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Engineering students' spatial abilities in Budapest and Debrecen

Rita Nagy-Kondor[a], Csilla Sörös[b]

[a]University of Debrecen, Debrecen, Hungary
rita@eng.unideb.hu

[b]Szent István University, Budapest, Hungary
soros.csilla@ybl.szie.hu

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Abstract

The goal of this paper is to provide the level of first-year engineering students' spatial abilities. We made our comparative survey at the Szent István University Budapest and University of Debrecen, Faculty of Engineering among first-year students of architecture. We made the survey among those students, who were successful in Descriptive Geometry I and II. We were looking for the answer for the question whether which part of the first-year architecture students' spatial ability and spatial geometrical knowledge is incomplete, and whether the students of two universities have sufficient differences between their spatial ability. The test results have been statistically evaluated and conclusions formulated.

Keywords: Spatial ability, Descriptive Geometry education

MSC: 51N05

1. Introduction

Spatial ability is very important for engineering students; it is decisive for their career. This ability is not determined genetically, but rather a result of a long learning process. [12] The definition of spatial ability according to Séra and his colleagues is [13] "the ability of solving spatial problems by using the perception of two and three dimensional shapes and the understanding of the perceived information and relations" - relying on the ideas of Haanstra [3] and others. McGee [7] defines spatial ability as “the ability to mentally manipulate, rotate, twist or invert pictorally presented stimuli” and classifies five components of spatial skills as

- Spatial perception
- Spatial visualization
- Mental rotations
- Mental relations
- Spatial orientation

Maier [6] distinguishes five branches of spatial intelligence too:

- Spatial perception: the vertical and horizontal fixation of direction regardless of troublesome information;
- Visualization: it is the ability of depicting of situations when the components are moving compared to each other;
- Mental rotation: rotation of three dimensional solids mentally;
- Spatial relations: the ability of recognizing the relations between the parts of a solid;
- Spatial orientation: the ability of entering into a given spatial situation.

Vásárhelyi's [17] definition of geometrical spatial ability: the mathematically controlled complex unity of abilities and skills that allows: the exact conception of the shape, the size and the position of the spatial configurations; the unequivocal illustration of seen or imaginary configurations based on the rules of geometry; the appropriate reconstruction of unequivocally illustrated configurations; the constructive solution of different spatial (mathematical, technological) problems, and the imagery and linguistic composition of this solution.

In the classification of the exercises we followed the recommendation of Séra and his colleagues [13] who approach the spatial problems from the side of the activity. The types of exercises:

- Projection illustration and projection reading: establishing and drawing two dimensional projection pictures of three dimensional configurations (Task 3, Task 4, Task 5);
- Reconstruction: creating the axonometric image of an object based on projection images (Task 6);
- Transparency of the structure: developing the inner expressive image through visualizing relations and proportions;

- Two-dimensional visual spatial conception: the imaginary cutting up and piecing together of two-dimensional figures;
- Recognition and visualization of a spatial figure: the identification and visualization of the object and its position based on incomplete visual information;
- Recognition and combination of the cohesive parts of three-dimensional figures: the recognition and combination of the cohesive parts of simple spatial figures that were cut into two or more pieces with the help of their axonometric drawings;
- Imaginary rotation of a three-dimensional figure: the identification of the figure with the help of its images depicted from two different viewpoints by the manipulation of mental representations (Task 7);
- Imaginary manipulation of an object: the imaginary following of the phases of the objective activity (Task 1 and Task 2);
- Spatial constructional ability: the interpretation of the position of three-dimensional configurations correlated to each other based on the manipulation of the spatial representations;
- Dynamic vision: the imaginary following of the motion of the sections of spatial configuration.

The measurement of spatial abilities is standardized by international tests, among which the Mental Rotation Test (MRT) and the Mental Cutting Test (MCT) are of greatest importance. MRT is introduced by Vanderberg and Kuse [16]. MCT is widely used for testing the spatial ability at any level [14]. Németh and her colleagues [9, 10, 11] presented an analysis of MCT results of first-year engineering students, with emphasis on gender differences and attempted to find possible reasons of gender difference, concluding, that typical mistakes play central role in it.

In the second section we report about the circumstances of the survey. The third section contains the results of the survey and then we examine the most frequent mistakes. The last section is the summary of the article and our experiences.

