# PERIÓDICO TCHÊ QUÍMICA ARTIGO ORIGINAL

# HABILIDADE ESPACIAL GEOMÉTRICA COMO ELEMENTO DO PROCESSO COGNITIVO DE APRENDIZAGEM

# GEOMETRIC SPATIAL ABILITY AS AN ELEMENT OF COGNITIVE LEARNING PROCESS

# ПРОСТРАНСТВЕННОЕ ГЕОМЕТРИЧЕСКОЕ ВООБРАЖЕНИЕ КАК ЭЛЕМЕНТ КОГНИТИВНОГО ПРОЦЕССА ОБУЧЕНИЯ

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# **RESUMO**

Cada vez mais os professores universitários enfrentam sérios problemas com o aprendizado de geometria e de disciplinas gráficas. Quanto a isto, é muito relevante obter um método eficiente para ensinar geometria e disciplinas gráficas. O objetivo deste estudo é testar a hipótese de que a causa dos problemas que surgem no processo de dominação das disciplinas geométricas e gráficas é a violação da continuidade do material educacional e o baixo nível de habilidade espacial dos estudantes. Na pesquisa, o método de entrevista (teste) e o método estatístico foram aplicados para processar os resultados. Estabelece-se que a imaginação espacial ajuda a pessoa a perceber a forma dos objetos geométricos, envolvendo-a no processo cognitivo de sentir e controlar os objetos espaciais. Os alunos que aprenderam na escola desenho técnico, da mesma forma que os alunos que não aprenderam, tiveram dificuldades em dominar as disciplinas geométricas e gráficas. Para os alunos que aprenderam desenho técnico nas escolas, a causa da má retenção do material da disciplina geométrica e gráfica é a baixa capacidade espacial geométrica. Para os alunos que não aprenderam desenho técnico na escola, mas que demonstraram alta capacidade espacial geométrica, a causa das dificuldades na retenção das disciplinas geométricas e gráficas está ligada à violação da continuidade do material educativo. Para ensinar efetivamente as disciplinas geométricas e gráficas, é necessário aplicar métodos de desenvolvimento da capacidade espacial geométrica e formar o conteúdo da disciplina usando o princípio da continuidade.

**Palavras-chave**: pensamento espacial; disciplinas gráficas; imaginação; representações espaciais; desenhos técnicos.

# **ABSTRACT**

University professors more and more often face serious problems of learning geometry and graphic disciplines. In this regard, it is very relevant to obtain a maximum efficient method to teach geometry and graphic disciplines. The purpose of the study is to test the hypothesis that the cause of problems arising in the process of mastering the geometric and graphic disciplines is the violation of continuity of the educational material and the low level of spatial ability of students. In the research, interviewing method (testing) and statistic method have been applied to process the results. It is established that spatial imagination helps a person to perceive the shape of geometric objects by involving him/her into the cognitive process of feeling and control of spatial objects. Students who learned in school technical drawing the same as students who did not learn experience difficulties in mastering the geometric and graphic disciplines. For students who learned technical drawing in schools, the cause of bad retention of the material of the geometric and graphic discipline is low geometric spatial ability. For students who did not learn technical drawing in school, but who demonstrated a high geometric spatial ability, the cause of difficulties in the retention of the geometric and graphic disciplines are connected with the violation of continuity of the educational material. To effectively teach the geometric and graphic disciplines, it is necessary to apply methods of developments of the geometric spatial ability and to form the content of discipline using the principle of continuity.

