SPATIAL SKILLS DEVELOPMENT FOR FUTURE ENGINEERS

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Abstract
According to previous studies there are correlations between spatial intelligence and performance of Science, Technology, Engineering and Mathematics (STEM). Spatial ability can predict academic achievement and are of great importance in next-generation engineering education, computer graphics and 3D modeling.

A collaborative research project between the University of Miskolc and the University of Debrecen resulted in a multi-phase development plan designed to enhance the spatial ability of engineering students, in response to the results obtained during a multi-aspect assessment of the spatial abilities of first-year engineering students and their perceived deficiencies. We compared the freshman mechanical engineering students' spatial skills between University of Miskolc and University of Debrecen with regard to many spatial tests to investigate their spatial problem-solving methods so that we can develop these skills. The goal of this report is to present this multi-stage development plan in next-generation engineering education. The multi-phase development plan enhances students' understanding of spatial concepts, maximizes their university learning experience, and equips them for success in dynamic professional environments.

Keywords: *Problem Solving, Spatial ability, Mathematics education, Engineering education.*

1. Introduction

Spatial ability is related to performance in engineering studies, so it is worth paying attention to examining several components of spatial ability at the same time. The correlation between spatial ability and STEM education has been discussed in the papers (Lubinski, 2010; Nagy-Kondor, 2024; Nagy-Kondor et al., 2021; Turgut et al., 2013) examining individual differences, while others relied on descriptive analyses for inferring specific difficulties (Berkowitz et al., 2021).

Spatial ability is a predictor of success in engineering education and is of great importance in mathematics, computer graphics, architecture and arts (Kiss-György, 2020; Nagy-Kondor, 2024; Nagyné Kondor et al., 2009; Rozgonyi, 2020, 2024; Szíki et al., 2017; Tosto et al., 2014). We can define spatial ability as the complex system of cognitive component, consisting of the ability to connect constructed and perceived images of 3D world (Nagy-Kondor, 2024).

We can measure the aspects of spatial ability with many different methods (Nagy-Kondor, 2024; Pawlak-Jakubowska et al., 2023), and during the last few years researchers have developed Virtual Reality aided applications, generate tasks for example with Blender, or using interactive geometry software and examine there impact on learning from (Betts et al., 2023; Darai et al., 2015; En-nhiri et al., 2025; Guzsvinecz et al., 2021; Laricheva et al., 2023; Tóth et al., 2023; Tóth et al., 2023) various perspectives. Several different methods are used to test the spatial intelligence, among which the Mental Rotation Test and the Mental Cutting Test (MCT) are of greatest importance. The standard MCT (CEEB, 1939) consists of 25 items. Each item presents a three dimensional object which is to be cut with an assumed cutting plane in perspective projection, and five alternative views of the resulting section (one correct alternative and four incorrect alternatives), resulting from the cut. MRT is introduced by Vanderberg and Kuse (1978). 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.

In many cases, the successful completion of engineering studies can be hindered by an inadequate level of spatial visualisation skills (Nagy-Kondor, 2024; Rozgonyi, 2024; Szabó et al., 2023). Developing spatial ability is the key to understanding and creatively solving complex design challenges and engineering problems at university level, as such its development during tertiary education is essential for students' cognitive, professional and personal development.

Reasons of developing spatial perception:

- enhances problem-solving skills: developing spatial vision helps to better understand and solve complex, multi-dimensional problems, an essential skill in any technical field,
- helps prepare for careers in engineering and design: in engineering, architecture, design and many other technical fields, the ability to visualise and represent spatial relationships accurately is essential,
- develops creative thinking: a strong spatial perception allows students to generate new ideas and alternative solutions, thus fostering creative thinking,
- important in site-specific knowledge: many areas of science, such as geography, geology or biology, require specific spatial knowledge, the understanding of which is essential for a thorough knowledge of the subject,
- necessary for the use of modern technologies: 3D modelling requires high level of knowledge of spatial vision, essential for the effective use and understanding of latest technologies.

