance levels. It is known from statistics literature that the most probable values for the parameters of estimated normal distribution — according to the maximum-likelihood method — are: $m \approx$ sample mean and, $\sigma^2 \approx$ unbiased sample variance. If these values are applied to estimate the parameters of normal distribution, with the discretization of the problem and in order to use the test of goodness of fit, the following statistics is calculable:

$$\chi^2 = \sum_{i=1}^{13} \frac{(g_i - b_i)^2}{b_i}$$

where g_i denotes frequency, b_i denotes estimated frequency derived from calculated normal distribution. Considering the number of clusters and estimated parameters, presently it gives a χ^2 distribution with 10 degrees of freedom.

Therefore, we tried to find an answer for the null hypothesis below:

H_0*: some empirical distribution function = cumulative distribution function of some normal distribution.*

Considering surveys in September, we concluded that the aforesaid null hypothesis is not supportable at 95% significance level, if we analyse the full sample civil engineers or architects.

5. Analysis of gender distribution

Surveys conducted with MCT tests reveal — as it was mentioned in the introduction — that there is a considerable difference between the achievement of males and females. Therefore, we expected that if we analysed their results separately, our hypothesis would be maintainable. With respect to the data gained from the survey conducted in September, at 95% significance level, we found that the value received from the equation above stays under the values of the distribution chart regardless of the gender of students of architecture. Therefore, for architecture students the hypothesis is supportable. However, if civil engineers are considered, the hypothesis cannot be supported.

Further tailoring the screening of civil engineering students enabled us to declare that male and female students successfully completing the semester (with a pass-mark at least) separately followed the normal distribution, as well as those male and female students that failed to complete the semester. Data from the sampling in December showed some changes, though. Civil engineering females, regardless of their achievement, can be represented by a single bell curve, while male students failing to complete the semester follow normal distribution, however, for students with at least a pass-mark for the term the hypothesis is maintainable.

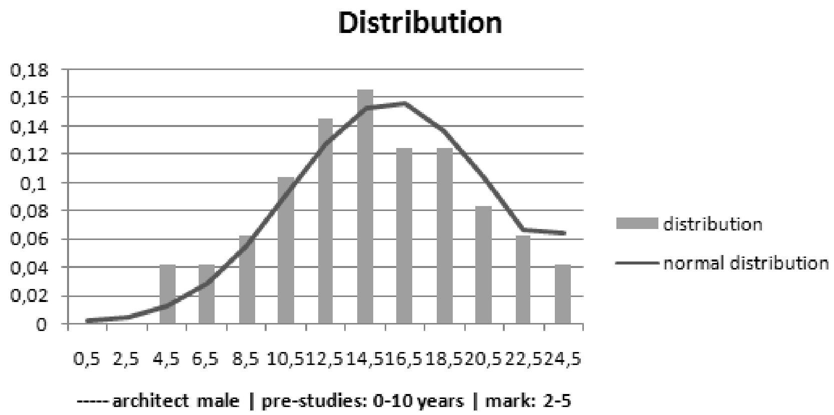

Figure 2: Distribution of male architects with the fitting bell-shaped curve

An inspection of the expected values and variation reveals that civil engineering females reach the lowest achievement compared to female architects and to male students in both departments. It is also significant that the results of civil engineering males show the highest value of variation, while the achievement of civil engineering females have the lowest value of the same.

We explain the observed tendencies with the fact that mathematical and geometrical skills of the students of architecture far exceed those of the civil engineers — in accordance with their admission test scores, but in a higher level than the scores reflect. The tendency goes so far that we may declare that civil engineering students are at least one semester behind: their

Table 1: Expected values and variation in certain analysed students groups

Groups	*September*		*December*	
	expected value	*variation*	*expected value*	*variation*
Architecture males	13.94	4.56	16.12	4.18
Architecture females	12.26	3.98	13.92	4.50
Civil engineering males	12.11	5.05	14.41	5.78
Civil engineering males, successful	13.73	4.81	15.68	5.32
Civil engineering males, unsuccessful	10.53	4.82	10.83	5.67
Civil engineering females	8.15	3.03	10.70	3.35
Civil engineering females, successful	8.36	3.36	10.91	3.56
Civil engineering females, unsuccessful	7.89	2.65	10.13	2.80

results in December reflect the same achievement as the results of ure students in September. Civil engineering females constitute a far more disadvantaged group for they are behind with more than one semester. Reasons have to be found in proven gender differences.