**Keywords**: spatial thinking; graphic disciplines; imagination; spatial representations; technical drawings.

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Преподаватели вузов всё чаще сталкиваются с серьезными проблемами освоения геометрографических дисциплин. В этой связи актуальным является вопрос получения максимально эффективной методики преподавания геометро-графических дисциплин. Целью исследования является проверка гипотезы о том, что причинами проблем, возникающих в процессе освоения геометрографических дисциплин, является нарушение преемственности образовательного материала и низкий уровень развития пространственного воображения обучающихся. При проведении исследования применялся метод опроса (тестирования) и статистические методы для обработки результатов. пространственное воображение помогает человеку Установлено, что воспринимать геометрических объектов за счет вовлечения его в когнитивный процесс представления и управления пространственными объектами. Затруднения в освоении геометро-графических дисциплин испытывают и студенты, изучавшие в школе черчение, и студенты, не изучавшие черчение. Для студентов, изучавших черчение в школе, причиной плохого усвоения материала по геометро-графическим дисциплинам является низкий уровень пространственного геометрического представления. Для студентов, не изучавших черчение в школе и при этом показавших хороший уровень развития пространственного геометрического представления, затруднения в освоении геометро-графических дисциплин связаны с нарушением преемственности образовательного материала. Для эффективного геометро-графических дисциплин необходимо применять преподавания методики пространственного геометрического представления, а также формировать содержание дисциплины, применяя принцип преемственности.

**Ключевые слова**: пространственное мышление, графические дисциплины, воображение, пространственные представления, черчение.

#### 1. INTRODUCTION

"Space representations are representation of spatial and spatiotemporal properties and relations: a size, form, relative location of objects, their forward movement and rotational movement, etc." (Mescheryakov and Zinchenko. 2002). Βv content, representations are divided into representations of single objects or their images (image of the drawing) and representations that reflect common spatial relations between different objects (Mescheryakov and Zinchenko, 2002). Space representation is the element of spatial ability. It necessary element of intellectual knowledge in the technical-vocational activity. The ability of a student to reproduce properties of objects in different graphic form (as a technical drawing, drawing, scheme) is key to future success in professional activity as an engineer because this profession is directly connected with constructive thinking and technical creativity. In their article, Berkowitz and Stern (Berkowitz and Stern, 2018) have analyzed the effect of cognitive abilities on academic performance. It was noted that space representation has the grates impact on an ability to construct compared to other cognitive abilities (Mussabayev et al., 2018; Kenshimov et al., 2017).

The spatial ability allows an engineer to

design new mechanisms and constructions more perfect and also to find new technical solutions. Albert Einstein said: "Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world, stimulating progress, giving birth to evolution." (Kravtsova and Prihod'ko, 2017).

A large number of scientific papers devoted to spatial thinking and methods of its development is associated with problems of development of schoolchildren spatial thinking (Badanova, 2009). Along with this, professors more and more often face serious problems of learning geometric and graphic disciplines by students of technical universities - future engineers! Typically, low preparedness to learn geometric and graphic discipline in a university is associated with the fact that students did not study enough technical drawing and basic geometry in school, and, as a result, experience difficulties in the representation of spatial objects (Osmolovskaya and Krasnova, 2018). It is necessary to note that technical drawings and basic geometry are propaedeutics of geometric and graphic disciplines studies in a university. Subjects studied within geometric and graphic disciplines are continuation and intensification of subjects studied within school technical drawing and basic geometry. In conditions when the studied material is based on already acquired

knowledge and is focused on the level of knowledge in "the area of the closest knowledge" (Novikov and Novikov, 2014), a student perceives a material better. That is why the principle of continuity is very important to form the content of educational material. In the case when a student has not to study technical drawing or has poorly learned basic geometry, continuity of education material is being broken, and as a result, there are problems in learning geometric and graphic disciplines (Ruiz et al., 2018; Shen et al., 2018; Rutherford et al., 2018; Ionova et al., 2018).

There is a logical connection between the ability of spatial ability and ability to learn graphic disciplines: from the one side without a certain level of the ability of spatial ability the process of learning graphic disciplines would be impossible. from the other side, graphic disciplines contribute to the development of human spatial ability (Starostina, 2016). This interdependence makes the matter of development of spatial ability is very relevant for the students of designing disciplines (Knapp, 2011). Professors-researches come to the conclusion that in the absence of necessary level of ability of spatial thinking, at the beginning of learning the geometric and graphic disciplines in а university, the ability propaedeutics methods of spatial development should be used in parallel with graphics disciplines (Bairaktarova et al., 2015; Varlamova, 2018; Hsi et al., 1997; Williams et al., 2010; Gridina and Andreev, 2018).

