# Can Spatial Ability be Developed in Engineer Education?

János Katona, Gyula Nagy Kem

Szent István University YMÉK

Practitioner Notes:

1. The spatial intelligence and problem solving is deeply considered
2. The spatial intelligence helps to become a problem solver in the engineering
3. CAD courses can improve the spatial skills of the engineering students.
4. We recommend a more differentiated education in 3D modeling

Keywords:

Spatial Intelligence; Problem solving; 3D modeling; Engineering education; Computer Added Design;

**Acknowledgement**

We express our thanks to our colleague Gergely Mészáros for developing the frame system and activating the students for the completion of the tests.

Abstract

The spatial or 3-dimensional ability is deeply considered, but little is known about students' learning and understanding of technology problems and about what it means to become more technologically capable. We examined the spatial intelligence of first-grade engineering students, how much that improved to the effect of 18 hours course of computer-aided 3D modeling. According to the result of the tests, one-third of the engineer candidates has good spatial intelligence. We introduce some useful problems in 3D education, the presented problems help students learn how to solve technology problems, and design objects. Our CAD course excellently improves the spatial skills of the middle third of the students. We recommend a more differentiated education of students in 3D modeling, as this is not only developed their spatial skills, as we discussed, but also the development of their creativity.

## Introduction

How to support problem solving in engineering? The ancient masters know a simple answer: We need to provide the student with appropriate geometry problems. Thus, we develop a wealth of solution techniques; these help us in approaching new challenges. Teaching 3D modeling and Geometry as a component of global technology and design education is an established practice, and yet many questions remain to be unanswered. The nature of spatial intelligence is deeply considered, but little is known about students' learning and understandings of technology problems and about what it means to become more technologically capable i.e. to become a real problem solver in the engineering. We believe in the principle that the geometry and 3D education is the base of the knowledge of technological and designs and natural science. Alberti said, “And since geometry is the right foundation of all painting, I have decided to teach its rudiments and principles.” (Dürer, 1525).

Similarly, the geometry was taught in the ancient Greek also. The teaching of geometry decreased the last decades. We were curious to know what the spatial intelligence of first-grade design and engineering students looked like after a semester of descriptive geometry. Could improve it the effect of an 18 hours course of computer-aided 3D modeling. In the spring semester of the previous academic year, with the students of our faculty, we did an educational experiment.

## Review of the Concept of Spatial Intelligence

Most of the developed living creatures possess the ability of biological-physical space-perception. The primary function of this ability is depth perception and distance estimation used for example for the adequate accomplishment of a bounce. In animals having two organs of vision, this ability is based – in the case of close objects – on binocular sight. For distant objects, space-perception is experimental. Its base is perspective, air perspective, analysis of overlaying and movement, and the system of light and shade.

On that, spatial intelligence (spatial skills, spatial abilities, spatial thinking) is an intellectual-psychological-pedagogical ability exclusively attributable to man. Some of the definitions of spatial skills widely accepted: “adaptive spatial thinking” (Hegarty, 2010). Gardner differentiates eight types of human intelligences, one of them is spatial intelligence: ability to develop a mental model of the 3D world and to orientate and act using this model. (Gardner, 1983). The entry on “spatial ability” Hungarian Pedagogic Encyclopaedia by Séra: “Capacity to perceive two and three-dimensional shapes, to be aware of the perceived information and relations, and to use them to solve spatial problems.” (Báthory, & Falus, 1997), (Séra, Kárpáti, & Gulyás, 2002), as to the general spatial ability in our study, the geometrical spatial ability requires three further skills (É. Vásárhelyi's personal notice):

1. clear-cut representation of perceived or conceived figures based on the rules of geometry
2. proper reconstruction of unanimously represented figures
3. a constructive solution of spatial problems and the formulation of the solution graphically and verbally

Our test is respondent only to the second one of these three.

Pittalis and Christou compared the different definitions, in their opinion, the parts of spatial abilities are spatial visualization, spatial orientation, spatial relations, representation of 3D shapes, spatial structuring, measurement, conceptualization of mathematical properties (Pittalis, & Christou, 2010).