The group of civil engineering males includes both more and less skilled students, in the same manner, the hand hard-working and the less studious in any match. Therefore, we will find hard-working and less studious students with good and poor stereoscopic vision among the students who completed the course. Similarly, the group of those students who were unsuccessful in completing the course contains both hard-working and less studious students with either good or poor stereoscopic vision. This explains higher variation values.

It is also true that 60% of the civil engineering students complete the course of Descriptive Geometry, while this rate is 75% for females — female students are more industrious, devoted and homogeneous, while male students though having better results at the beginning drop out more easily — therefore they constitute a more heterogeneous group.

It is visible that in case of architecture the male students also have an advantage over female students with regard to MCT tests, however, in a much less amount than in case of civil engineering students. There is no considerable difference between the rate of the genders completing the subject, which is 69% in case of males and 67% in case of females. Therefore, we can say that students of architecture show a more coherent picture.

6. Homogeneity tests for both genders

The previous statements are supported by the results of homogeneity tests based upon χ^2-test. We tested the following hypothesis:

H_0*: the distribution of* X *and* Y *probability variables is identical.*

where X and Y are probability variables derived from the elements of the sample, the frequencies of which are denoted by f_i and g_i, the number of elements of the population is n

and m. For 13 clusters, we calculated the value

$$\chi^2 = nm \sum_{i=1}^{13} \frac{\left(\frac{f_i}{n} - \frac{g_i}{m}\right)^2}{f_i + g_i}$$

that follows — considering the number of classes — a χ^2-distribution with 12 degrees of freedom.

It was found that at 95% significance level the hypothesis saying that male and female civil engineering subjects follow identical distribution pattern cannot be maintained for students who successfully completed the course, as results of the surveys conducted in September and December show. In the meantime, with regard to successful students, results of male and female subjects can be analysed together to maintain our hypothesis at 80% significance level. Furthermore, results in December show even less difference in such a measure that the aforesaid hypothesis can be supported even at 20% significance level.

However, the hypothesis cannot be maintained — even at 99% significance level — if architecture and civil engineering females are compared; the distributions of the two sample groups are different, hence, the two are not to be analysed as one group. This applies when only those completing the course are compared. At the same time, for male subjects, statistics does not indicate any differences from the hypothesis. In another word, male architects and civil engineers do not show considerable differences when subjected to homogeneity test.

7. Comparison of beginning and end-term results of male/female subjects

We went on to find an answer to the question which level of improvement subjects reached in those factors of spatial thinking measurable by Mental Cutting Test.

Mean scores of the sample represented in the chart of Table 1 show that the values of indexes increased in all groups. We examined for more aspects the measure and the characteristics of the increase.

We subjected the hypothesis to homogeneity test stating that the results (in September and December) of subjects successfully completing the course follow an identical distribution in certain subject groups.

We concluded that the results of male or female architects follow identical distribution even at 12% significance level, while for male and female civil engineering subjects, the hypothesis cannot be supported at 65% and 93% significance level, respectively. Hence, an improvement is mainly visible in the results of civil engineering females.

Meanwhile, other subject groups show some development too that is expressible with development percentage index. In fact, male architects reached in December the 125% of the base in September, while female architects and the civil engineering students reached 115% and 121%, respectively, female subjects reached 136%.

The development percentage, as an index, may be misleading in numerous cases, since in case of a low-scoring student (e.g. 2 points score) the index indicates 200% improvement for a poor achievement of climbing up to 4 points, even though this result is considered quite a low achievement.