The hypothesis of the research is the hypothesis that the reasons for the problems in the process of learning geometric and graphic disciplines are:

- The violation of continuity of educational material;
- 2) The low ability of spatial ability of students.

To find out whether this hypothesis is true or false, the research has been conducted, within which the level of ability of spatial thinking and the presence of problems in learning geometric and graphic disciplines of students who studied technical drawing in school and who did not, were determined.

# 2. MATERIALS AND METHODS

In the research, interviewing method (testing) and statistic method have been applied to process the results. In testing 55 first-year students of designing disciplines of Moscow Aviation Institute (National Research University)

participated. Testing has been conducted after the first semester of the first year as students learned the discipline "Descriptive geometry". Testing has revealed that of the 55 people surveyed, 16 people study technical drawing in school. Then, the measurement for two groups has been conducted, in the one of which there were students who studied drawing at school (group N = 16 people), respectively, the second group did not have a drawing at school (group M = 55-16 = 39 people).

The point of the research was to determine the level of ability of spatial thinking by testing of 10 control questions (tasks). The measurement has been conducted on the scale of relations. The number of correct answers has been chosen as the characteristic (feature) of a student. For the convenience of the further assessment, the scale of relations has been replaced by the ordinal scale.

The ordinal scale (rank scale) with three gradations (L=3, wherein L- the level of ability of spatial thinking: low (the number of correct answers is less than or equal to 4), medium (the number of correct answers is more than or 4, but less than or equal to 7), high (the number of correct answers is strictly more than 7)). The upper limits of the ranges are shown in Table 1.

In accordance with the level of ability of spatial thinking (low, medium, high) points are given – 1, 2, and 3. Basing on results of the testing for both groups, the number of members who got points of one or other range is calculated (Tables 2, 3). To compare these groups properly, it is necessary to make the histogram (Figure 1).

The alternative hypothesis (the hypothesis of the significance of differences of groups N and M characteristics) has been formulated as a statistic hypothesis. To determine the validity of differences for experimental data, the criterion of homogeneity  $\chi^2$  is used. Herein the level of significance is  $\alpha$ =0.05. The characteristic of the group is the number of its members scored a certain point (see Tables 2, 3). For the group N the vector of points is n=(n1, n2, n3)=(3, 13, 0), wherein n<sub>k</sub> is the number of group members scored k point, k=1, 2, 3. For the group M the vector of points is m=(m1, m2, m3)=(4, 29, 6), where m<sub>k</sub> is the number of group members scored k point, k=1, 2, 3. Empirical value Zemp for the compared selection is calculated upon Equation 1:

$$\chi^{2}_{emp} - N M \cdot \sum_{t=1}^{k} \frac{(\frac{n_{t}}{N} - \frac{n_{t}}{M})^{2}}{n_{t} + m_{t}},$$
 (Eq. 1)

wherein N – the number of students who learned technical drawing in school (N=16 people); M – the number of students who did not learn technical drawing in school (M=39 people); k – the points corresponding to the level of ability of spatial thinking (low – 1 point, medium – 2 points, high – 3 points);  $n_{\rm i}$  – the number of members of the N group who got i point; mi – the number of members of the group M who got i point.

The value of  $\chi^2_{mm}$  is gained from Equation 1 (calculation 1). From a comparison of the obtained empirical value with a critical value  $\chi^2_{0.06} = 5.99$ .  $\chi^2_{emp} = 10.6 > \chi^2_{nng} = 5.99$ , it follows that the reliability of differences in the

characteristics of the N and M groups is 95%.

### 3. RESULTS AND DISCUSSION:

According to the results of the study, the states of the N and M groups differ. Therefore, it can be concluded that differences of the level of ability of spatial thinking for groups N and M are significant, where, according to histogram on Figure 1, the level of development of spatial thinking of students who have been taught technical drawing at school is lower than that of students who have not been taught technical drawing. At Figure 2, the results of the survey for all 55 students are represented.