2. The comparative survey

At the Faculty of Engineering at the University of Debrecen, the architecture students selected for the engineering program acquire the basics of the Descriptive Geometry - the elements of the Monge projection, axonometric representation, perspectivity - for a year, with two lectures and two seminars per week, which they use later in their professional subjects. The lecturer made two tests and four technical drawings for the students in all semesters. The Descriptive Geometry I, II end with exam mark.

At the Szent István University, Faculty of Engineering students of architecture need to do 3 semesters of Descriptive Geometry as a basic and compulsory subject. Geometry I and II are introduced in the first two semesters with one lecture and two seminars per week and thematically structured in the classical method which is familiar with the structure of the University of Debrecen. The lecturer made two tests and ten technical drawings for the students in Descriptive Geometry I; and one test, four technical drawings and two models in Descriptive Geometry II. The Descriptive Geometry I, II end with exam mark. Descriptive Geometry III is introduced in one semester with one seminar per week. We made the survey among those students who were successful in Descriptive Geometry I and II.

The short syllabus of the Descriptive Geometry I and II at our universities:
`http://www.eng.unideb.hu/userdir/mat/hallgatok/tantargy.html`
`http://asz.tanszek.ymmf.hu`

We made our comparative survey at the Szent István University Budapest and University of Debrecen, Faculty of Engineering among first-year students of architecture. At the university in Budapest 111 students, at the university in Debrecen 87 students took the test. The test took place on the last week to check the students' spatial abilities. The students had 60 minutes to complete the task sheet.

We prepared the test in a way that it contained the important components of spatial ability. Following the theory of Séra and his colleagues [13] we made the task sheet from the more important types of tasks.

The survey:

1. We have marked a cube on three sides with three different signs: /, V, X, leaving the other three sides empty. These cubes are the ones with a star next to them. Circle the cube from among the rest of the cubes that could be the same one in a different position. (Figure 1)

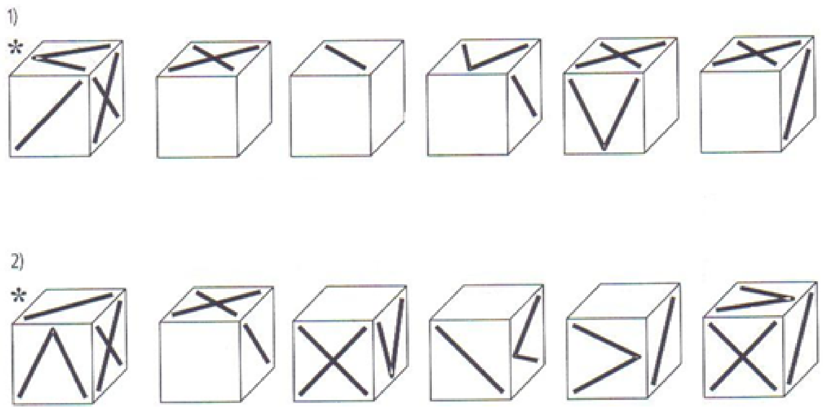


Figure 1

2. Next to the illustrations marked with a star you can see 5 objects, assembled of identical cubes, showing all the edges of the all the cubes, including the normally

hidden ones. Circle the object that could be rotated to fit through the hole in the one marked with a star. (Figure 2)