Spatial abilities are a relatively constant quality of each people that may transmit to other skills through cognitive processes and the change of knowledge structure, and may develop by practice and an abundance of experiences (Lohman, & Nichols, 1990). The skill development may achieve by mastering and restructuring a declarative knowledge, or in a procedural manner (Olson, & Bialystok, 1983). This, latter means that by practicing the knowledge required for accomplishing the action, new skills are developed, or the existing ones are refined. Both declarative and procedural learning are relevant in developing skills. The former may be characterized briefly by the words "know what", the latter by "know how."

Researchers consider spatial cognition several points of view, including psychologists, geographers, cartographers, architects, designers, linguists, anthropologists, biologists, computer scientists. They consider acquirement and development, how we navigate, how we use language and graphical symbols to communicate about space, and how aspects of spatial believes, and reasoning are different among groups of people (Kyllonen, Lohman, & Woltz, 1984).

During the development of spatial skills, the selection of resolution strategies and their teaching by a clear explanation of rules and the types of solutions is useful (Montello, 2014). Metacognitive skills usually get critical importance in geometric problem solving (understanding and verifying of cognitive processes); several articles may be read on the salutary effect of the use of taught strategy (Schoenfeld, 1985), (Sternberg, & Ben-Zeev, 2001).

Spatial abilities of men and women differ. Measuring of spatial skills shows significant differences between the two genres (Eliot, & Fralley, 1976), (McGee, 1979).

Since spatial ability is developed mainly by experimental factors, spatial skills may be practiced and developed by suitable experiences (irrespective of the age) (Newcombe, & Frick, 2010), (Sorby, 1999), (Mohler, 2008) (Lean, & Clements, 1981). Not surprisingly spatial skills are developing by drawing, and computer-aided modeling 3D objects, and by solving problems of space geometry (Mohler, & Miller, 2008), (Kirby, & Boulter, 1999), (Olkun, 2003), (Sorby, 2007).

## The Test Measuring Spatial Skills that We Use

We measured spatial abilities at the beginning of the semester by a traditional multiple-choice test, then at the end of the course, they made the same test, but the questions and responses have been rearranged, only the order of the questions and the possible answers were mixed, to prevent information flow during the test.

The test includes 22 simple multiple-choice questions. Each question was given three or four possible answers to choose from, one being correct. Each correct answer was worth one score; students received no score for incorrect and omitted answers. Students were briefed on these conditions beforehand.

Students completed the test on a computer. The questions included, at least, one, often five figures: one for the questioning, four for the answers. Multimedia visualization not only made the exercises spectacular but also assisted in the apprehension. The picturesque formulation of the activities contributed to the adjustment of intellectual differences: we stressed visualization instead of verbal communication. The comprehension of our exercises was assisted by a precise geometric formulation that, based on the visual recognition and knowledge, had to provide only reinforcement for the accurate understanding of the problem. Therefore, they did not find it difficult. We ignored compound exercises requiring the succession of several ideas.

The computer-aided frame system mixed the questions, mixed the order of the answers, so each student saw a slightly different sequence of tasks. The software made the timing and also provided that a student may complete the test only once, letting everyone log in with his or her code, and each code could start only one test.

Tests were to be finished in 20 minutes, providing some less than a minute for answering each question. There was no period for any of the questions, so one could think of a question 3 or 4 minutes while answering the other issues in half minutes. The term proved to be long, only a few of the students utilized the entire 20 minutes.

Concerning the questions, we aspired diversity. The questions included usual “Mental Cutting Test”-type, also typical “Mental Rotation Test”-type, and also widely popular “Paper Folding Test”-type exercises. The following test exercises on Figure 1 are the most complex of the tasks requiring a sequence of spatial actions:

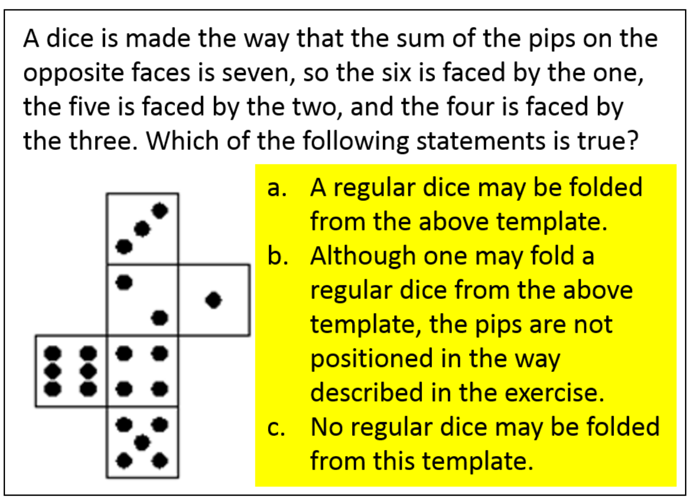
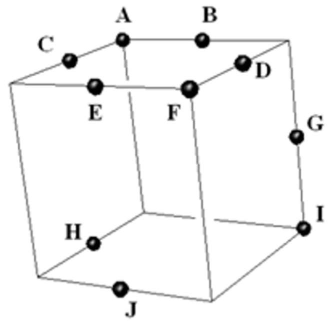