Since the part of students demonstrated the medium result quite large in the total mass (76%), they were separately counted for the number of correct answers (Figure 3). Students who answered correctly to 5, 6, and 7 questions are students with the "medium" level of development of spatial thinking. Among 55 surveyed, 34.5% answered that they had difficulties in solving problems in the discipline "Descriptive geometry" and 38.2% have problems with understanding of theoretical material (Figure 4).

Also, 25.2% of surveyed admitted that had difficulties to mentally imagine the location of objects in space when solving problems on descriptive geometry. 34.5% of surveyed having difficulties in solving problems and 38.2% of surveyed having problems in understanding theory indicated that it is difficult to apply the studied theory to solving problems in practical classes and also had difficulty in representing spatial objects. It is obvious that in this, they have difficulties at the stage of abstraction. Based on this, we can conclude that the difficulties in

studying the discipline "Descriptive geometry" are associated with an insufficient level of development of spatial thinking.

In view of the foregoing we propose:

- 1) To introduce entrance testing to check students preparedness to learn geometric and graphic disciplines in university;
- 2) at the first classes in geometry-graphic disciplines, renew the main provisions of plan geometry and solid geometry, which they studied in secondary school, taking into account the results of the entrance testing;
- 3) in parallel with the study of current topics in geometric and graphic disciplines, to apply methods of developing the spatial representation of students

Entrance testing should contain tasks to check the level of development of the spatial representation of students, knowledge terminology, and basic knowledge of plane geometry and solid geometry from the course of secondary school. Here is an example of such testing. It contains open and closed questions. These questions may be divided into the following categories: questions check to knowledge of basic geometry (No 1, 2, 6), questions to check knowledge of plan geometry (No 4, 5, 8, 9), questions to check solid geometry (No 3, 11, 12), and questions about space representation (No 7, 10).

- 1) What is a geometric locus of points equidistant from a given point?
  - 2) What is a regular pyramid?
  - 3) How many edges tetrahedron has?
- 4) What properties of a diagonal rhombus do you know?
- 5) What properties of an isosceles triangle do you know?
- 6) Give the definition of a geometrical object.
- 7) Which of the listed geometric shapes can be a section of a parallelepiped? (several options are possible)
  - a) Pentagon;
  - b) Parallelogram;
  - c) Trapezoid;
  - d) Rhombus.
- 8) Separate the circumference to 5 equal parts without the help of a protractor.

- 9) Build a tangent to the circumference from a point not lying on this circumference.
- 10) What is the maximum number of vertices of a polygon that is a section of a hexagonal pyramid?
  - a) 4; b) 5; c) 6; d) 7; e) 8.
- 11) What curves can be obtained in cross-section of a conical surface by a plane?
- 12) What is the property of a plane tangent to a sphere?

Entrance testing for the first-year student that has been conducted before learning the geometric and graphic disciplines demonstrated the following results. 86% of surveyed answered correctly to questions on terminology; 74% – to question on plan geometry; 69% – to question on solid geometry; 64% – to questions on space representation. Basing on this, it can be concluded that the greatest difficulties for first-year students are topics related to solid geometry and requiring a developed spatial geometric representation (surfaces, bodies, and their intersection).

We propose according to results of the entrance testing to include propaedeutics subjects (renewing of the main notions, definitions, theorems, and properties) in the content of first classes on geometric and graphic disciplines:

- 1) geometrical construction (one academic hour): construction of a regular polygon (regular pentagon, hexagon, etc.), dividing a segment into equal parts using a compass, building a median perpendicular to the segment using a compass;
- 2) the mutual arrangement of lines in space (one academic hour): parallel lines, skew lines, concurrent lines;
- 3) the mutual arrangement of a line and plane (one academic hour): parallelism of lines and planes, perpendicularity of lines and planes;
- 4) the mutual arrangement of planes (one academic hour): parallelism of two planes, perpendicularity of two planes, dihedron.
- 5) polyhedrons (one academic hour): pyramid, prism, regular polyhedrons;
- 6) solid of revolution (one academic hour): cylinder, cone, sphere;
- 7) curves (one academic hour): circumference, ellipse, hyperbola, parabola.

