Multidiszciplináris Tudományok, 14. kötet, 2. szám (2024) pp. 55–63. **https://doi.org/10.35925/j.multi.2024.2.6**

DEVELOPMENT AND ENHANCEMENT OF SPATIAL PERCEPTION AMONG UNIVERSITY STUDENTS FOR BETTER RETENTION

Erika Rozgonyi
associate professor, University of Miskolc, Institute of Mathematics, Departure of Decriptive Geometry
3515 Miskolc-Egyetemváros, e-mail:erika.szilvasine.rozgonyi@uni-miskolc.hu

Abstract

During the compilation of this article, the primary aim was the exploration of the available opportunities regarding the development and improvement of spatial perception, and the creation of a future plan for assessing the spatial intelligence of engineering students attending the University of Miskolc. After carefully studying several publications, the Barke-style test was chosen, which is showcased in detail in this article. In my version, the essence of the test would remain the same, only the the tasks would be altered, and the incoming engineering students would participate in the survey, in a way similar to the mathematical competency survey that already exists at the university. Depending on the results of the survey, my plans include the creation of recommendations as part of my research, aimed at strengthening spatial competency among the engineering students attending the University of Miskolc.

Keywords: *spatial perception, spatial intelligence, engineering student*

1. Introduction

When we mention spatial perception, it is not a given that everyone can define it, or that we will think of the same concept. If we open up the Explanatory Dictionary of the Hungarian Language, under the entry of spatial perception, we will find the following: "The mental ability, which enables a person to sense objects according to their shape, size, and dimensions, while being able to view them in relation to each other, and place them in a unified image." (Explanatory Dictionary of the Hungarian Language, 1962) In pedagogy, spatial perception is defined as "the ability to imagine and reconstruct objects based on pictures, using spatial vision". (Drahos, 1988). Psychologist John Eliot wrote the following: "our knowledge of the position of objects, and the ability to use this knowledge for solving mental and physical problems" (Eliot, 1987). This skill is with us from birth in most cases, and can be developed in several ways. There has been significant progress made in the field of visual research in recent decades. This field of science has been renewed in many ways, for example in its terminology, contents, and common views.

2. Importance of spatial perception

The perception and processing of spatial information is a fundamental ability for an individual, which plays an important role in our everyday lives. Our navigational abilities help us orient ourselves in our man-made and natural enviroments. We call upon our ability to reconstruct when we are tasked with assembling a wardrobe based on the provided instructions. We face a similar situation when we are shown the technical drawings for our newly built house by the designer, and we also use our spatial abilities during our everyday activities, when we are buying the paint for our living room, or when we want to figure out the most optimal way to load the luggage into the car for our holiday journey. If we wish to stay on familiar grounds, we can just think of the campus of the University of Miskolc. The freshman students face a significant challenge in their first weeks of attendance, as they try to navigate their way to the different lecture halls and other rooms through the numerous corridors. We can find excercises related to spatial geometry in many surveys related to mathematics, natural sciences or physics. The majority of researchers have highlighted that we must put a greater emphasis on spatial-visual intelligence in our education system, which at the moment is biased more towards verbal intelligence. (Babály et al., 2015)

3. Spatial ability structure

When talking about spatial perception, it is important to clarify which subskills appear as individual factors, that can be distinguished from other subskills. For a long period (circa 1960s), researchers identified two factors: perception and visualization. The majority of published tests were spatial visualization, as they consisted of tasks requiring mental manipulation. However, in the years afterwards, researchers were aiming to define the exact components that make up spatial abilities using exactly defined spatial operations. Firstly, the ability of mental rotations was seaparated from visualization.In the present day, five spatial components are accepted by most researchers (Sorby, 2009; Babály, 2020; Horváth et al., 1991):