Figure 1. Conceptual folding and the different side examination.

In this exercise, a theoretical folding has to be done first, and then one has to examine which of the faces will be opposite each other after the folding. A more rarely applied, and an exercise more challenging than usual was the following on Figure 2:

On the wire frame of a cube, we marked certain corners and the midpoint of certain edges, as seen in the figure. Which of the following statements is true?




a. Points C, E, J and H are not in a plane.
b. Points C, E, J and H are on a plane and determine a square.
c. Points C, E, J and H are on a plane, but they do not determine a square.

Figure 2. This question expects the routine steps of problem solving.

This issue assumes the student the method of the following sequence of thought:

- finds the points corresponding to the letters on the edges,
- imagines the figure in space based on the axonometric projection,
- determines the metric relations and
- knows the attributes of the plane figures included in the question.

The above figure includes more points marked than referred to in the issue because the same picture was used in more exercises. Perhaps this made the solving more difficult. The questions and the possible answers include the following plane figures: triangle, quadrangle, a regular triangle, rectangle, and square.

Engineers use geometrical and graphical methods of communication and problem solving, it is significant that future engineering students have strong spatial abilities and the visualization and graphicacy skills developed in their education the latter was consider in (Danos, Barr, Górska, & Norman, 2014).

The testing of mirroring, moving, intersection, folding and constructing, the determination of skill levels, were accomplished by the increase or decrease of the complexity of forms, or the growth in the complexity of operations to be achieved mentally, the way it was published by (Babály, Budai, & Kárpáti, 2013)

Another more rarely applied type of exercise on Figure 3:

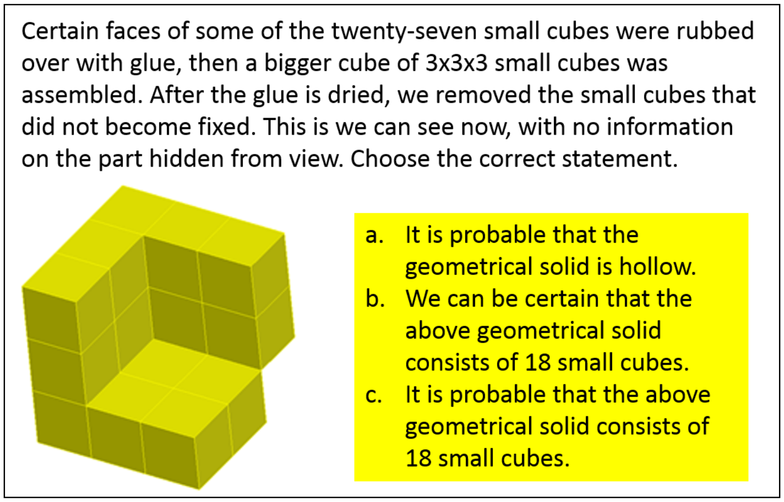



Figure 3. The next strategy gives a fast answer. It is certain that nine small cubes are missing, so only the last one is the right answer.

The first answer is easy to be excluded because 27 small cubes would make a hollow only by removing one single cube, the middle. This reply is impossible now because many of the adjacent cubes are missing, on the contrary, this “glued” construction excludes the formation of a hollow from the outset. Then, it is advisable to count the visible small cubes; they add up to 14. It is easy to mistake because there are small cubes that show only one face, there are some that show two faces, and there are also some that show three faces. Some minor cubes are hidden, so the last answer is correct. The strategy of the problem solving is important: it is certain that nine small cubes are missing (the right one in the lower back and another part facing us of 2x2x2 cubes), there is no information on some hidden cubes, so only the last one is the right answer.