Certainly, it is needed to consider total

hours for the discipline and, if necessary, to give students some propaedeutics subjects for self-learning. However, in such case, a professor should control a student, for example, using the e-learning system. We suppose in following classes on geometric and graphic disciplines in parallel with learning current material to use methods of development of spatial representation.

Results of the analytical research demonstrated that difficulties learning in geometric and graphic disciplines are related to students' insufficient level of spatial ability. Also, the absence of connection between the level of spatial ability of student and propaedeutics learning of technical drawing and basic geometry in secondary school and the ability to learn geometric and graphic disciplines.

In such a way, regardless of the level of initial geometric-graphic student's the preparation, it is expedient to apply methods of developing spatial ability in parallel with the current study of material on geometric-graphic disciplines. This will allow developing spatial thinking at the stage of abstraction and, therefore, improve academic performance on geometric and graphic disciplines. It is also expedient to start learning geometric and graphic disciplines in university from propaedeutics, i.e., renewing of the main provisions of plan geometry and solid geometry, which have been studied in secondary school.

Basing on the results of this research, it may be concluded that students who have learned technical drawing and who have not learned technical drawing in school experience difficulties in learning geometric and graphic disciplines. For students who have learned technical drawings in school, the reason for poor learning of geometric and graphic disciplines is the low level of space geometric ability that is proof of p.1 of the hypothesis. Also, the absence of a direct connection between the level of spatial ability of a student and the fact that he studied technical drawing in school has been found. In the view of the authors, it is explained by the fact that a final result (the level of geometric spatial ability after learning technical drawing in school) is also affected by the content of the discipline "Technical drawing", academic performance of a student, his or her entry level of geometric spatial ability (before he started learning technical drawing).

For the students who have not learned technical drawing in school, but demonstrated a

good level of geometric spatial ability, differences in learning geometric and graphic disciplines are associated with the violation of continuity of educational material that proves p.2 of the hypothesis. Such students with developed geometric spatial ability have the potential to succeed in learning the geometric and graphic disciplines. In this situation, learning achievement depends on the ability of a professor of geometric and graphic disciplines to "build" a chain of continuity of educational material for such students.

The spatial ability helps a human to perceive a form of geometric objects by his involvement in the cognitive process of imagining and managing spatial objects. To develop the spatial geometric ability of first-year students, the authors of the article propose to use three-dimensional computer modeling (Hartatiana and Nurlaelah, 2018). However, to perceive three-dimensional computer models properly, it is necessary to have an advanced level of spatial ability. That is why, in our view, it is expedient to use three-dimensional computer modeling after learning descriptive geometry within which spatial geometric ability is being trained and developed.

The advanced spatial geometric ability is important to learn engineering very mathematical disciplines successfully. authors of the article have conducted the testing to assess the level of development of the spatial geometric ability of students of senior years (Gold et al., 2018). Testing assessed the ability of students to imagine spatial objects and rotate them in mind. In the article "Entry-Level Spatial and General Non-verbal Reasoning: Can These Abilities Be Used as a Predictor for Anatomy Performance in Veterinary Medical Students?" the research has been conducted, assessed the impact of entry-level of spatial ability of first-year students on the success of learning by them special disciplines (Gutierrez et al., 2018). In testing of the level of development of spatial ability, the tests were used that contained tasks on mental rotation of spatial objects ('mental rotation test' - MRT), tasks on visual-space thinking ('Guay's visualization of views test' - VVT), tasks on non-verbal thinking ('Raven's Advanced Progressive Matrices Test' – APMT). In the testing conducted by the authors of this article, in addition to imagining and mental rotation of spatial objects, the ability of students to determine logically and select significant parts of an object or thing, which should be compared, has been assessed. This ability is important to consider because characteristics of spatial

intelligence include several stages with specific features:

- 1) Analysis dividing an object and its tasks into components;
- 2) Synthesis the reverse process of analysis a compounding of object or task in a coherent whole.
- 3) Abstraction determination of stages that should be in the task. At the stage, the form of the notion;
- 4) Generalization determination and selection of significant parts of an object or thing that should be compared;
- 5) Specification the reverse process of generalization a selection of characteristics to a task stage, which is not related to stages of solutions (Varnakova, 2018).