1. Spatial perception: the component also called spatial recognition covers the recieving and processing of visual stimuli. Several researchers classify the creation and fixation of mental images as part of this component. In the relevant literature, the processes of perception, perception and internal imaging are considered inseparable.
2. Spatial visualization: due to the considerable diversity of tasks that are classified as spatial visualization, we can find several definitions in literature. Typically, tasks containing complex, multi-step manipulations or spatial operations that cannot be classified under other components are labelled as visualization. Several researchers consider mental transformation and mental rotation to be subcomponents of visualization.
3. Mental rotations: imaginary movement of two- and three-dimensional shapes, where the object is rotated in its entirety.
4. Spatial orientation: With mental rotation, the position of the object changes in space, while with spatial orientation, we perform an operation where the position of the objects does not change, we only move our own point of view.
5. Spatial relations: this factor refers to the ability of quickly and correctly rotating or mirroring an object. It shows a significant overlap with mental rotation. (Babály, 2020).

4. The competency neccessary for solving a task related to spatial geometry

In this chapter, we will review the competencies neccessary for solving tasks related to spatial geometry. If we think it through, when faced with a task related to mathematics, physics, or any other subject, that also involves knowledge of spatial geometry, we utilize the following steps in order to solve it:

1. *understanding the text:* The basis of solving the tasks is the correct understanding of the description of the task. If this is not performed, students may not utilize the correct methods for reaching the solution, or may not even be able to start processing the task at hand. This is one of

the most crucial competencies, which is used to filter the text and differentiate between useful information and meaningless details.
2. *creation of a proper drawing:* The task is visualized in this step, which helps with solving, and showcases the possible solutions. This step requires good spatial vision and representational skills. If the drawing is created improperly, or not prepared at all, then solving the task becomes impossible.
3. *creating the plan for finding a solution:* After processing the text, and collecting data, a plan has to be created, which will be followed until the solution is found. This requires planning skills.
4. *usage of mathematical symbols:* When solving mathematical problems, the usage of mathematical symbols is essential. They have to be used precisely and methodically while solving the problem. Using several symbols at once must not be an issue, and the meaning of each one has to be clearly understood.
5. *recognition of connections:* In this step, based on the interpretation of the drawing and the text, the students must formulate conclusions based on their existing knowledge.
6. *computer and ICT device usage:* Students can also use calculators or ICT tools during problem-solving. Many high school classes are already digital, meaning they learn on computers, so proficiency in this area is also important.
7. *Advanced analytical (breaking the whole into parts) and synthetic thinking (building the whole from parts):* These thinking methods are necessary to achieve good and quick solutions, so that there are no unnecessary steps in the process that could cause the student to lose a lot of time.

This sequence of steps not only applies to mathematical problems, as several competencies are also necessary for engineering students who may encounter a problem within the subject of Descriptive Geometry or when they face the task of creating a shape using CAD programs during a computer-aided design class. Correctly interpreting the written text is also fundamental in such cases, the same being true for the creation of a sketch and an appropriate solution plan. Symbols and well-known notations also play an important role. Just think of a technical drawing of a machine part where, among other things, the diameter, radius, and section symbols can be found. After correctly interpreting the relationships, it is necessary to plan the solution process with advanced analytical and synthetic thinking, and without unnecessary steps. Unfortunately, it can be seen while observing many students that if they are not confident in their knowledge, for example, when designing in CAD systems, they do not create the required shape in the simplest way, because they do not fully understand how to design it in the simplest manner. A good example of this can be when several edges of a part need to be rounded with the same radius and (if the system allows) they do not perform it in one step, but instead apply the rounding commands repeatedly, one after another.

5. Tests Focusing on Spatial Perception

The first paper-pencil test measuring spatial perception was published in the early 1900s. Since then, several tests have been developed to measure various components of spatial perception (see, for example, Séra et al., 2002), which measure:

- spatial orientation (cube comparison, card rotation),
- visualization (shape assembly, paper folding, surface development).