So, development of spatial perception is therefore not only essential for specific professional skills but is also key for students in the modern labour market and in the face of technological developments.

In the light of the existing literature, this study reports on a multi-aspect assessment of the spatial abilities of first-year engineering students. In our study, we seek answers to the following questions:

- Are there differences between students from the two institutions in certain components of spatial abilities?
- Which task types correlate with each other?
- Which task type most indicates critical difficulties in Descriptive geometry?

In response to the results obtained and the deficiencies experienced, we developed a multi-stage development plan to improve spatial ability of university students.

2. Methodology

The goal of this article was to measure spatial intelligence of freshman engineering students and developing a multi-stage development plan in response to the results obtained and the deficiencies experienced. We compared the freshman mechanical engineering students' spatial skills between University of Miskolc and University of Debrecen with regard to many spatial tests. The number of elements in the two samples is different: At the University of Debrecen, 80 first-year engineering students took the tests, while 46 first-year engineering students participated at the University of Miskolc. At universities, curricula and topics of Descriptive geometry vary by major, but they basically contain elements of the Monge projection. The test took place in the first week to check the students' previous knowledge. The proportion of female students in the Debrecen group is very low (4 students, 5%), therefore we did not examine gender differences. The examination of the students' prior education and age is not the subject of the current study.

Descriptive geometry is the basis of subjects of engineering drawing, technical drawing and computer-aided design. That is why it is worth examining spatial ability components that are important to us separately. To select the test task types, we followed the grouping of Séra and his colleagues (2002), who approach the spatial problems from the side of the activity. Based on the task types considered important for Descriptive Geometry, we selected four tasks from two types from internationally used tests.

The types of tasks:

a) Imaginary manipulation of an object: the imaginary following of the phases of the objective activity.

b) Mental rotation of a three-dimensional object: the identification of object with the help of its images depicted from two different viewpoints by the manipulation of mental representations.

The tasks:

- MCT: is in connection with the intersection of a polyhedron with a plane. MCT measures the understanding of the structure, the correctness of the mental picture and the recognition of 3 dimensional objects. Our test contains 5 MCT problems. One point is given for a problem. The best possible score in the MCT is 5. In Descriptive Geometry: It is useful for constructing intersection of polyhedrons with lines and planes and intersection of polyhedrons with each other.
- Task I: Task I/a and Task I/b focus on the imaginary manipulation of the solid. The task is to follow phases of the objective activity that consist of the complex spatial transformation of the solid (Figure 1). Task I/a is the identification of the figure, and third task is the manipulation of mental representations. Task I/b: We have marked a cube on three sides with three different signs, leaving the other three sides empty. The task is to find among the other five cubes those cubes which may be the same in a different position (Séra et al., 2002).

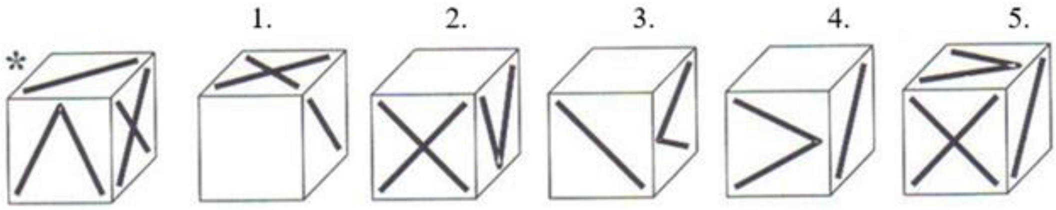

Figure 1. *Sample of task I* (Séra et al., 2002)

- Task II: Given 5 objects made up of identical dice showing all the edges of all the dice, including those that are normally hidden (Figure 2). The task is to select the object that can be rotated so that it fits completely through the given hole (Séra et al., 2002). Our test contains 2-2 tasks of this type. 5 points are given for a task. The maximum score for these tasks is 10. Standardization has taken place.