Also, the spatial ability of students of senior years has been assessed by testing. According to observations of the authors of the article, the more time students spent to solve tasks of the testing, the best result they demonstrated (Yoon and Mann, 2017). In testing, the authors of this article did not take into account time factor (time spent to solve tasks).

# 4. CONCLUSIONS:

Basing on all mentioned above, it can be concluded that this research has proved that the low geometric spatial ability leads to serious difficulties in learning geometric and graphic disciplines. The scientific contribution of the research is in revealing and substantiating the reason of difficulties in learning geometric and graphic disciplines by students with a good level of geometric spatial ability, which is a violation of continuity of educational material.

The ability to determine logically and select significant parts of an object or a thing that should be compared is important at the stage of generalization in the spatial representation of objects. To effectively teach geometric and graphic disciplines, it is necessary to use methods of development of geometric spatial ability and form the content of discipline with the use of continuity principle showing and emphasizing a connection of new material with previously studied.

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$$\chi^{2}_{emp} = 16.39 \cdot \left[ \left( \frac{3}{16} - \frac{4}{39} \right)^{2} / (3+4) + \left( \frac{18}{16} - \frac{29}{39} \right)^{2} / (13+29) + \left( \frac{0}{16} - \frac{6}{39} \right)^{2} / (0+6) \right] = 10.6.$$
(Calculation 1)

Table 1. Results of the testing of the ability of spatial thinking

| The level of ability of spatial thinking | Maximum number of correct answers |
|--|-----------------------------------|
| Low                                      | 4                                 |
| Medium                                   | 7                                 |
| High                                     | 9                                 |

**Table 2.** The levels of ability of spatial thinking of members of group N

| The level of ability of spatial thinking | Frequency<br>(number of people) |
|--|---------------------------------|
| Low (1 point)                            | 3                               |
| Medium (2 grades)                        | 13                              |
| High (3 points)                          | 0                               |

Table 3. The levels of ability of spatial thinking of members of group M

| The level of ability of spatial thinking | Frequency (number of people) |
|--|------------------------------|
| Low (1 point)                            | 4                            |
| Medium (2 points)                        | 29                           |
| High (3 points)                          | 6                            |

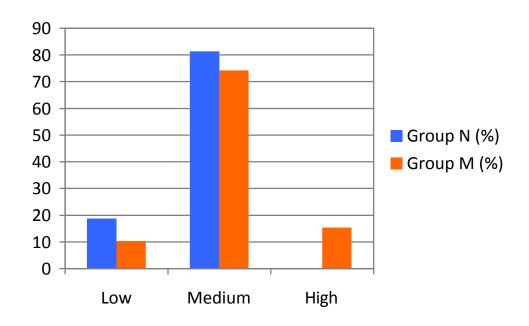


Figure 1. Histogram of groups N and M based on results of the testing

Figure 2. The level of development of spatial thinking

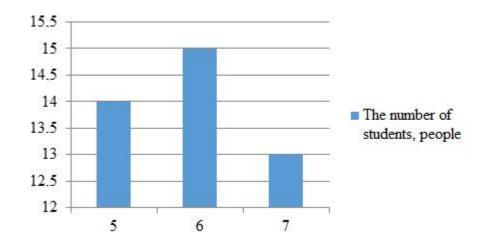
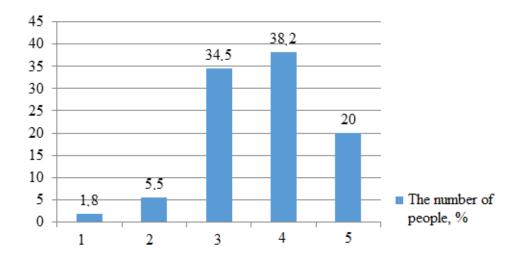


Figure 3. The number of correct answers among students with the medium level of spatial thinking



- 1 I understood almost nothing;
- 2 I understood a small part;
- 3 I have difficulties with solving problems;
- 4 I can solve problems, difficulties are in ....
- 5 All clear

**Figure 4.** Answers to the question "How much did you understand the course of descriptive geometry?"