This fact justifies our practice that we also introduced relative numbers of distribution to measure improvement, which relative numbers describe the improvement/decline of test subjects. Since it is easy to assume that the same subject produce different results within a short time period in the same test influenced by his momentary state, a 1 point difference in the achievement of the subject between results in September and December was not considered an improvement or a decline. Evaluating results from this aspect makes it clear that achievements improved in all groups. Civil engineering females performed best: 65% improved and only 3% produced a decline, while the rate of male civil engineering subjects was: 57% improved and 20% declined.

The achievement of architecture subjects is more balanced, 50% of the male architects and 48% of the female architects improved their results, 17% and 14% achieved at least 1 point less at the second survey, respectively. These data supports our previous observations that civil engineering females start from the lowest level of previous knowledge, but they are the most developable. Studies in Descriptive Geometry develop 3-dimensional view (or spatial ability) in all groups and act towards the reduction of initial differences.

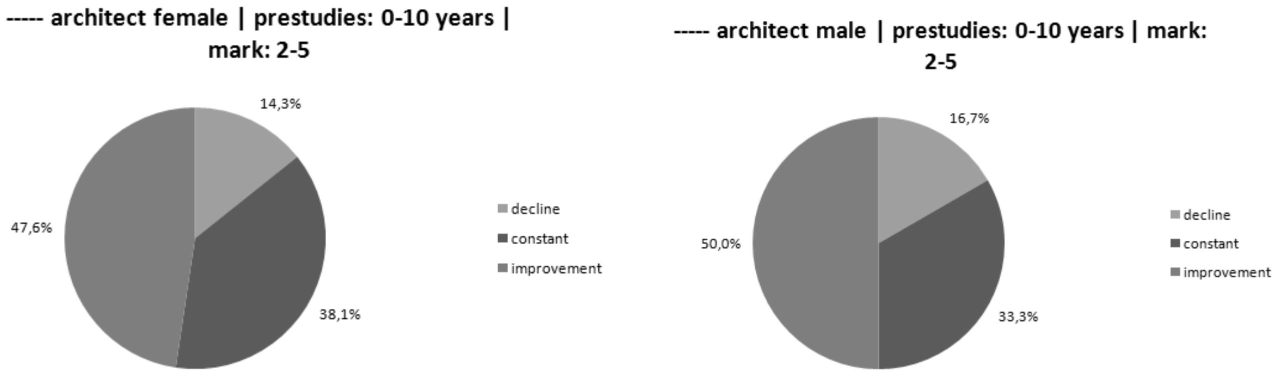

Figure 3: Achievement of architecture males/females

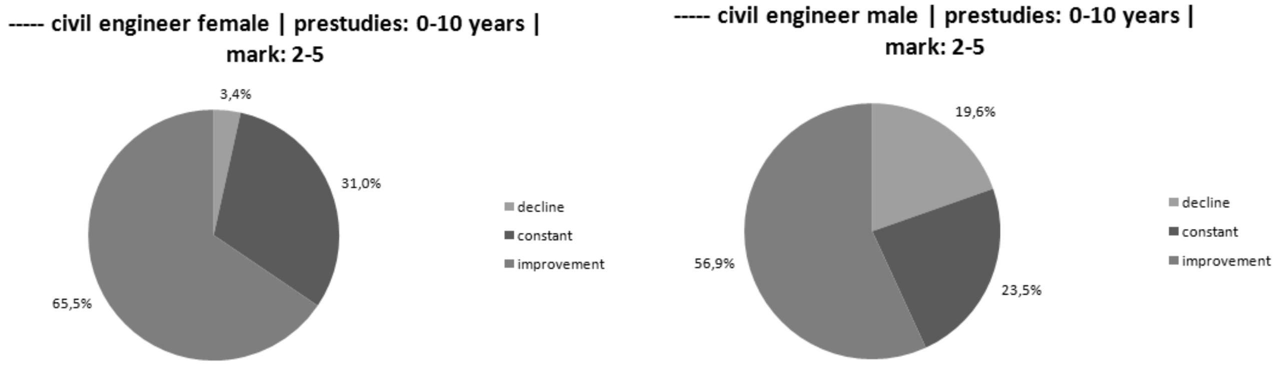

Figure 4: Achievement of civil engineering males/females

8. Describing improvement level with saturation test

The improvement of results presents a more complex problem to be described suitably by the aforesaid relative numbers. Since the limit of achievable scores is maximised, it is more difficult to get higher scores above a certain level of knowledge. E.g., a student who moved up from 10 to 12 points reached 120% improvement and was registered under the label 'improved' according to the second practice, while another getting 25 after 24 points had 104% improvement, which according to the second evaluating practice is not considered as an improvement, though the subject scored maximum points. Hence, we considered another method to describe improvement by introducing a denoting the level of saturation:

$$a = \left(\frac{h}{m}\right)^2$$

In the equation h denotes change in the number of received points in the test, m denotes the number of scores still achievable by the subject. Considering the previous example of the subject improving from 10 to 12 points, $h = 2$ and $m = 15$, since he needs 15 to reach the maximum, that is 25 points. For him, $a = \left(\frac{2}{15}\right)^2 \approx 0.02$, while for the other subject $a = \left(\frac{1}{1}\right)^2 = 1$. We believe that this index describes the improvement of the subjects more adequately, since it also considers the possessed level of knowledge.

The diagrams in Figs. 5 and 6 show a significant shift towards the dominion of positive values. At a closer inspection it reveals that the results of most civil engineering females show no change (51%), both the rate of improvement and decline are the lowest in this group. The results of civil engineering males also reflect the heterogeneity of the group in this aspect, a relatively high proportion (24%) show decline, however they are also the first in improvement rates and they produce the highest level of improvement. We also find here the highest expected value of improvement (11.11%) of all the four subject groups, however, the highest level of variation (23.33%), too. Considering the results of architecture males and females the small difference between the expected values (6.35% and 9.22%) and even more between the values of variation are significant. Although, after a more careful consideration, it reveals that female architects are rather excel in exceeding declension rates and not so much in improvement, while male architects show no tendency towards decline, but reach high level of improvement, since 48% of them produced better results and 25% improved their former achievement by at least 15%. Hence, we may declare that they constitute the subject group most reliably developable and on a suitable level.

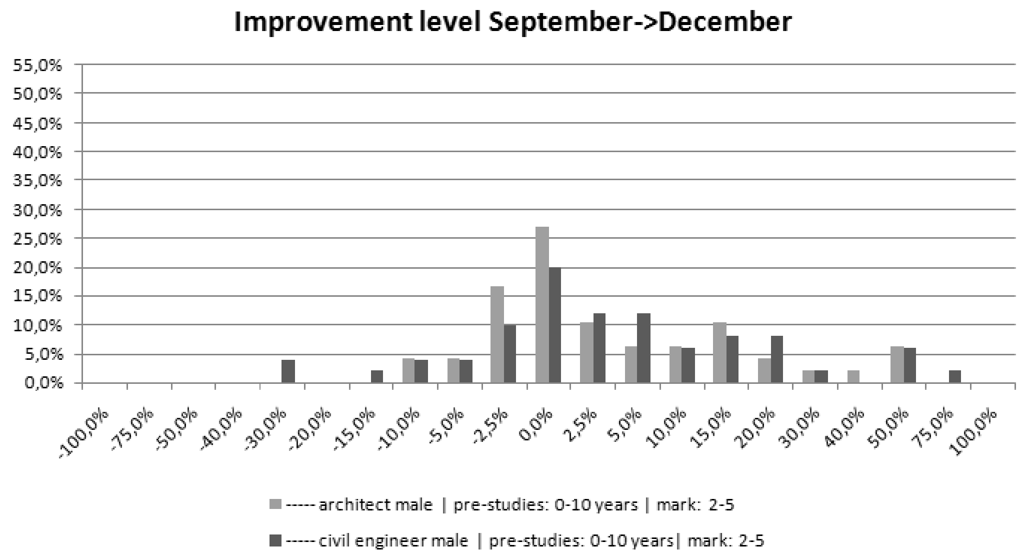

Figure 5: Distribution of the improvement of male subject with successful completion of the course