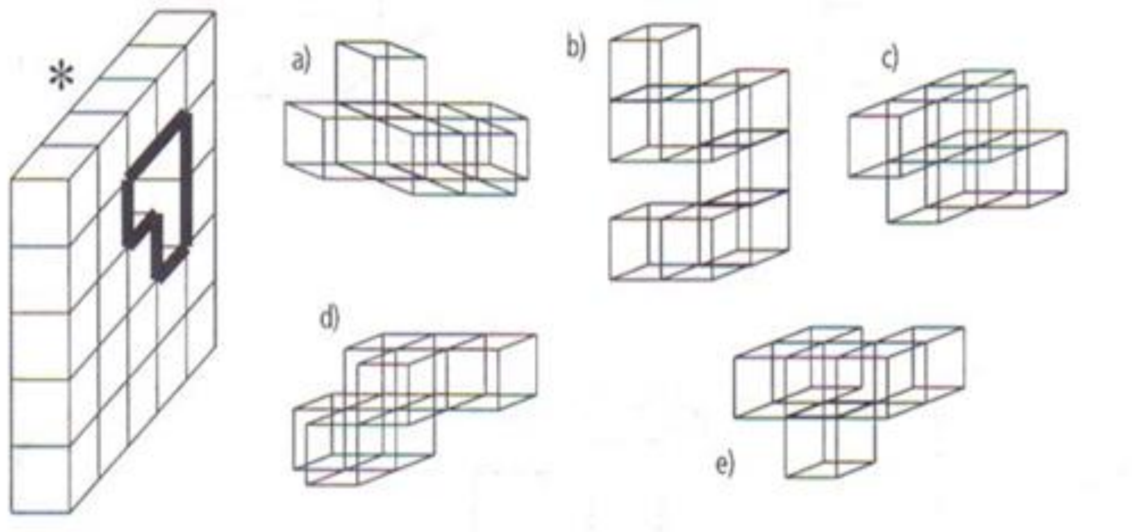

Figure 2. *Sample of task II* (Séra et al., 2002)

- MRT: The last task contains 6 MRT problems. 2 points are given for a problem. The best possible score in the MRT is 12. In Descriptive Geometry: The ability is necessary for the imagination of 3 dimensional objects, for the introduction of new image planes, for the determination of visibility after performing the construction.

Data were analysed using the SPSS statistical analysis program in order to data analysis.

3. Results

We examined whether there is a significant relationship between first-year engineering students' performance in four task types of spatial ability on University of Miskolc and the University of Debrecen.

Data analysis in Table 1 showed that there is a significant correlation between scores of first-year students of University of Debrecen in some task types. So MCT has significant correlation with Task II ($r = 0.359$, $p = 0.001$, $p \leq 0.01$), and Task I has significant correlation with Task II ($r = 0.396$, $p = 0.000$, $p < 0.01$). Data analysis (Table 1) showed that there is a significant correlation between Task I and MRT solutions by students ($r = 0.239$, $p = 0.033$, $p < 0.05$). But there is no significant correlation between other task types.

Although in both Task I and Task II the object had to be mentally rotated, we only found a significant correlation with MRT in Task I.

Data analysis in Table 2 showed that there was not a significant correlation between MTC and Task I scores of first-year students of University of Miskolc ($p = 0.246$, $r = 0.175$), and between MTC and Task II scores ($p = 0.279$, $r = 0.163$), and between MTC and MRT scores ($p = 0.342$, $r = 0.143$). Similarly, there was not a significant correlation between Task I and Task II scores of first-year students of University of Miskolc ($p = 0.565$, $r = 0.087$), between Task I and MRT scores ($p = 0.926$, $r = –0.014$), and between Task I and MRT scores ($p = 0.547$, $r = 0.091$).