## The Testers

The testers were architect and civil engineer freshmen in the full-time department. All of them took the test seriously because they could obtain credits that would be included in the mid-year grade. Those, who completed the test correctly was gotten ten credits; that means a grade higher exactly. Besides, even one credit could mean a grade higher when one was at the upper edge of a grade based on the credits received for the midterm tests.

The test was thrown in on the practical class of the subject Technical Computing 2. Since the subject Technical Computing 1 contains mainly spreadsheets and databases, it did not develop spatial skills. (However, it is suitable for filtering out the least diligent and the unmotivated, for only those students could enter Technical Computing 2 who had accomplished the prerequisite of the subject. Thus, we could work with students who had acquired some experience in spreadsheets, databases, and other application programs.)

120 students completed the entering test at the beginning of the semester, unfortunately, by the end of the semester, this diminished to 41. These factors affected this: a part of the students just “vanish” in the middle of a semester (not only in this subject), but they also do not attend classes, do not write their exams, and there are even few who get the subject canceled. Another part of them was sick in the last week and did not make up for the test. The third reason is that many of them collected enough credits from midterm tests for a mark five. Therefore, they were not motivated in completing the test.

As regards the comparison, we could consider only those, evidently, who wrote both tests. This group is not quite a big sample as compared with the total number of students attending technical higher education, though since the results have small dispersion, as we will see in the following sections, the measure is proper for drawing meaningful conclusions.

## Developing Spatial Intelligence by 3D-Modelling

The entering test predates the semester of computer-aided modeling within the subject Technical Computing 2. The subject has continuous examining, so it results in a practical mark. Three hours in the computer lab per week and the examining also takes place in the computer room. The results of both the two midterm exams and the one mid-year exercise to be submitted are CAD files; students receive practical grades on their basis. The level of passing is 56%, excellent starts at 86%.

When compiling the curriculum, we considered the experiment done by Rowe and expounded by (Eliot, 1987), in which spatial intelligence was developed by programs including exercises requiring two and three dimension and mental transformation. We aspired to the diversity of the practices, for according to Lohman: the biggest change in the development of spatial abilities may be achieved by experiences that enable a gradual development of an abundant declarative knowledge base (Lohman, 1988).

In the first part of the semester, we draw in the plain; the first exam is a 2D drawing. The second half of the semester and both the second review and the exercise to be submitted is a 3D modeling. In the first half of the semester, the students learn to manage the CAD software, so in the second half of the semester, they have a chance to study further the program, but also to develop general spatial skills. According to Paivio is the double coded theory, during creative learning, referential relationships evolve between the concurrently developing mapping of visual and verbal information, that would enable the penetrability between the two systems (Clark, & Paivio, 1991). By applying this, we outline the exercise to our students in several ways, and if he cannot proceed independently, we help him interactively with resolution sketch, video tutorial, tangible, actual 3D model (Robert, & Chevrier, 2003).

In the following figures, some types of exercises of the course are illustrated:

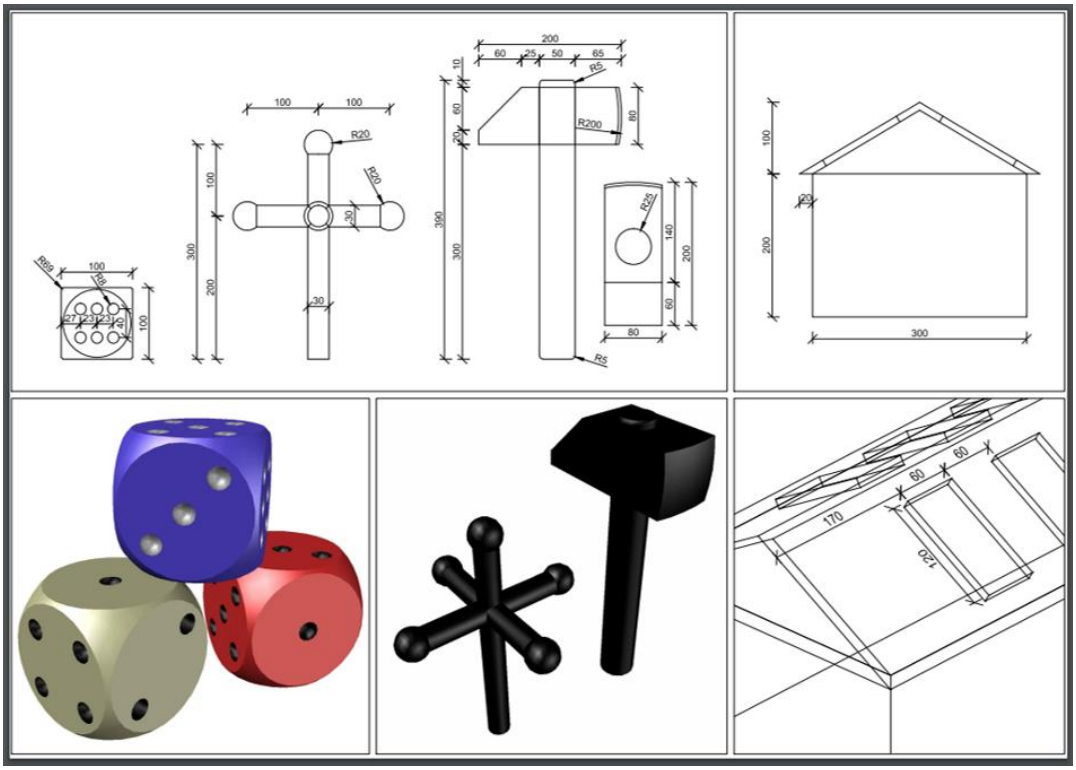


Figure 4. The dice is the intersection of a cube and the sphere almost tangential to each edge of the cube. Thus, it rolls through it also stands solidly on its bottom face when it stops. To draw the other models is simpler.

The first solid model is a dice on the left on Figure 4. When preparing the pips (dots), it is advisable to work with transformations (reflection to plain (mirroring), rotation around an axis, and arraying, which is extraordinary powerful feature of the CAD), so not each of the 21 dots has to design separately. These solid-state operations were practiced, when preparing the following model, soccer ball on Figure 5 or cross (quadripartite) vault: union, subtract, intersect. The command “shell” may also come in handy; this one leaves only the outer surfaces of a solid.

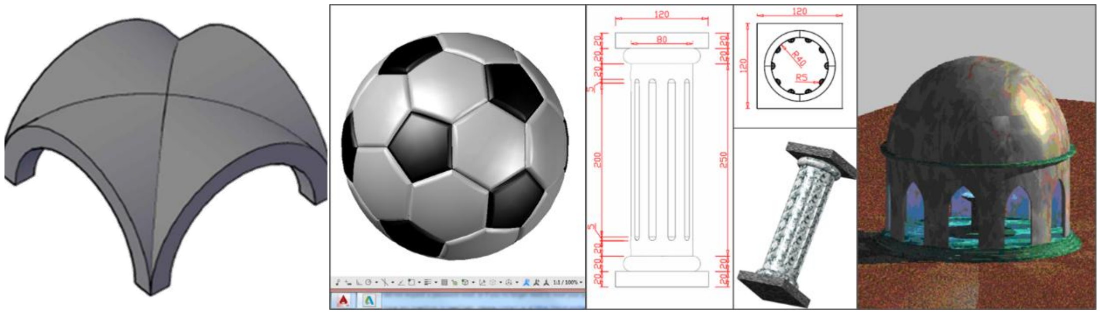


Figure 5. This two drawing are the most important parts of the course. In the middle and on the right, we can see only the rendered model.

The third (a column) on the left side on Figure 5 is the union and subtraction of simple solid-state-primitives: cylinder. A better option the fillet command of a cylinder for the capital instead of the torus (advisable to adjust the base plane and the cover plane of the cylinder to the cuboids so that no hollow remains inside the torus) and last the cuboid for the abacus, the materials are used firstly in this lecture. The fourth model may be prepared by the revolve option, the openings by extraction, polar array and subtracting. The rendering option lights shadows, perspective projection are also used in this lecture.

The exercises develop spatial abilities well, the view options have to be often shifted, spatial rotations have to be applied, the base plane has to be adjusted on different superficies, and so force. We also use the trick of providing only 2D documentation for the modeling exercise and students have to reconstruct the 3D solid from that.

We offer our students intellectual pleasure of problem solving through 3D problems, their persistence of the 3D model space often leads to activity because they creativity can work freely. A new world (just virtual) will be available them. They give help from the instructors to use her or his ability to create new objects.