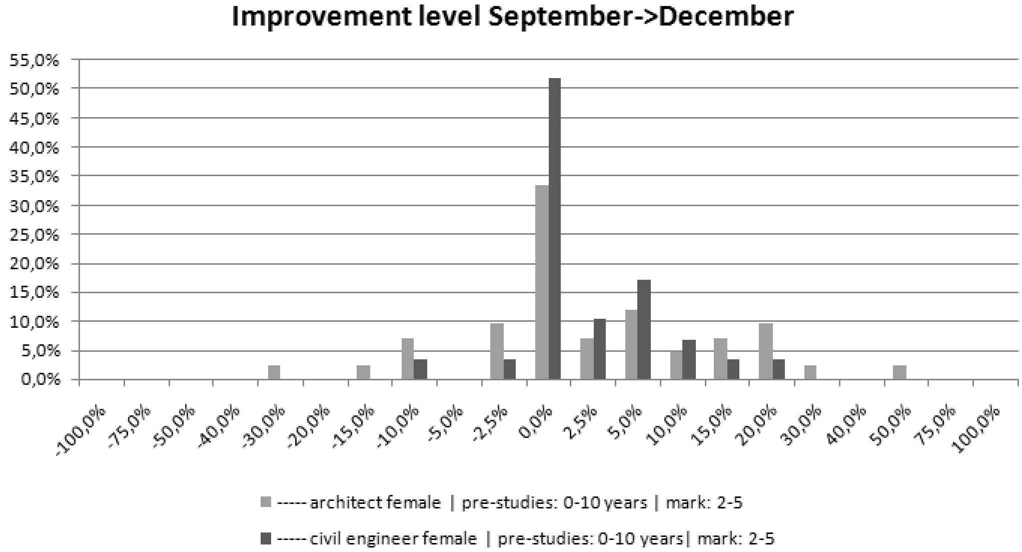

Figure 6: Distribution of the improvement of female subjects with successful completion of the course

9. Impact of previous studies on student improvement

Another tendency was defined among the factors that influenced student improvement. We analysed those subjects who successfully completed the subject. In the Architectural Engineering Department those who had no previous studies in Descriptive Geometry produced higher level of improvement that those with some previous knowledge in the discipline. However, we observed just the opposite with Civil Engineering subjects.

Those architects possessing no previous studies improved their results by 2.4 points on the average, while those having some previous studies in the discipline started from a higher level of knowledge, but produced lower results, they improved their results by 1.1 point on the average.

57% of those subjects having no previous studies improved their results, while those having it, on the average, showed neither improvement nor decline (51%). In the Civil Engineering Department 48% of those having no previous studies improved to 13.5 points, by 1.9 point on the average, while 61% of those already having attended Descriptive Geometry improved their achievement by 3.2 points on the average to 15.7 points.

Table 2: Average scores of each student group classified according to their previous studies

	Previous studies			*No previous studies*		
	Mean scores in September	*Mean scores in December*	*average level of improvement (points)*	*Mean scores in September*	*Mean scores in December*	*average level of improvement (points)*
Architect engineers	14.1	15.2	1.1	13.5	15.9	2.4
Civil engineers	12.5	15.7	3.2	11.6	13.5	1.9

Differences between course material and the depth of procession in the two departments are considered as the explanation. In the Civil Engineering Department students attend Descriptive Geometry for one semester that allows for laying down only the basics of the discipline, hence, those students has a clear advantage who brought some previous knowledge. In the Architectural Engineering Department students attend the course for more semesters, therefore they have to acquire a higher level of knowledge than merely the basics of the discipline. However, previous knowledge of the introductory chapters might influence students towards becoming less studious, since they do not start their studies from the elementary level. They have problems with catching up with the material later, when tasks and study material become more difficult to process. Their improvement is much slower than that of those students for whom every piece of information is new and who have to work hard to process the material.

