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THE INFLUENTIAL FACTORS IN IMPROVING THE SPATIAL ABILITIES OF ARCHITECTURE STUDENTS

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THE INFLUENTIAL FACTORS IN IMPROVING THE SPATIAL ABILITIES OF ARCHITECTURE STUDENTS

ABSTRACT

In this paper, the factors that influence the improvement of spatial abilities of architecture students were examined. The main question was whether the course in Descriptive Geometry at the Faculty of Architecture, Civil Engineering, and Geodesy at the University of Banja Luka had an impact on students' spatial abilities. The study examined 118 students of the first year comparing their success at Spatial Ability tests in relation to whether they attended the Descriptive Geometry course. The obtained results of the study showed a significant improvement in students' spatial abilities in general and that the Descriptive Geometry course did not have a substantial influence on spatial abilities development. The SPSS v.20 analytical-statistical software package is used for the statistical analysis.

Key words: *spatial abilities, descriptive geometry, architecture, statistical analysis*

ФАКТОРИ КОЈИ УТИЧУ НА ПОБОЉШАЊЕ ПРОСТОРНИХ СПОСОБНОСТИ СТУДЕНАТА АРХИТЕКТУРЕ

Апстракт: У овом раду испитивани су фактори који утичу на побољшање просторних способности студената архитектуре. Главно питање је било да ли је курс Нацртне геометрије на Архитектонско-грађевинско-геодетском факултету Универзитета у Бањој Луци утицао на побољшање просторних способности студената. Студија је испитала 118 студената прве године упоређујући њихов успјех на тестовима просторних способности у односу на то да ли су похађали курс Нацртне геометрије. Добијени резултати студије показали су значајно побољшање просторних способности студената уопште, као и да курс Нацртне геометрије није имао велики утицај на развој просторних способности. За статистичку анализу кориштен је аналитичко-статистички програмски пакет SPSS v.20.

Кључне ријечи: просторне способности, нацртна геометрија, архитектура, статистичка анализа

1. INTRODUCTION

1.1. SPATIAL ABILITIES AND THEIR IMPORTANCE FOR ENGINEERING STUDIES

Spatial cognition proved to be very significant for success in many STEM fields (Science, Technology, Engineering, and Mathematics), including engineering professions. It has been highly correlated with success in mathematics [1,2]. A direct correlation between spatial skills and the ability to solve several types of PISA mathematics problems was established from the study results in [1]. Architects communicate with others primarily by graphical means, so the spatial abilities of architecture students must be well-developed. The assessment and improvement of spatial skills is an essential research topic for the study of architecture.

It is necessary to understand the meaning of concepts and the difference and the connection between spatial abilities, spatial skills, spatial thinking, and spatial intelligence in understanding spatial abilities.

The spatial ability is the ability to retain, retrieve and transform visual images [3]. A person is born with such abilities. On the other hand, *spatial skills* have been learned or acquired through some formal or informal training [4]. There is not much difference between these terms in literature since there has not been any training of these abilities in formal education. *Spatial thinking* involves thinking about shapes, arrangements, and interrelations of objects in the space and spatial processes, such as the deformation of objects and the movement of objects and other entities through the space. *Spatial intelligence* can be defined as adaptive spatial thinking, and it is also central to many scientific domains. Spatial ability tests are commonly used to measure and determine the fundamental spatial thinking components/factors. This approach is used in most research on spatial skills [5, 6].

The question and challenge for researchers dealing with this topic are whether spatial abilities can be learned and improved and in what way and which factors influence the improvement of spatial abilities and skills.

For engineering students, an essential ability is to visualize 3D objects and perceive the way they look (appear) from different viewpoints or what their appearance would be if they were rotated or transformed in the space [7]. Some authors proved that spatial skills could be developed through practice or some courses at the University, such as Engineering Graphics [7, 8], Descriptive Geometry, or Preparatory course (Spatial Perception and Presentation course) for the entrance exam at the Faculty of Architecture [9].

For the past decade, the importance of descriptive geometry was pushed back in many curricula of engineering studies. Geometry education was often substituted by training in CAD software and representation techniques. This development leads to a deficiency in the spatial visualisation abilities of engineering students. The Descriptive Geometry course provides foundations for creating and understanding 2D drawings of 3D objects, and it helps develop spatial visualization abilities [10].

In this paper, we will focus on examining the factors that influence the improvement of spatial abilities of architecture students and whether the course in Descriptive Geometry is one of them.