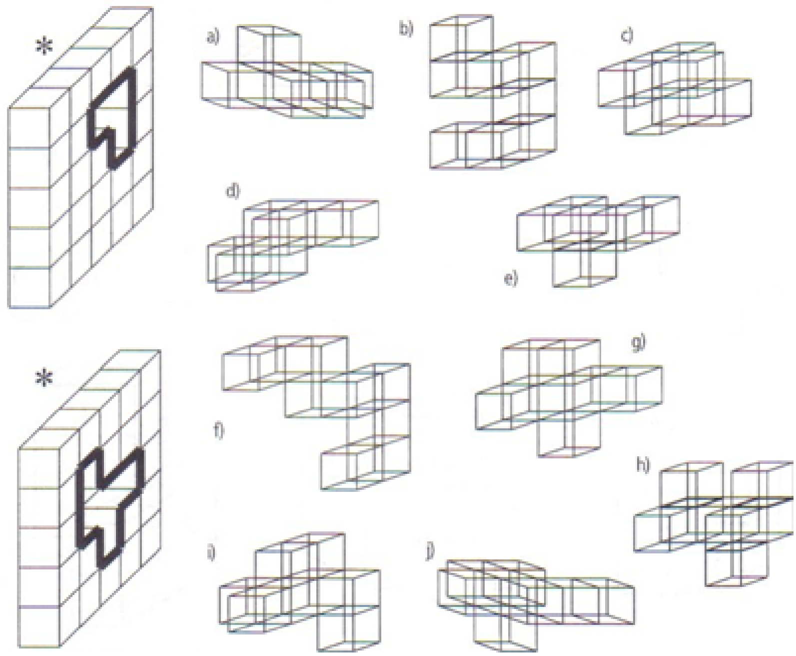


Figure 2

3. Draw the projections of the objects below, which have been cut out of cubes. Frontal view (E), Side view (O), Top view (F), based on the axonometric pictures of the objects. (Figure 3)

4. The exercises below each show two or three different perspectives of the same cable twisted into a certain shape. If we consider the first drawing as the front-view, then which view is the right side view, the left side view, back view or top view? (SZEMBŐL: Front) (Figure 4)

5. There is an axonometric picture of a wire framework built inside of a cube. The vertices of the figure are the same as the vertices of the cube or the midpoints of the sides of the cube. How can this figure be shown from the front, top, back, left and the right side? (Figure 5) (F: Top, E: Front, H: Back, J: Right, B: Left)

6. Reconstruct the solids by drawing the visible picture of it! Draw only the visible edges! (Figure 6) (F: Top, E: Front, O: Left)

Mental Rotation Test:

Of the four objects to the right which ones are identical to the original (to the left), rotated into another position? In each case there are two correct solutions. (Figure 7, Figure 8)

The first and second tasks focus on the imaginary manipulation of the solid. The task is to follow the phases of the objective activity that consist of the complex