## Test Results

So, the entrance test was made at the beginning of the semester, followed by the computer-aided modeling course, then the post-test. The result of the comparative analysis in Table 1 and Figure 6, students may be divided into two groups with a high degree of certainty: those who remained at their level and those who improved much. This is because these two statements may characterize the test:

1. 64% of the students made at least 14 credits in the first test, reaching the same amount of credits or improving or worsening 1 or 2 credits.
2. 32% of the students made less than 13 credits in the first test though improved at least 5 credits. There were some who grew 9 or 10 credits, in fact, one student could reach an improvement of 12 credits.

The remaining one student (4%) may not be included in any of the two categories. Students belonging to group 1 may be described as having good or excellent spatial skills at the beginning of the semester, and this did not change by the end of the semester. In our opinion, give or take 1 or 2 credits may be considered neither an improvement nor a deterioration that may be a result of a mere inattention or the pintsize change of circumstances and the temporary change in the state of mind. The students had different levels of pre-training in computing; some of them had known and used CAD software before, though usually in 2D. The factor to be considered is that they grew up playing 3D games that influence orientation and movement in a virtual environment big time, assisting well getting acquainted with mental operations (Prensky, 2007), (Oei, & Patterson, 2013).

Table 1:

| ID 3D | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Before** | 21 | 21 | 21 | 14 | 20 | 15 | 16 | 13 | 19 | 18 | 22 | 20 | 10 | 11 | 7 | 14 | 7 | 13 | 18 | 18 | 12 | 13 | 7 | 16 | 18 | 17 | 11 | 17 | 18 | 16 | 13 |
| **After** | 22 | 20 | 22 | 13 | 19 | 17 | 18 | 18 | 17 | 20 | 22 | 18 | 16 | 17 | 19 | 15 | 8 | 19 | 16 | 21 | 21 | 15 | 15 | 15 | 19 | 16 | 21 | 17 | 20 | 16 | 21 |

First, it is favorable that spatial ability of the majority of engineer candidate students is right or excellent. We cannot improve their spatial skills spectacularly, or the test does not cover that, in their case, we had to stress on introducing the software the deepest possible.

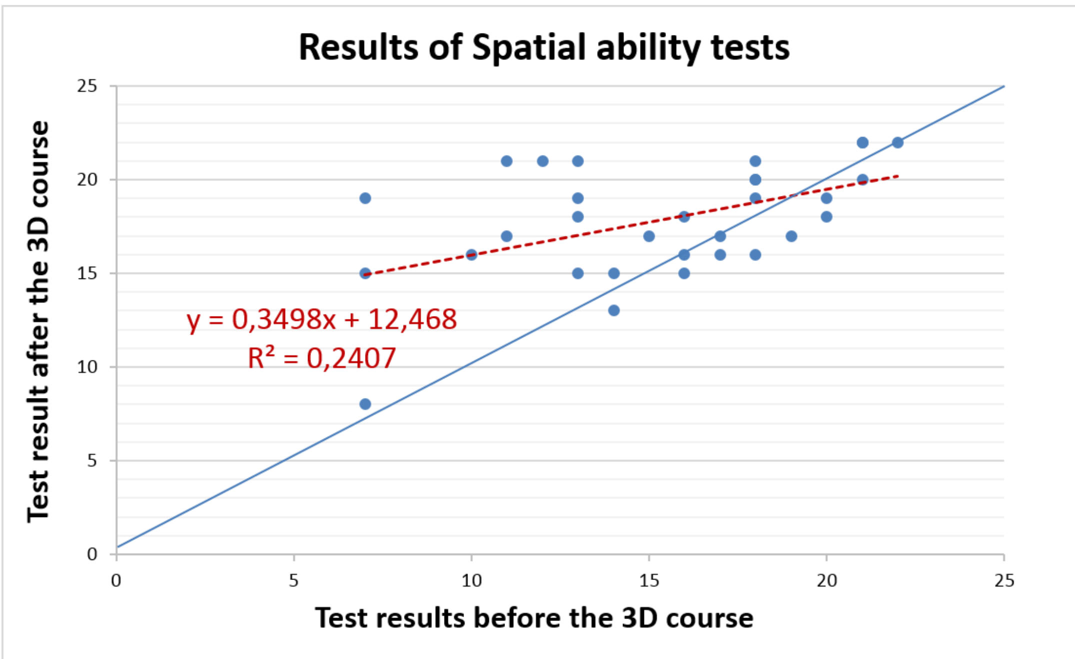



Figure 6. The graph contains the results of the same test after 3D course against the product of the test before the 3D CAD course. The result of id 1 and id 3, and similarly id 10 and id 19 are the same; the corresponding points cover each other on the graph. Hence, we can see 29 points instead of 31.