1.2. SPATIAL ABILITY TESTS, SPATIAL ABILITY TRAINING COURSE, AND DESCRIPTIVE GEOMETRY COURSE

Since 1930, when spatial abilities became an important research topic in educational psychology [1], various tests for measuring spatial skills have been developed. Classical tests important to engineering teachers consist of tasks that measure the same factors, crucial to spatial visualisation.

There are many types of tasks that are used for assessing spatial abilities in literature, and the most common ones are the Mental Rotation Test (MRT), the Differential Aptitude Test: Space Relations (DAT: SR), and the Mental Cutting Test (MCT) [4].

The Mental Rotation Test (MRT): A 3D object is given, and the task is to choose the correct form from four alternatives that would result from the rotation of the given object.

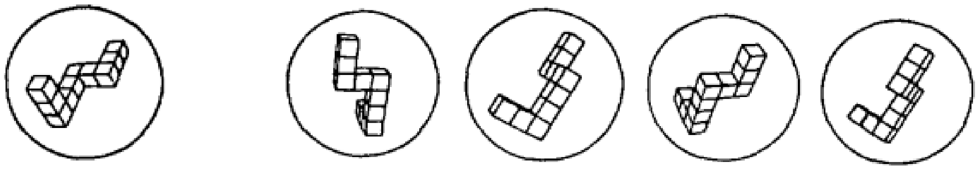

Figure 1. Vandenberg and Kuse Mental Rotations Test [11]

The Differential Aptitude Test: Space Relations (DAT: SR): The task is to choose the correct 3D object from four or five alternatives that would result from folding the given 2D pattern.

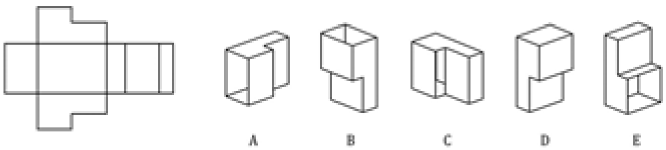

Figure 2. An example of the Differential Aptitude Test [4]

The Mental Cutting Test (MCT): The task is to recognize the correct shape of the section after a 3D object has been cut with a plane.

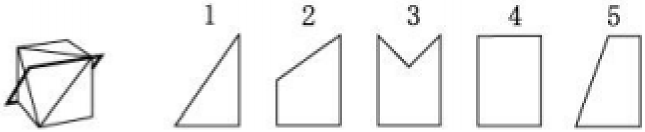

Figure 3. An example of the Mental Cutting Test [12]

Some forms of Spatial ability tasks have been included in the entrance exam at the Faculty of Architecture, Civil Engineering, and Geodesy in Banja Luka (FACEG) for the prospective students of architecture. These tasks are based on the aforementioned types but with some adaptations specifically aimed to assess higher levels of candidates' spatial abilities/skills. Since those skills have not been trained in candidates' earlier education, the FACEG has been organising the Spatial Perception and Presentation course for the enrollment at the Faculty for the past ten years. The 20-hour course is held during the two weeks of June, just before the entrance exam, and this course combines spatial ability tasks and tasks from the previous entrance exams. Since this course is not obligatory and some candidates had an introductory course in Descriptive Geometry in their secondary education, the level of candidates' spatial abilities/skills differentiates very much by the time they enrol at the first year at the FACEG.

The Descriptive Geometry course at the FACEG has been held in the first year of architecture studies. It combines basic theoretical terms of a point, line, plane, and solids in Monge's projections. Students learn about the techniques of their precise construction, applying them in theoretical tasks drawn by hand. Even though students had some training in solving spatial tasks while preparing for the entrance exam at the Faculty, or some of them had this subject in their secondary education, the majority of them still find this subject one of the hardest in the first year of their studies.

In this paper, we examine the influence of those factors on students' spatial ability starting with the premise that the Descriptive Geometry (DG) course had an effect on improving those skills. Later we introduce the impact of the preparatory course and previous contact with Descriptive Geometry in high school (DGhs) on those skills.

2. RESEARCH METHODS AND ORGANISATION

To determine the influence of the DG course on students' spatial abilities, we conducted a spatial ability test designed for this research on two groups of students - those who finished the DG course and those who had not by the time the Spatial ability test (SAT) was conducted. We compared their success.

Usually, the Descriptive Geometry course is held in the second semester of the first year of architecture studies. Still, since last year, the generation of 2020/21 enrolled according to the new curriculum; unlike previous generations, they took a course in Descriptive Geometry in the first semester. At the same time, two spatial ability tests (SAT) have been conducted for the past three years - at the beginning and at the end of the first semester.