In Hungary, Andrea Kárpáti, János Gulyás, and László Séra developed a spatial perception test in 2002 (Séra et al., 2002). The tasks in this test were based on two ability factors of spatial perception:

recognition and manipulation (Séra et. al., 2002). The tests primarily included topics related to elementary and secondary visual culture subjects and geometry curriculum tasks. These tests were aimed at seventh and eleventh graders. A slightly different approach appears in chemistry didactics literature, where a spatial perception test containing chemical content, the so-called Barke test, was published in 1992 (Barke and Kuhrke, 1992).

The Barke test primarily measures imaginative work and manipulation, which are important in chemistry, especially in operations involving structural models. Unlike the tests developed by Andrea Kárpáti and her colleagues, Barke used the same tasks for different age groups (7th–12th grade) to assess the spatial perception of students in these grades. Due to the fact that this test, which also contains chemical contents and visualization tasks, has components that can be utilized for students of different ages, it is still widely used to this day (Tóth et al., 2003). Measurements using this test were conducted at the University of Debrecen in 2003 (Tóth Z. et al., 2003). The utilization of this test allowed the authors to compare their results with those of international measurements. The English-language test was translated and its usability among different age groups of Hungarian students was checked during pilot measurements. In this publication (Tóth et al., 2003), the spatial perception test itself is presented, experiences related to the test's domestic adaptation are described, and suggestions for further development of the test are formulated.

6. Measurement of Students at the University of Miskolc

Experience shows that the mathematical knowledge of students applying to higher education varies significantly. One key reason for this is that students come from different types of secondary schools, where they encountered different curricula and teaching methods. It can happen that students from certain types of vocational schools have an advantage in some university subjects (such as Descriptive Geometry) due to their previous studies in technical drawing and machine drawing. However, it is often observed that these students find it more difficult to grasp subjects that build on mathematical knowledge, such as Analysis or Linear Algebra, since they studied mathematics with fewer hours in their secondary schools. These differences are further deepened by the fact that admission to technical and IT programs does not necessarily require a higher-level matriculation exam in mathematics. The lack of solid foundations makes it difficult to master university-level mathematics material and to progress successfully. Therefore, it is crucial to identify deficiencies early and provide effective support to students when necessary. This is the purpose of the mathematical competency assessment for incoming students, in which I have participated from the beginning, both in compiling the tasks, administering the tests, and conducting remedial courses.

The practice of mathematical assessment has existed for decades at the Faculty of Mechanical Engineering and Informatics (GÉIK) of the University of Miskolc and its predecessor institutions. However, in September 2022, we extended the assessment to other faculties as well, meaning all first-year undergraduate students at the University of Miskolc with any mathematics subject in their standard curriculum were included. The analysis of the results of the mathematical competency assessment conducted among first-year BSc students in the fields of IT, engineering, and economics during the first semester of the 2022/2023 academic year was detailed in a previous article (Homolya et al., 2022).

For technical and IT BSc programs, the mandatory courses include a semester-long course on Descriptive Geometry and CAD basics, where Descriptive Geometry knowledge is also highly needed. Most students find these foundational courses difficult to complete because they must master a significant amount of new knowledge, and good mathematical foundations, geometric knowledge, and adequate spatial competencies acquired in secondary school are essential for successful completion.

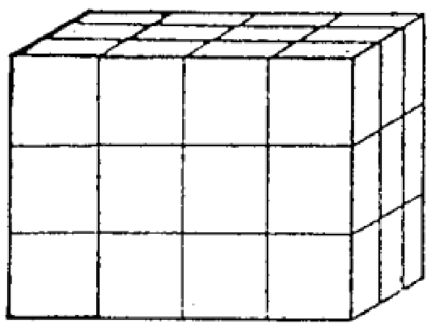
Without these, students find it significantly harder to solve tasks in midterms and exams. Students with gaps in their knowledge need to learn not only the new material but also catch up on the relevant chapters from their secondary school studies to successfully complete the courses. Therefore, it is justified to measure the incoming competencies of admitted students at the beginning of their university studies to provide timely interventions and leveling up, thus avoiding potential dropouts later. Starting from September 2024, I would extend this assessment beyond mathematics to include Descriptive Geometry as well. I have searched the literature for a suitable test that would give an accurate picture of the student's knowledge, spatial perception, and plane and spatial geometry skills.