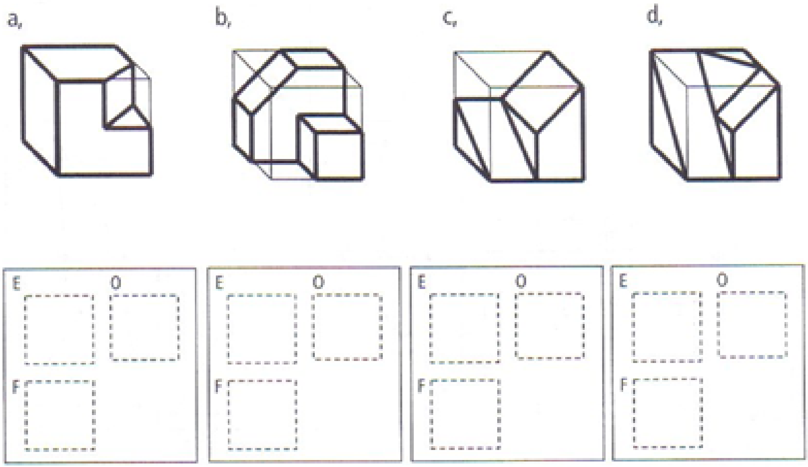


Figure 3

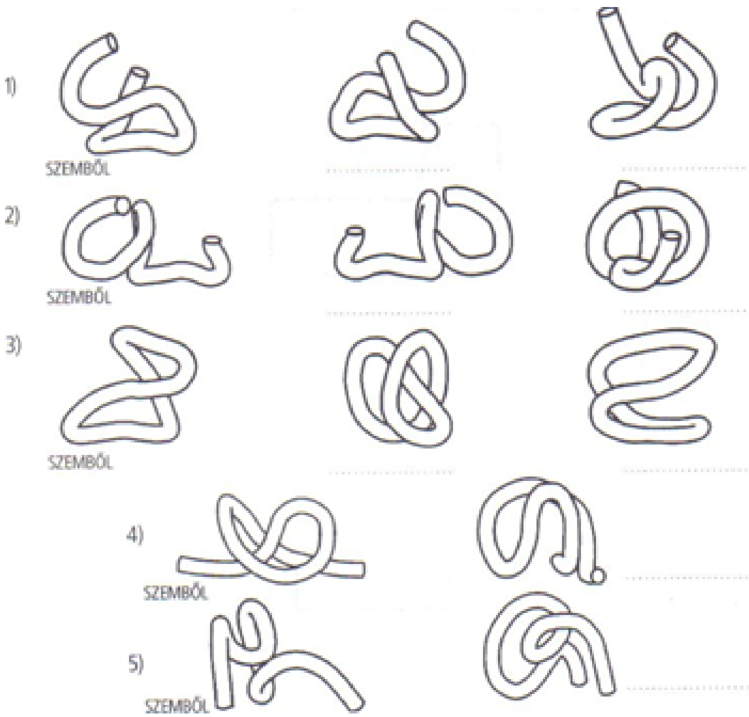


Figure 4

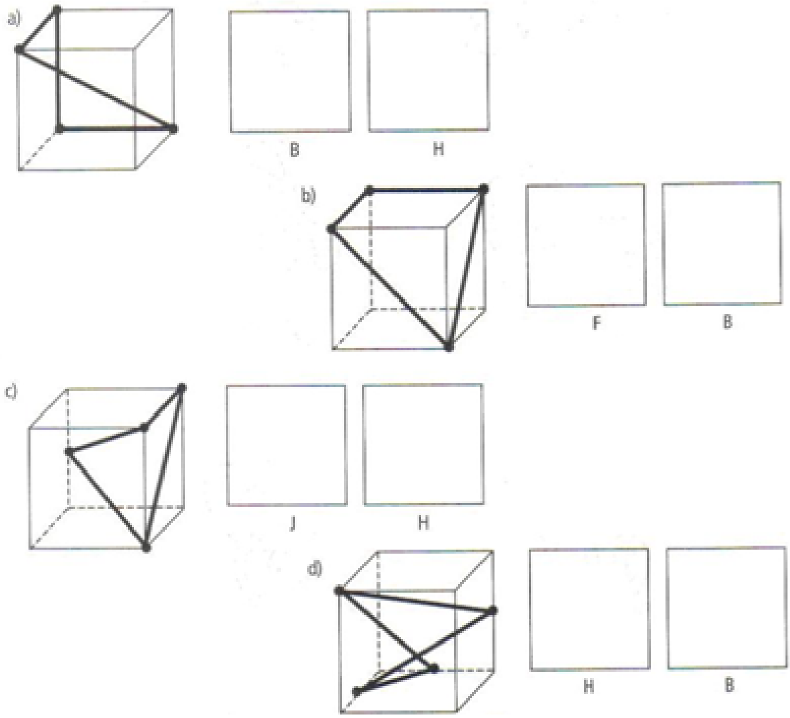


Figure 5

spatial transformation of the solid. The first task is the identification of the figure, and the second task is the manipulation of mental representations.

The third, fourth and fifth tasks belong to the types of tasks that deal with representation and reading of the projection. Mobilizing the experience of the motion, changing the inner viewpoint, imaginary rotation, manipulation of mental representations, and the task is to produce and draw the two-dimensional projection picture of a three-dimensional solid. This type of task is characterized by analytical operations from concrete to abstract.

The sixth task is a task of reconstruction. We have to create the axonometric picture of the solid based on the projected pictures. During the reconstruction the student synthesizes the visual information by studying the projected pictures. The map will be constructed by the series of changing the inner viewpoint by harmonizing three channels.

The last task is a sample of the MRT problem. Each problem is composed of a criterion figure, two correct alternatives and two incorrect alternatives. Correct alternatives are structurally identical to the criterion, but shown in a rotated position. The subjects are asked to find the two correct alternatives. The last task contains 5 MRT problems. Two points are given for a problem. The best possible score in the MRT is 10.