The SPA test was designed specifically for this research. It consisted of 8 tasks in total: four tasks were from the group of the Mental Rotation tests (MRT), two tasks from the Mental Cutting Test group (MCT), and two tasks from the Differential Aptitude Test: Space Relations (DAT: SR). The first four tasks were more accessible (evaluated with 1 point each), and the other four were advanced level tasks (evaluated with 2 points each). So, the maximum score on each test was 12 points.

Out of 175 students of the first year at the Faculty of Architecture, Civil Engineering and Geodesy at the University of Banja Luka enrolled in the academic years 2018/19, 2019/20, and 2020/21, a total of 118 students were tested. Students were observed as two groups, depending on whether they attended the Descriptive Geometry course in the first or second semester. The first group (Group 1) of students of the 2018/19 and 2019/20 generation attended it during the second (summer) semester, while the second group (Group 2) of the 2020/21 generation attended it in the first (winter) semester according to the new curriculum. All students were tested in the first semester of the year they were enrolled in. Students took the first spatial ability test - TEST 1 at the beginning of the first semester and the second (control) spatial ability test - TEST 2 at the end of the first semester. The tests lasted 25 minutes each. The first and the second test were not identical, but they had the same structure and task types.

We used the SPSS v.20 analytical-statistical software package for the statistical analysis, using descriptive statistics for presenting and summarising data, the Paired Samples t-Test, nonparametric Mann-Whitney U test, $\chi 2$ test, and Spearman's rank correlation coefficient. The variables observed in this study did not have a normal distribution [13].

Table 1. *Number of students by years of enrollment and Descriptive Geometry course in high school*

			DGhs		
			Y	N	Total
YEAR	2018	Count	14	22	36
		% of Total	11.9%	18.6%	30.5%
	2019	Count	12	29	41
		% of Total	10.2%	24.6%	34.7%
	2020	Count	13	28	41
		% of Total	11.0%	23.7%	34.7%
Total		Count	39	79	118
		% of Total	33.1%	66.9%	100.0%

Table 1 shows that out of the total number of tested students, 33.1% (39) had a Descriptive Geometry subject in high school, and 66.9% (79) did not.

Out of the total number of tested students, 93 (78.8%) were female and 25 (21.2%) male.

The main questions of this research are:

RQ1. Does the course in Descriptive Geometry at the FACEG improve the spatial abilities of architecture students?

We compared the scores of the first and second spatial tests in two experimental groups of students. The aim was to determine if there was any significant improvement in the level of spatial abilities in the group that attended the DG course (second group) in relation to the first group.

After a general analysis of the results, the test structure was examined in more detail regarding the difficulty and task types to determine which tasks students had the most success with and whether there was progress in solving any particular kind of tasks.

RQ2. Does the course in Descriptive Geometry in high school or attending the Spatial Perception and Presentation course for enrollment at the Faculty impact success on the TPS1 test?

We compared the success of architecture students of all three observed generations on the first SAT (TEST 1) in relation to the attendance of preparatory classes and having the DG course in high school, in general, by groups, and by group types of tasks.

3. RESULTS AND DISCUSSION

3.1. THE ANALYSIS OF THE INFLUENCE OF DESCRIPTIVE GEOMETRY ON IMPROVING THE LEVEL OF SPATIAL ABILITIES

Table 2. *Overall success in the first and the second (control) test by years of study*

		N	Mean	Std. Deviation	Median	Min.	Max.
TEST 1	2018	36	.5244	.17682	0.54	.25	.92
	2019	41	.5139	.20151	0.50	.17	1.00
	2020	41	.5068	.16846	0.50	.08	.88
	Total	118	.5147	.18162	0.50	.08	1.00
TEST 2	2018	36	.6947	.21627	0.67	.25	1.00
	2019	41	.6210	.23208	0.58	.17	1.00
	2020	41	.5702	.20526	0.58	.21	1.00
	Total	118	.6258	.22217	0.63	.17	1.00

The Paired Samples t-Test showed a statistically significant difference in success between the first and second spatial ability tests in all students together (t=-5.256, df=117, p=0.000). Students achieved better scores in the second test (Table 2).

Table 1 shows that all three generations on the first test had about 50% success, and on the second test, they achieved significantly better success. The 2018 generation achieved the best success; they achieved a success rate of almost 70%.