One such spatial perception test is the Barke test, the first version of which contained only spheres and polyhedra (1978), and later included tasks with chemical structural models (1992). The test consists of five parts, each starting with a brief theoretical section and two practice tasks. This is followed by eight tasks in each section. The tasks relate to a spatial figure and generally require some operation on it. Some tasks involve counting units within the structure, rotating it around an axis, or creating new structures by moving parts. All tasks are multiple-choice and the test is time-limited. The tasks can only be solved in sequence, and a specific amount of time is allotted for the introductory and practice tasks, then followed by the main test.

Some Tasks from the Barke Test (Tóth et al., 2003):

The first subtest is "Cube Arrangement". The theoretical introduction of the subtest is the following:
"The structure of the material and the arrangement of the particles are demonstrated by structural models. On this page, you will see cubes representing the smallest particles of the material. In these tasks, you need to count the cubes in the model drawing. In most cases, not all cubes are visible, so you will have to imagine the hidden ones to solve the problem."

The following figure shows three items from the first subtest (along with the corresponding part of the answer sheet). The questions related to the tasks are the original ones under the images. (Tóth et al., 2003)



a) **How many cubes have one side visible from outside?**
b) **How many cubes can you see that have 2 sides visible from outside?**
c) **How many cubes are inside the cube structure, located in a way that they are not visible at all from outside?**

Possible answers: (* marks the correct):

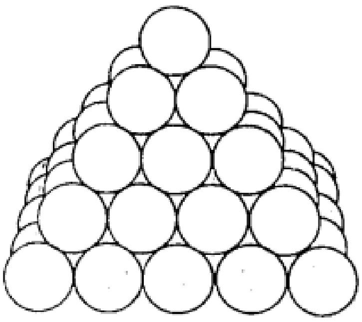
a) 4	**6**	**8**	**10***	**16**	**20**
b) 4	**6**	**8**	**10**	**16***	**20**
c) 1	**2***	**6**	**12**	**15**	**60**

Figure 1. *Task of Cube Arrangement from the Barke Test, and the answers*
(Tóth et al., 2003)

The second subtest is "Sphere Arrangement". The theoretical introduction of the subtest is the following:

"The structure of the material and the arrangement of the particles are demonstrated by structural models. On this page, we have modeled the smallest particles of the material with spheres. In these tasks, you need to count the spheres in the model drawing. In most cases, not all spheres are visible, so you will have to imagine the hidden ones to solve the problem."

The next figure shows three examples from the second subtest (along with the answer choices and the correct answer):



a) **How many spheres are contained in the structure?**
b) **How many spheres are present internally within the structure which are not visible from outside at all?**
c) **How many other speheres does one spehere contact within the structure?**

Possible answers: (* marks the correct):

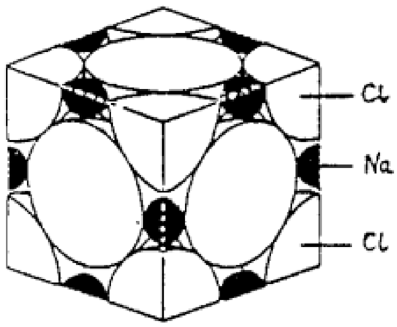
a) 30	**36**	**50**	**55***	**56**	**64**
b) 3	**4**	**5***	**6**	**7**	**8**
c) 6	**8**	**10**	**12***	**14**	**16**

Figure 2. *Task of Sphere Arrangement from the Barke Test, and the answers*
(Tóth et al., 2003)

The third subtest involves stacking layers of spheres on top of each other. In these tasks, students see layers of spheres in the image. They need to mentally stack these layers on top of each other and visualize the result, with the position of each sphere being important in this context.