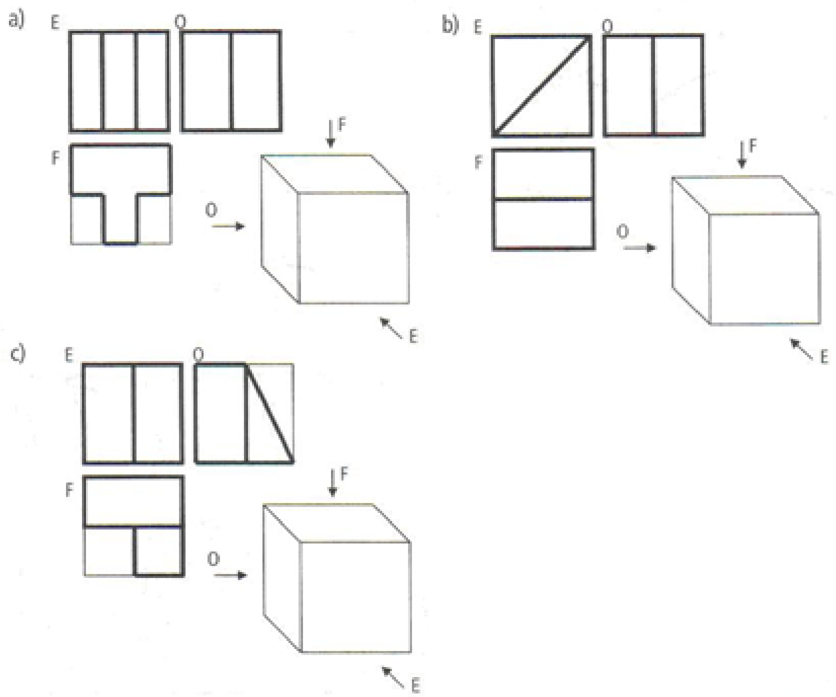


Figure 6

3. Results

The students of the Szent István University were 5% (Task 1) and 7% (Task 2) better on the tasks of manipulating the imaginary solid. At the Szent István University there were 2% more students, who knew the correct solution in the reconstructural task (Task 6).

In the exercises of the representation of projections the students of the University of Debrecen scored 1% (Task 4) and 5% (Task 5) better than the other one.

We examined furthermore the differences between the genders in solving these exercises. The list of 7 tests contained altogether 18 exercises. We looked at what percentage of the students gave correct answers for each exercise and then we examined them by gender: what percentage of the female students and what percentage of the male students succeeded. Of the 111 students at the Szent István University 57 were males (51%) and 54 females (49%). At the University of Debrecen of the 87 students 45 were males (52%) and 48 females (48%). At the Szent István University the male students performed better in 16 of the 18 exercises and in only 2 exercises did the female students give more right answers (1/1 and 6/b). At the University of Debrecen the male students did better in 15 exercises of the 18, the

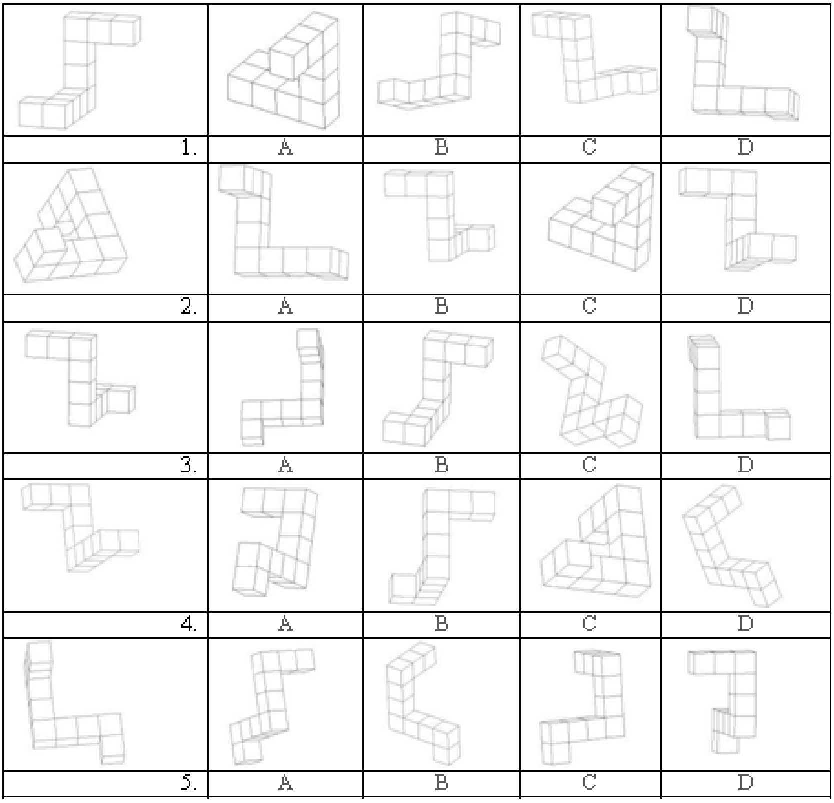


Figure 7

female students in 3.