***Table 1.** Relationship between scores of four tasktypes (University of Debrecen)*

		MCT	I	II	MRT
MCT	Pearson Correlation	1	,093	,359**	,170
	Sig. (2-tailed)		,412	,001	,131
	N	80	80	80	80
I	Pearson Correlation	,093	1	,396**	,239*
	Sig. (2-tailed)	,412		,000	,033
	N	80	80	80	80
II	Pearson Correlation	,359**	,396**	1	,202
	Sig. (2-tailed)	,001	,000		,072
	N	80	80	80	80
MRT	Pearson Correlation	,170	,239*	,202	1
	Sig. (2-tailed)	,131	,033	,072	
	N	80	80	80	80

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

So, there is significant relationship between first-year engineering students' performance in different task types of spatial ability on University of Debrecen, between MCT and Task II, between Task I and Task II, between Task I and MRT. There was not a significant correlation between scores of task types of first-year students from University of Miskolc.

We examined whether there is a significant difference between first-year engineering students from the two universities in terms of spatial intelligence in the four task types. Independent T-test results indicated that there was no significant difference between scores of students from University of Debrecen and University of Miskolc in MCT, in task I and in task II (MCT: $T = 0.908$, $p = 0.366$; task I: $T = 1.263$, $p = 0.209$; task II: $T = 1.594$, $p = 0.113$), just in MRT ($T = 1.976$, $p = 0.050$).

Data analysis in Figure 3 showed that students of both universities achieved the lowest score in Task II, this is imaginary manipulation of three-dimensional object (deciding whether a given object will fit through a given hole after being rotated), and students of both universities achieved the highest score in MRT. The students of University of Debrecen were 4% (MCT) and 5% (Task I and Task II) better in the tasks of imaginary manipulation of an object. In MRT task was the biggest difference between students from the two universities (92% students of University of Debrecen and 86% students of University of Miskolc with difference of 6%).

Table 2. *Relationship between scores of four tasktypes (University of Miskolc)*

		MCT	I	II	MRT
MCT	Pearson Correlation	1	,175	,163	,143
	Sig. (2-tailed)		,246	,279	,342
	N	46	46	46	46
I	Pearson Correlation	,175	1	,087	-,014
	Sig. (2-tailed)	,246		,565	,926
	N	46	46	46	46
II	Pearson Correlation	,163	,087	1	,091
	Sig. (2-tailed)	,279	,565		,547
	N	46	46	46	46
MRT	Pearson Correlation	,143	-,014	,091	1
	Sig. (2-tailed)	,342	,926	,547	
	N	46	46	46	46

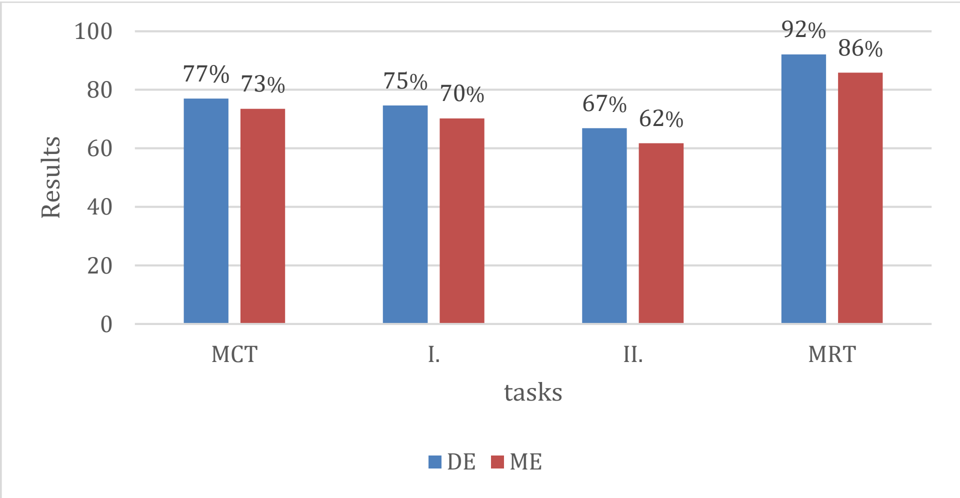

Figure 3. *Results (%) of all tasks*

Overall, we can say that students from both universities did better on task of mental rotation of a three-dimensional object, than tasks imaginary manipulation of an object.