Students belonging to group 2 may characterize by having a spatial ability average or worse at the beginning of the semester, what they could palpably improve by mastering the general knowledge the course provided. The sufficient credits are positioned in the upper left quarter of the graph. The constant of the blue trend line is 12.46, i.e. an average student having 0 starting credits could have obtained more than the half of the credits after the completion of the course – that would make us proud. Even this fact is acceptable, the scoring of our test did not respond to general principles, where the minimal value is set to a randomly completed test – this one is five credits in our case. Meaning that, the mentioned student has to achieve 14 credits, thus improving “only” nine credits by the end of the course. Regarding the performance of 50%, we take a result of 13.5 for basis, the pertaining value of substitution on the trend line is 17.17, corresponding to an improvement of 3.67; in the case of the control group, as we will later see, this is 0.5.

The steepness of the trend indicates that one credit higher compared to the result of the earlier test only about one-third credits of improvement in spatial ability are guarantied for an “average” student during the completion of the course. This critical when the trend line and line y=x intersect each other, for in that case what we see for an average student who follows the trend is a decrease instead of an increase regarding the acquired spatial skills. It is true, however, that this happens a bit earlier for tested students and in not more than three cases, and it does happen though indeed scarcely, the points corresponding to them are seen under the line y=x in the upper right corner.

We set a control group during the experiment; the first test was completed by 23 such persons while the second by 15 out of them. The gap between the two tests was also three months. The members of the control group did not attend any course that would develop their spatial skills. What we interested in was how the knowledge of the exercises solved in an earlier test influences the following completion of the test. The results of the control group are included in the following table 2 and chart in Figure 7.

Table2:

| ID control | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| first | 22 | 17 | 10 | 22 | 17 | 17 | 13 | 20 | 7 | 16 | 12 | 14 | 21 | 22 | 20 |
| second | 21 | 19 | 8 | 21 | 19 | 12 | 16 | 21 | 10 | 3 | 22 | 13 | 18 | 20 | 18 |

No improvement on the merits can be read from the result; the trend line shows that the ones who could hardly solve the first test more likely improved the second time, the ones who achieved success the first time, more likely worsened their results.


Figure 7. The graph shows the second test results of the members of control group against them first test results. The result of id 1 and id 4, and similarly id 2 and id 5 are the same; the corresponding points cover each other on the graph. Hence, we can see 13 points instead of 15.

The substitution value belonging to 13.5 is 14 (50% accomplishment also regarding random hits), meaning a minimum improvement regarding this performance. Therefore, we may state that the results of the control group did not improve; they shaped up according to expectancies.

The sequence of three-dimensional rotations and the composition of other 3D transformations may be complicated enough so that their comprehension is hard to achieve without theoretical fundaments. The fixation of probable errant or word-of-mouth ideas or theories only true in two dimensions may cause a problem, annul them takes many efforts. Spatial abilities developed by games provided by mobile devices may not be ignored; these chiefly have an encouraging effect on the development and improvement of one's spatial abilities, though they may also generate problems sometimes. Then, it is worth to return to the actual three-dimensional space. It is then worth to rethink and turn a Rubik's cube, create simple and complex models as our students made it during their project work Figure 9.

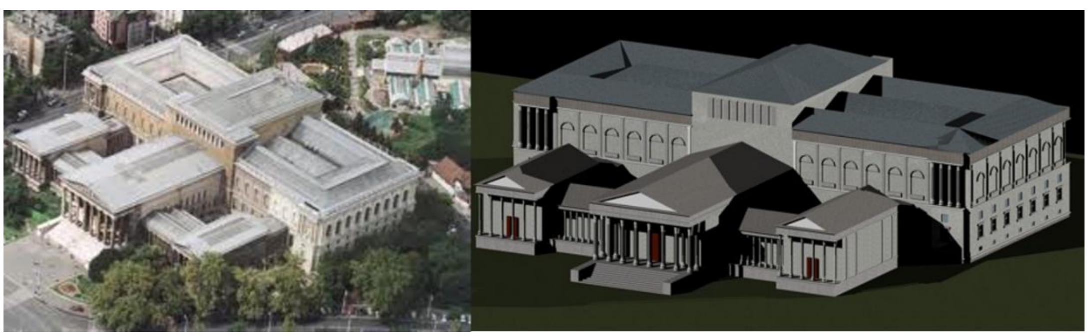


Figure 8. On the left a photograph of Museum of Fine Arts Budapest. On the right a rendered picture from the CAD model made one of the student from one of the considered course.