Interestingly enough, previous knowledge means an advantage for completing the course successfully only for females, both for architecture and civil engineering females the rate of successful completion is 83%. This rate is lowest for civil engineering males having previous studies, 51% — they have, as it seems, too high opinions of themselves with regard to completion of the course.

10. Improvement with regard to end-term marks in Descriptive Geometry

Improvement of MCT results may also be measured in terms of analysing groups of students receiving a certain end-term mark. Based on observations, in every end-term mark cluster scores show improvement at every test. However, interestingly enough, students with a pass-mark start from lower scores than those with a fail mark. This tendency might be explained on one hand by the fact that a number of students with good or medium abilities drop out along Descriptive Geometry courses (or leave the faculty for another institute) that also requires hard work from students. On the other hand, it is diligence and persistence that might lead to the successful completion of the course — even if typically with a pass-mark. It also has to be noted that student with an excellent mark show exceeding achievement — even in the first test. These tendencies mentioned apply both for the Architectural Engineering and the Civil Engineering Departments, however, levels are higher in every cluster in the Architectural Engineering Department.

The homogeneity test analysing the results (September) of subjects receiving pass and fail marks supported that these groups of students might be analysed as one group, the null hypothesis that says the distribution of two aforesaid groups is identical can be maintained at 33% significance level for civil engineers and at 76% significance level for architects.

We also tested the null hypothesis stating the identical distribution of students receiving a pass mark or at least a 3. The hypothesis was maintainable at 81% level for civil engineers, but considering architects we found significant differences even at 99% significance level.

11. Independence test of different characteristics and successful compliance

We analysed the results of the MCT tests in order to figure out which of the registered data — major, gender, hand preference, previous studies — influences most the successful completion

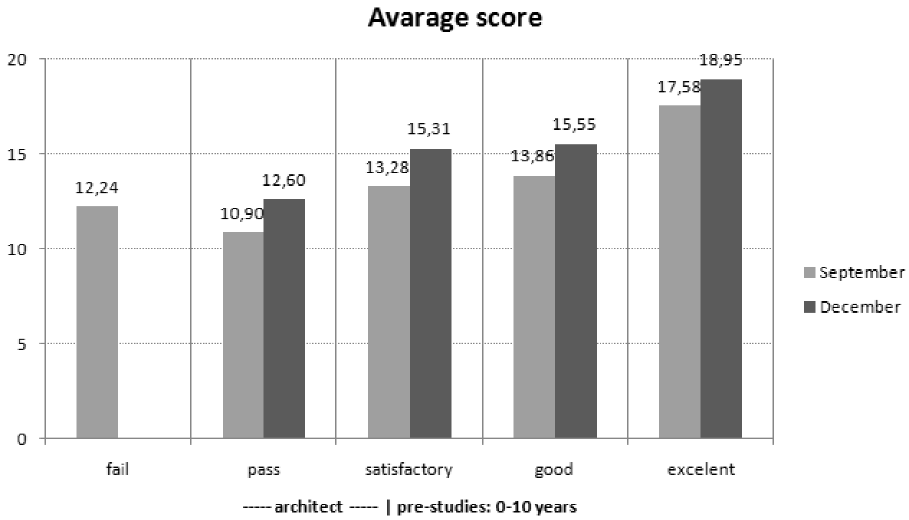

Figure 7: Change of mean scores with regard to end-term marks in the Architectural Engineering Department