The fourth and fifth subtests require students to solve chemical problems. The title of the fourth subtest is "Calculation from the Elementary Cell". The theoretical introduction to this section reads: "In chemistry, we describe the structure of crystals using the elementary cell. By using an elementary cell, we can build the entire crystal by moving it in three appropriate directions in space and imagining the connection between all the cells placed next to each other." Tasks related to the elementary cell of sodium chloride (NaCl) crystal lattice can be seen in the following figure.

The following elementary cell shows the arrangement of sodium and chlorine particles in the sodium chloride crystal lattice.



a) How many whole chlorine spheres are contained in the elementary cell, if we combine all parts?
b) How many sodium quarter spheres are contained in the elementary cell?
c) How many sodium spheres are contained in the elementary cell, if we combine all parts? Warning! You will find a whole sodium sphere in the middle of the cell.

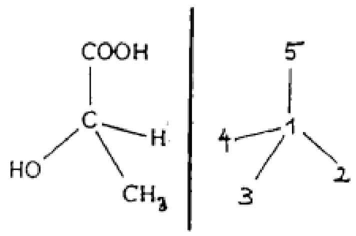
Possible answers: (* marks the correct):

a)	**2**	**4***	**6**	**8**	**12**	**14**
b)	**2**	**4**	**6**	**8**	**12***	**14**
c)	**1**	**2**	**3**	**4***	**6**	**8**

Figure 3*. Three tasks from Calculation from the Elementary Cell subtest and the correct answers* (Tóth et al., 2003)

The fifth subtest deals with the mirroring and rotation of models. In the introduction, Barke writes: "Molecular models depict the arrangement of atoms in molecules. Molecules are often symmetrically structured, so they can be transformed into other molecules by reflection in a plane mirror or rotation about an appropriate axis of symmetry."

The following figure shows the task related to this and the possible answers:



a) Where does the HO symbol end up after mirroring of the left hand side model (assuming identical tetrahedral angles)?
b) Where does the HO symbol end up after a 120° rotation and a mirroring afterwards? (The rotation is performed on the COOH-C axis, clockwise when viewed from above.)
c) Where does the COOH symbol end up after a 120° rotation and a mirroring afterwards? (The axis of rotation is the HO-C connection, clockwise when viewed from the left side HO.)

Possible answers: (* marks the correct):

a)	**1**	**2***	**3**	**4**	**5**
b)	**1**	**2**	**3**	**4***	**5**
c)	**1**	**2**	**3***	**4**	**5**

Figure 4*. Task of the fifth subtest and the answers* (Tóth et al., 2003)

Seventh, eighth, and ninth graders were examined concurrently by Barke, while paying particular attention to gender differences. On average, the surveyed students achieved a 30% success rate on these tests. They observed that the ninth graders performed much better than their peers one year below. Subsequent studies conducted with German (N = 762) and Ethiopian students (N = 743) in grades 7 through 12 confirmed that, although to varying degrees in the two different cultures and school types, students' spatial perception showed clear development with age (Barke et al., 2001; Tóth et al., 2003).

At the University of Miskolc, I would like to use a similar set of tasks among students in the upcoming semester. My aim is to assess the spatial perception of incoming mechanical engineering and earth science engineering students with completely similar tasks, but redesigned exercises. The neccessity of the tests is well supported by mathematical assessments, and in case it appears necessary, the structure of the descriptive geometry course can be adjusted based on the results. I am considering a course similar to mathematical remedial courses, where we can review planar and spatial geometric relations, and descriptive geometry skills. The teaching of descriptive geometry is currently done through the e-learning system of the university, where a closed e-learning group containing helpful short videos, tutorials on construction steps, PowerPoint presentations, and diagrams is present. These materials are organized by topic and divided into lectures and exercises. The database has been continuously expanding since 2020, updated and actualized every semester while being freely available to students. A spatial perception test would be incorporated into this system, which students would receive in a multiple-choice format at the beginning of the semester similar to the mathematical test. The test would be administered under supervision at the university within a specified time frame. Before the test tasks, there would be an introduction based on the Barke test, which students could continue with after a few minutes of study. Studying Barke's articles, the results show that the test is well suited for measuring spatial perception.