The students of the Szent István University did better than the students of the University of Debrecen in all the exercises that concentrate on mental rotation. They were better by 6% at 1/1, 3% at 1/2, 9% at 2/1, 6% at 2/2. At the Szent István University the female students did better by 1% at exercise 1/1, while at the University of Debrecen they did 6% worse than the male students. At both universities the males performed better in all the rest of the exercises of both tests.

Task 2, in which both genders performed less well, is composed of 2 exercises. Both groups managed to solve the Task 2 the worst of all, and this exercise was the biggest difference between the two groups. In the diagram we can tell that the second part proved to be the more difficult one. Both the male students and the female students made the most mistakes in this part. This exercise can be solved with mental rotation and requires excellent spatial abilities. The MRT shows that mental rotation was not the difficulty because this is where they actually did the best. This exercise can be linked to number 4 where we could rephrase the question and ask whether there are any perspectives of the given objects that can be fit

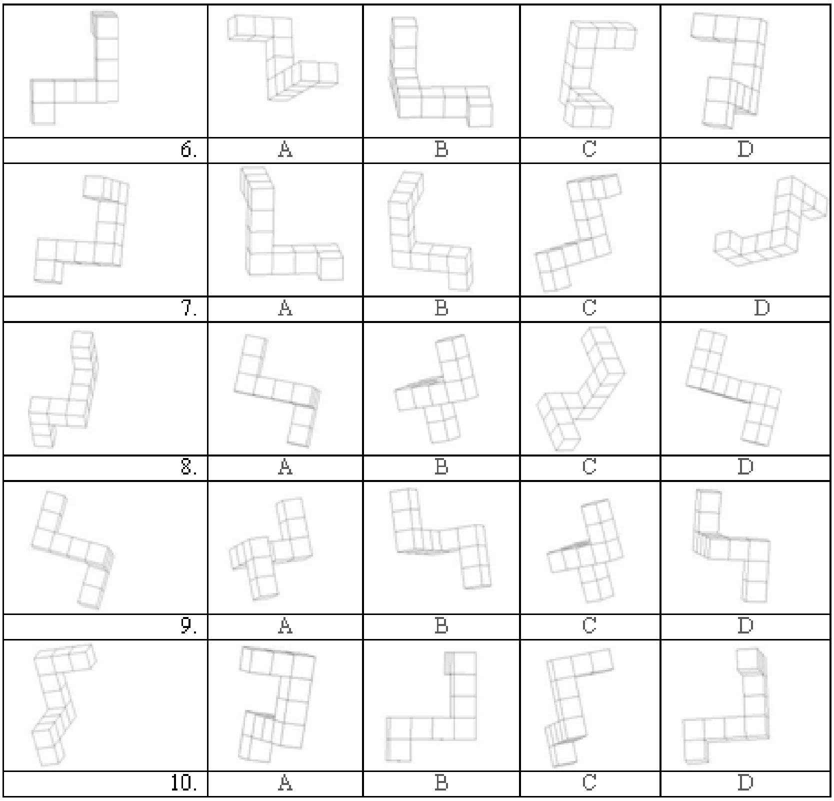


Figure 8

through the holes. So for successfully solving this task they need to be able to deal with perspectives and rotation. The hidden edges being shown further complicated the task.

The students of the University of Debrecen performed better at most of the tasks concentrating on representation and reading projection. 9% better at 3/b, 1% at 3/c, 1% at 4, 6% at 5/a, 4% at 5/b, 12% at 5/c. At the University of Debrecen the female students were better by 4% at 3/a, by 8% at 3/b and by 2% at 5/b. In all the part of tasks 3, 4 and 5 the male students did better at both universities, while the most difficult for all of them was 5/d.