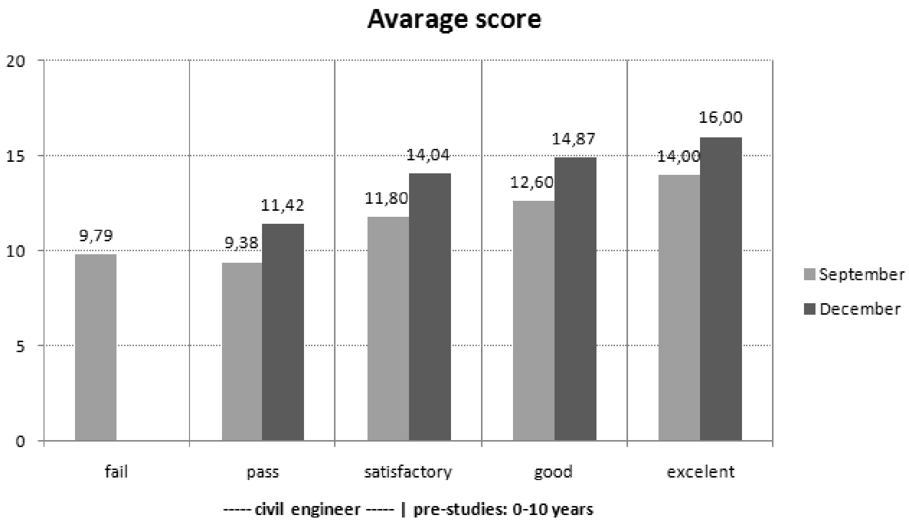

Figure 8: Change of mean scores with regard to end-term marks in the Civil Engineering Department

of the course.

To test it, they were submitted to estimated independence test leading to χ^2-test. The following statistics

$$\chi^2 = n \sum_{i=1}^{r} \sum_{j=1}^{s} \frac{\left(f_{ij} - \frac{\varphi_i \varphi^j}{n}\right)^2}{\varphi_i \varphi^j}$$

became calculable, where n denotes the number of sample elements, f_{ij} denotes frequency, φ_i and φ^j are the cumulative frequencies of the criteria. After comparing the calculated value χ^2-distribution with the chart of $(r-1)(s-1)$ degrees of freedom, the hypothesis of independence might be argued for/against.

We found that the completion of the course is not influenced by differences in major or gender; when these variables were tested, the calculated value did not contradict the hypothesis even at low significance level. Previous studies were not relevant in case of civil engineers, however, the hypothesis stating the independence of previous studies and successful compliance cannot be maintained even at 99% significance level in case of architectural engineering students.

The results of the independence test of MCT test results and end-term marks should also be considered. In the Civil Engineering Department end-term marks and test results show independence (even at 48% level), while at architectural engineers they are not independent even at 98% level, therefore the hypothesis cannot be supported.

These observations have to be examined thoroughly. We believe that the tendency might be explained partially by differences in previous studies in the discipline discussed previously. Since the training of architects requires a more profound and thorough knowledge, it presupposes that students having previous studies in the subject have a clear advantage. In case of architect students' differences in the acquired level of knowledge were more visible in recitations; good performing students received a better mark, while the poor performing got a lower mark. This tendency, as it is, was not observed at civil engineers, though. Students with good spatial thinking performed worse due to their laziness and similarly students with moderate abilities but hard working could reach a higher achievement.

In conclusion, the discipline is taught for only one semester in the Civil Engineering curriculum, which allows introducing students to the basics. Marks most of the time rarely reflect the real abilities of 3-dimensional thinking — numerous students complete the course, but the development of their spatial thinking is not satisfactory.

In case of architectural engineers the discipline is taught for more than one semester, which allows that the real changes in the 3-dimensional thinking of students are better reflected in their marks.

12. Open questions and further research objectives

In the evaluation of tests we also analysed the impact of hand preference. The hypothesis stating the independence of hand preference and successful completion was confuted at 78% significance level. Nevertheless, this high value suggests a relation between the two. Observations show that left-handed civil engineering females improved their results by 14%, while right-handed females by 37%. However, right-handed male subjects produced 19% improvement, while the rate of improvement for the left-handed males was 42%.

The rate of improvement for left-handed male students of architecture was 134%, while for right-handed male students or females with either hand preference was only 15–17%. Due to the unsatisfactory size of the sample far-reaching conclusions should not be drawn, but we might say it as an assumption that the spatial thinking of left-hand user males might be developed better than that of the others. This observation needs to be tested by further analysis — a sample with a higher number of elements. Architectural engineering subjects completed the MCT test for the third time — at the end of the second semester. We plan to publish the evaluation of those results compared with the improvement in the first and the second semesters in another publication.

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