4. Multi-stage development plan

Descriptive geometry is the basis of many subjects. We were looking for an educational model that would allow the largest percentage of our students to achieve optimal results and develop their spatial abilities. As a result of a joint research project between the University of Miskolc and the University of Debrecen, we have developed a multi-stage development plan to improve the spatial perception of university students. The article currently presents a development plan, but does not yet prove its effectiveness here. The steps of the development plan are as follows:

Step 1 involves a survey of incoming students using a paper-based test, followed by an evaluation of this test.

In Step 2, after the evaluation of the test, the schedule of the descriptive geometry course for the semester is optimised, taking into account, within this:

- in the first step (during the first week of the semester), students acquire theoretical knowledge about the concept of space, geometric shapes and spatial relationships, incorporating knowledge they lack based on their test results,
- as a second step, in the second week of the semester, students create hand-drawn sketches in different perspectives to develop their dexterity and spatial visualisation skills,
- in a third step, around the third week of the semester, teams (5-6 students) are formed based on the test written at the beginning of the semester, which are a mix of better and lower scoring students who are required to participate in teamwork exercises where students co-create and critique spatial designs to develop their communication skills and spatial interpretation,
- throughout the semester, the groups are given several tasks to carry out together, the results of which they present in class in a short presentation,
- with outstanding projects, students will also have the opportunity to participate in the university's TDK (Scientific Students' Association, 'Tudományos Diákkör' in Hungarian) competition,

In Step 3, an end-of-semester assessment will be carried out to validate the development plan, with similar tasks as at the beginning of the semester in the experimental and control groups.

In Step 4, taking into account the results of the end-of-semester assessment test, the curriculum for the following semesters will be developed taking these results into account.

The above steps are designed to curb dropout and develop spatial perception. Tertiary education is highly suitable for introducing students gradually and in stages to the complex world of spatial perception. This approach is effective for the following reasons:

- finding the right balance between theory and practice: the university is the ideal place to develop theoretical knowledge and practical skills in an integrated way, as theory provides the necessary knowledge that can be deepened through practical exercises,
- solving increasingly complex problems: progressing from basic concepts to the minutiae allows students to build on a solid foundation of knowledge and thus be better prepared for higher level and more complex design challenges,
- ability to support different learning styles: multi-stage teaching allows each student to work according to their preferred learning style,
- technological suitability: at each level, students can familiarise themselves with tools ranging from hand-drawing to the latest computer modelling and design software,
- professional sharpening and competition between groups: multi-stage training modules reflect the real labour market environment, where the complexity of projects and the level of skills required gradually increase, with universities, as the training sites for industry professionals, responsible for preparing students for these real work environments,

- the importance of personal and professional development: progressive development supports students' personal growth and adaptability, while helping them to discover their own strengths and identify areas for improvement through the input test, thus laying the foundations for their professional future.

Overall, multi-stage development not only allows for a deeper understanding and lasting mastery of information but also helps students to take full advantage of their university experience and better prepares them for the challenges of a changing, multidisciplinary work environment.

5. Conclusion

Spatial ability is considered a high priority for engineering education. Descriptive geometry is the basis of many subjects. Developing spatial ability is the key to understanding and creatively solving complex design challenges and engineering problems at university level, as such its development during tertiary education is essential for students' cognitive, professional and personal development. We were looking for an educational model that would allow the largest percentage of our students to achieve optimal results and develop their spatial abilities.

The spatial abilities of first-year engineering students have been studied in this paper, in four task types at two universities. Based on this survey, we can conclude that many first-year engineering students had problems with the imaginary manipulation of spatial objects. A collaborative research project between the University of Miskolc and the University of Debrecen resulted in a multi-phase development plan designed to enhance the spatial ability of engineering students, in response to the results obtained during a multi-aspect assessment of the spatial abilities of first-year engineering students and their perceived deficiencies. The goal of this report was to present this multi-stage development plan in next-generation engineering education. The above steps are designed to curb dropout and develop spatial ability. This multi-stage development plan enhances students' understanding of spatial concepts, maximizes their university learning experience, and equips them for success in dynamic professional environments.

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