One of the typical errors the students made was not to do with their spatial abilities but rather their consistency. In exercise 3, where they had to draw perspectives of objects, the problem was that they couldn't prepare the drawing. The ability to make these drawings is expected of students of architecture that had taken two semesters of Descriptive Geometry, drawing and other basic studies. The most common mistake was inconsistency in their drawings. In some cases they included in their drawing the frame that had been prepared for them ahead, while in other cases they didn't. The students of the Szent István University 21%, the University of Debrecen 22% made the mistake of not being consistent with using the frame. The students of the Szent István University 38%, while the University of Debrecen 37% gave a perfect solution for the task.

We can see a great difference between the male students and female students of the Szent István University at exercise 4, where 70% of the female students and 80% of the male students gave the correct solution, while at the University of Debrecen 75% of the female students and 77% of the male students solved the exercise well. This is a perspective task where the object has to be left unrotated and the student has to decide which perspective the given object matches. Although this exercise was not where they performed worst, after completing the test they all agreed that this had been the most difficult for them to solve.

At task 5 some students couldn't picture mentally the perpendicular projection of some parts of the twisted cable. They either didn't draw any of the projections or left out parts of the object. In the three parts of this task (5/a, 5/b, 5/c) the students of the University of Debrecen performed better.

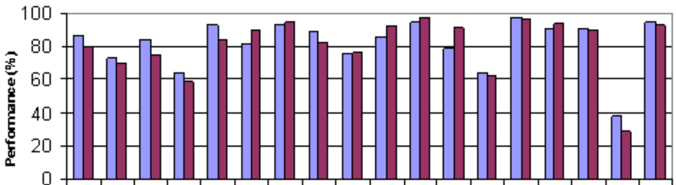
Of the reconstruction tasks in 6/a both groups performed at 97%, this is the part of task both groups did better at. The students of the University of Debrecen did better by 4% at 6/b, which is one where the female students at the Szent István University did better by 5% than the male students. At all the part of task 6 the male students performed better at both universities. At 6/a and 6/c the students performed with the same results at both universities. In 6/d Szent István University did better by 9%. 6/a was the one where both universities did best and 6/d where they did worst. 6/d has proved to be by far the most difficult one of task 6 for all the students. Here most of the students made were the reconstructions of object either incomplete or wrong. This is where we can observe the largest difference between the male students and female students: at the Szent István University the males performed better by 27%, while at the University of Debrecen by 11%.

Based on these findings we can conclude that there is no significant difference between the performances of the students of these two universities.

The students of the Szent István University were better in the tasks of manipulating the imaginary solid and in reconstructural task. Based on the comparison of the curricula, tests, technical drawings and the results of our test we can conclude that the students of the Szent István University were better at imaginary manipulation of the object, since they have more technical drawings and models creating.

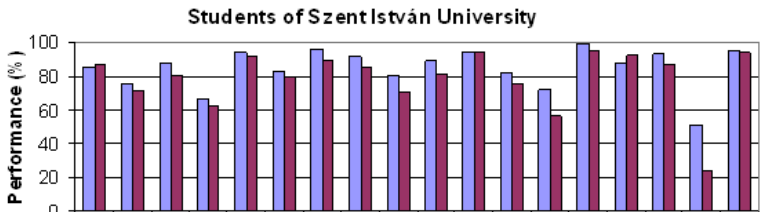
But in the exercises of the representation of projections the students of the University of Debrecen scored better than the other one, maybe because and they spent more time with descriptive geometry in two lectures per week, so they can see the connections better and have more practice in description and reading of projection tasks solving.

Figure 9, Figure 10 and Figure 11 show the performance of the students on the test.



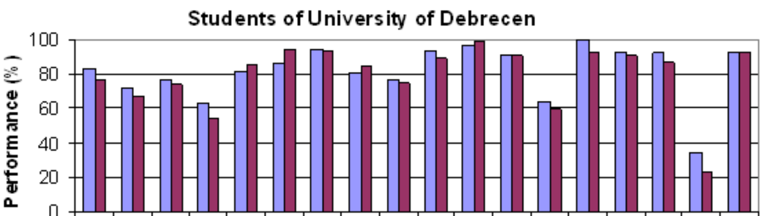
	1/1.	1/2.	2/1.	2/2.	3/a.	3/b.	3/c.	3/d.	4.	5/a.	5/b.	5/c.	5/d.	6/a.	6/b.	6/c.	6/d.	MRT
Students of Szent István University	86	73	84	65	93	81	93	89	75	86	94	79	64	97	90	90	38	94
Students of University of Debrecen	80	70	75	59	84	90	94	83	76	92	98	91	62	97	94	90	29	93