7. Conclusion

Due to changes in the mathematical curriculum (a new National Core Curriculum was introduced in 2020), a large portion of students coming from high schools have very little experience with reading and understanding technical drawings. In contrast, the students coming from technical schools, where they had subjects like technical drawing during their high school studies, have an advantage. My experience is that many of today's high school students struggle to visualize relationships depicted in mathematical tasks. This makes it difficult for them to perform well in higher-level mathematical subjects, physics, descriptive geometry, or technical drawing at university. After reviewing several research papers aimed at developing spatial intelligence, I have come to the conclusion that one of the main contributing factors for these difficulties is the low level of spatial intelligence among many students.

The primary goal of writing this article was to explore opportunities for improving spatial perception and to create a future plan for assessing the spatial intelligence of engineering students at the University of Miskolc. Based on the results of this assessment, my plans include continued research to develop new methods for strengthening spatial competence among engineering students at the University of Miskolc. The Barke test was my main choice due to the fact that its results, background, and tasks convinced me that it is well-suited for measuring students' spatial competence. The assessment would be conducted in the form of a multiple-choice test at the beginning of the semester, similar to the mathematical competency assessment, under supervised conditions at the university. The test would be structured similarly to Barke's, with each task preceded by an introduction that students could study for a few minutes before solving the task. Similar to the Barke test, it would also include chemical molecular models. Tasks would need to be solved in a linear progression, and the test would be divided into five parts, similar to Barke's structure.

References

[1] Babály B., Kárpáti A. (2015): A téri képességek vizsgálata papír alapú és online tesztekkel. *Magyar Pedagógia*, 115. évf., 2. szám, pp. 67–92., https://doi.org/10.17670/MPed.2015.2.67

[2] Babály B. (2020): *A térszemlélet fejlődésének vizsgálata a vizuális nevelés szemszögéből: mérőeszközök és fejlődési korszakok és pedagógiai javaslatok*. Phd-értekezés, Budapest, ELTE.

[3] Barke, H.-D., Kuhrke, R. (1992): Einführung in die Chemie. Lang, Frankfurt, New York.

[4] Barke, H.-D., Engida, T. (2001): Structural chemistry and spatial ability in different cultures. Chemistry Education: Research and Practice in Europe, 2, 3. sz., pp. 227–239. (http://www.uoi.gr/cerp)

[5] Homolya, Sz., Rozgonyi, E. (2022): The results of the university competence measurement in mathematics in the view of the tasks. *Mathematics in Education, Research And Applications*, 8, 1, pp. 24–32., 9 p., https://doi.org/10.15414/meraa.2022.08.01.24-32

[6] Horváth J., Kiss A., Horváth L., (1991): Néhány gondolat a térszemlélet fejlesztéséről, Szombathelyi Berzsenyi Dániel Tanárképző Főiskola Tudományos Közleményei, VIII. Módszertani dolgozatok, Szombathely.

[7] Séra L., Kárpáti A., Gulyás J. (2002): A térszemlélet. A vizuális-téri képességek pszichológiája, fejlesztése és mérése. Pécs, Comenius Kiadó.

[8] Sorby, S. A. (2009): Developing 3–D spatial visualization skills. Engineering Design Graphics Journal, 63. 2. sz. 21–32.

[9] Tóth Z., Kiss E., Barke, H.-D. (2003): Egy kémiatanításban használható térszemléleti teszt hazai adaptációja. *Magyar Pedagógia*, 103. évf., 4. szám, pp. 459–479.