Table 3. *Overall success in the first and the second (control) test by groups*

		N	Mean	Std. Deviation	Median	Min.	Max.
TEST 1	Group 1	77	.5188	.18920	.50	.17	1.00
	Group 2	41	.5068	.16846	.50	.08	.88
	Total	118	.5147	.18162	.50	.08	1.00
TEST 2	Group 1	77	.6555	.22641	.67	.17	1.00
	Group 2	41	.5702	.20526	.58	.21	1.00
	Total	118	.6258	.22217	.63	.17	1.00

The Mann-Whitney U test did not show a statistically significant difference in success on the Test 1 between students of the Group 1 (N = 77, Md = 0.5) and Group 2 (N = 41, Md = 0.5), (U = 1557.000, z = -0.122, p = 0.903), while on the Test 2 it showed a statistically significant difference in success (U = 1225.000, z = -2.004, p = 0.045). Students of the 2018 and 2019 generation (N = 77, Md = 0.67) showed better joint success compared to the 2020 generation (N = 41, Md = 0.58).

The obtained results indicate that Descriptive Geometry did not significantly impact the development of spatial abilities with students of the 2020 generation. This shows that their spatial abilities did improve during the first semester, but the reason for that might not lie in learning Descriptive Geometry.

3.1.1. Analysis by types of tasks

Analysing the tasks by types, we grouped them as follows:

a) four tasks from the group of the Mental Rotation Test (MRT) with a total of 6 points;
b) two tasks from the Mental Cutting Test group (MCT) with a total of 3 points;
c) two tasks from the Differential Aptitude Test: Space Relations (DAT: SR) with a total of 3 points

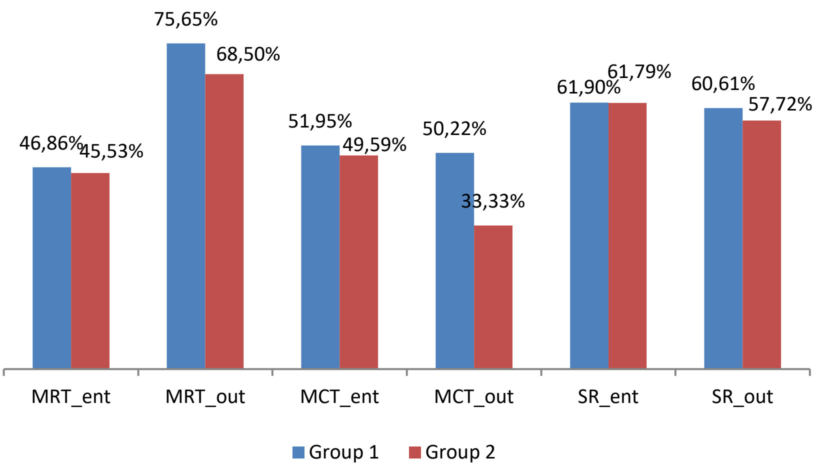

Chart 1. *The average success of both groups by types of tasks on tests (in percentages)*

Graph 1 shows the most progress in Mental Rotation tasks (MRT) for both groups. Group 1 achieved an average of 46.86% success in Test 1 on tasks of this type, and 76.65% in Test 2, while Group 2 achieved an average of 45.53% success in Test 1, and 68.50% in Test 2. The Paired Samples t-Test showed a statistically significant difference in success at MRT tasks between Test 1 and Test 2 ($t=-7.683$, $df=76$, $p=0.000$) in Group 1 and Group 2 ($t=-5.699$, $df=40$, $p=0.000$).

The Mann-Whitney U test did not show statistically significant difference in success at the mental rotation (MRT) tasks in Test 1 between Group 1 ($N = 77$, $Md = 0.4167$) and Group 2 ($N = 41$, $Md = 0.4167$) ($U = 1534{,}000$, $z = -0.254$, $p = 0.799$), nor in Test 2 ($U = 1293.500$, $z = -1.639$, $p = 0.101$). Both groups were equally successful in solving these tasks.

Regarding MCT tasks, Graph 1 shows that Group 1 had almost the same success in both tests (51.95% in Test 1 and 50.22% in Test 2), while Group 2 had less success on these tasks in the second test (49.59% on Test 1 and 33.33% on Test 2). The Paired Samples t-Test showed a statistically significant difference in success at MCT tasks between Test 1 and Test 2 ($t=2.178$, $df=76$, $p=0.035$) for Group 1.

χ^2 did not show a statistically significant difference in success between groups at MCT tasks in Test 1 ($\chi^2 = 2.184$, $df=3$, $p=0.535$), but did in Test 2 ($\chi^2 = 8.271$, $df=3$, $p=0.041$).

χ^2 did not show a statistically significant difference in success between groups at the Space Relations (DAT: SR) in Test 1 ($\chi^2 = 0.886$, $df=3$, $p=0.829$), and in Test 2 ($\chi^2 = 5.650$, $df=3$, $p=0.130$). Graph 1 shows that tasks of this type were done equally successful in both tests.