Figure 9: Students' performance



	1/1.	1/2.	2/1.	2/2.	3/a.	3/b.	3/c.	3/d.	4.	5/a.	5/b.	5/c.	5/d.	6/a.	6/b.	6/c.	6/d.	MRT
Male	86	75	88	67	94	83	96	92	80	89	95	82	72	99	88	93	51	95
Female	87	71	80	62	91	80	90	85	70	81	94	75	56	95	93	87	24	94

Figure 10: Students' performance



	1/1.	1/2.	2/1.	2/2.	3/a.	3/b.	3/c.	3/d.	4.	5/a.	5/b.	5/c.	5/d.	6/a.	6/b.	6/c.	6/d.	MRT
Male	83	72	76	63	82	86	95	81	77	94	97	91	64	100	92	92	34	93
Female	77	67	74	54	86	94	94	85	75	89	99	91	60	93	90	87	23	93

Figure 11: Students' performance

4. Conclusion and further research

Spatial abilities of first-year engineering students have been studied in this paper. Their abilities were tested by several tests (MRT, imaginary manipulation, representation and reading of the projection, reconstructural task). The results of our survey prove that the reconstruction and representation of the projection cause a problem for many students, as well as to imagine a spatial figure.

Stachel and his colleagues' [15] results were as follows in an experience: There were statistically significant differences between males and females in almost all groups except one. In accordance with the international experiences [2] [4] we observed improvement after two semesters of descriptive geometry courses. [8] [11] Several research papers reported gender differences in the results of the spatial abilities test, and we have observed in our research gender differences too. Female students may not have the same spatial ability skills as male students, which can partly explain gender differences in spatial ability test; also female students choose typical mistake in some tasks more frequently, than male students.

The results of the survey prove that it causes a problem for many students to imagine and manipulate a spatial figure. It would be very useful for the university courses some review-systematization classes should be devoted for the summary of spatial ability, spatial geometry and solving spatial geometrical tasks. The effectiveness of teaching spatial geometry can be influenced to a great extent by using several different models, more technical drawings, manipulation activities with spatial models, especially dynamic, in the demonstration of relations between spatial models and operations with them. Vásárhelyi [17] calls the attention to the use of computers besides the traditional models. The three-dimensional models can be a great help in the teaching and learning of geometry. It is much easier to imagine and represent different views of a solid when we can see the formal characteristics. The proper use and frequent study of spatial visual aids can result in such an inner spatial vision that makes the individual imagination of the spatial relations possible.

Lord [5] applied a 30 minutes practice on a 14 weeks course with first/second year students where they had tasks in which they had to cut three-dimensional solids in their mind and then they had to draw the surface of the two-dimensional planes they got. In the post-test the spatial awareness and efficiency became better. Field [1] describes work conducted at Monash University aimed at measuring spatial skills, improving the sensitivity of visualization tests, and developing the skill for some engineering undergraduates. The testing of undergraduate students at Monash University has indicated the following factors:

- First level engineering students are to possess specially higher spatial skills than the general population.
- Spatial skills are not measurably developed by a conventional mechanical engineering undergraduate course.
- A special course with about 50 contact hours appears to have been successful in developing visualization skill in first level engineers. (There is some evidence that freehand drawing of three dimensional objects, in orthogonal, isometric and perspective views makes a major contribution to the development of spatial skill.)

We all agree in that the development of the spatial ability is a very important task because we have to understand and develop the geometry knowledge of the students in the unity of the theoretical knowledge and the spatial abilities. Every skill, like the spatial ability as well can be developed at the right age with the suitable teaching strategy. The results of the survey prove that it causes a problem for many students to imagine a spatial figure and this way it affects the solving of spatial geometrical tasks as well. Therefore it would be very useful to start the teaching of spatial geometry with spending more time with the models of spatial solids, and should be devoted for the summary of spatial ability, spatial geometry and solving spatial geometrical tasks. The effectiveness of teaching spatial geometry can be influenced to a great extent by using several different models, manipulation activities with spatial models, especially dynamic, in the demonstration of relations between spatial models and operations with them. Future work will be focused on task based student interviews to reveal the problems and their results.

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