3.2. THE ANALYSIS OF THE RESULTS IN RELATION TO THE ATTENDANCE OF THE PREPARATORY COURSE AND DESCRIPTIVE GEOMETRY IN HIGH SCHOOL

Out of the total number of observed students, 58 attended the Spatial Perception and Presentation course (SPP) for enrollment at the faculty, and 60 of them did not. The Mann-Whitney U test did not show a statistically significant difference in success in Test 1 or 2 between students depending on their SPP course attendance (Table 4).

For students who attended a preparatory course in SPP, there is no statistically significant correlation between success in Test 1 and Test 2.

For students who did not attend the preparatory course in SPP, there is a statistically significant high positive correlation between success in Test 1 and success in Test 2 (r_S=0.539).

Table 4. *Overall success in the first and the second test according to the attendance of the preparatory course by groups*

Group	PPS course	TEST 1 N	Mean	Std. Deviation	Median	TEST 2 N	Mean	Std. Deviation	Median
Group 1	Y	39	.5097	.18142	.5000	39	.6890	.23554	.6700
	N	38	.5282	.19887	.5000	38	.6211	.21427	.5800
	Total	77	.5188	.18920	.5000	77	.6555	.22641	.6700
Group 2	Y	19	.5358	.15316	.5800	19	.5968	.19568	.6300
	N	22	.4818	.18036	.4800	22	.5473	.21503	.5400
	Total	41	.5068	.16846	.5000	41	.5702	.20526	.5800
Total	Y	58	.5183	.17176	.5200	58	.6588	.22579	.6700
	N	60	.5112	.19206	.5000	60	.5940	.21572	.5800
	Total	118	.5147	.18162	.5000	118	.6258	.22217	.6300

3.2.1. Analysis by groups

For students who attended the SPP course, the Mann-Whitney U test did not show a statistically significant difference in success in Test 1 between students of Group 1 (N = 39, Md = 0.5) and Group 2 (N = 19, Md = 0.58) (U = 330.500, z = -0.666, p = 0.505), nor in Test 2 (U = 273.000, z = -1.622, p = 0.105) (Table 4).

For students who did not attend preparatory course in SPP, the Mann-Whitney U test did not show a statistically significant difference in success in Test 1 between students of Group 1 (N = 38, Md = 0.5) and Group 2 (N = 22, Md = 0.48) (U = 375.000, z = -0.663, p = 0.508), nor in Test 2 (U = 333.000, z = -1.310, p = 0.190) (Table 4).

For Group 1, who did not attend a preparatory course in SPP, there is a high positive correlation between Test 1 and Test 2 (r_S=0.508).

For Group 2, who did not attend a preparatory course in SPP, there is a statistically significant high positive correlation between success in the first and second test (r_S = 0.592).

By observing students' success in relation to whether they had a Descriptive Geometry subject in high school, positive correlations were obtained between success in the first and second test (r_S = 0.357) only for students who did not have Descriptive Geometry in high school.

Also, the Mann-Whitney U test did not show a statistically significant difference in success in Test 1 and Test 2 between students who had DG in high school.

4. CONCLUSION

The study results showed a significant improvement in spatial ability in students of architecture in general during the first semester of studies. However, they also showed that the Descriptive Geometry course did not have a significant influence on the development of spatial abilities, at least in the case of a traditional approach in mastering this subject - with abstract tasks and theoretical application, as such methods develop spatial thinking, rather than spatial abilities. A similar conclusion was obtained in the paper [4]. Furthermore, the results show no positive correlation between the spatial ability and the attendance of Descriptive Geometry subjects in high school. Both student groups achieved the most outstanding progress in mental rotation tasks (MRT). There was no statistically significant difference in success at the mental rotation tasks in both tests between Group 1 and Group 2. Both groups were equally successful in solving these tasks.

Also, there was no statistically significant difference in success in the tests depending on the preparatory course (SPP) attendance for enrollment at the FACEG. For students who did not attend a preparatory course in SPP, there was even a highly positive correlation between success in Test 1 and Test 2. This points to the fact that some subjects in the first semester may have affected the improvement of spatial abilities.

This question raises the issue in further research in defining the specific factors that assess spatial thinking. Since the significant improvement in spatial ability is evident, this also raises the question of looking for potential causes in other courses related to the architecture curriculum taught in the first semester.

In order to improve architecture students' spatial abilities, we recommend further actions simultaneously: including these task types (spatial ability tasks) in the Descriptive Geometry course syllabus and a possible adaptation of the current DG task to simulate and assess spatial ability factors.

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