It is well known that spatial thinking is not supported enough in our educational system similarly to the problem solving ability and that current system depends on the selection of the gifted students for spatially demanding disciplines than on developed the spatial intelligence of all students (Janelle, Hegarty, & Newcombe, 2014), (Nagy, 2017). Courses of 3-dimensional geometry that create models by 3D software programs; also assist the development of spatial intelligence of our students and the expansion of their design creativity on a grand scale (Velichová. 2002), (Bölcskei, Kállay-Gál, Kovács, & Sörös, 2012), (Starkey, Toh, & Miller, 2016). Of course, achieving this are made possible by our students in their studies. This assumption offers possibilities of development that adjust the acquisition of abilities required for problem solving to our students' current level and provides a wider spectrum of acquirable knowledge.

## Conclusion

The described training process and the related test led to the following outcomes:

- According to the trial, one-third of the engineer candidates has a good spatial intelligence.
- Our course can improve the spatial skills of the middle third of the students.
- Computer-aided 3D modeling also bridges the gap for students with a poor spatial ability.
- Dealing with students in a more differentiated way about CAD modeling would be advisable. For the moment, this means that students are advancing faster get more exercises.

What could we do so that spatial abilities be improving during our CAD education? On a language course, language classes, it is natural to have a placement test at the beginning of the course. If making classes concurrently in different computer laboratories were possible, it would be worth considering accomplishing the grouping based on the entering spatial ability test. In this way, it would be possible to give students with a better spatial intelligence not only more but other types of exercises, at the same time, in the group of students with weaker spatial skills, the development of general abilities could be emphasized. Unfortunately, the test could not appraise the improvement of students having completed the test successfully, even for the first time. The next target would be to schedule a more difficult test in which even the best would reach 70 to 80% for the first time, thereby, their improvement may become measurable too.

One of the recent results of (Chang, 2014) is the following: in 3D-CAD applications, students with better spatial abilities were superior to those with relatively poor spatial abilities with regard to creative performance. The consequence of the result of Chang we have to recommend a more differentiated education of students in 3D modeling, as this is not only their spatial skills, as discussed our paper, but also the development of their creativity.

# References

Dürer, A. (1525). *Underweysung der messung, mit dem zirckel und richtscheyt, in Linien ebnen und gantzen corporen*. Nüremberg: [Hieronymus Andreas Formschneider].

Hegarty, M. (2010). *Components of spatial intelligence. Psychology of Learning and Motivation,* Vol. 52. pp. 265-297.

Gardner, H. (1983). *Frames of mind: the theory of multiple intelligences.* New York: Basic books.

Báthory, Z. & Falus I. Szerk. (1997). *Magyar Pedagógiai Lexikon.* Budapest: Keraban Kiadó.

Séra, L., Kárpáti, A. & Gulyás, J. (2002) *A térszemlélet.* Pécs: Comenius.

Pittalis, M. & Christou, C. (2010) *Types of reasoning in 3D geometry thinking and their relation with spatial ability*. Educ Stud Math Vol. 75. pp. 191–212.

Lohman, D. F, & P. D. Nichols. (1990) *Training spatial abilities: Effects of practice on rotation and synthesis tasks.* Learning and Individual Differences 2(1):67–93.

Olson, D. R. & Bialystok, E. (1983) *Spatial Cognition.* Published by Psychology Press ISBN 10:0898592526 ISBN 13: 9780898592528

Kyllonen, P. C., Lohman, D. L. & Woltz, D. J. (1984) *Componential modeling of alternative strategies for performing spatial tasks.* Journal of Educational Psychology, Vol. 76. pp. 1325–1345.

Montello, D. R. (2014) *Spatial cognition and architectural space: Research perspectives.* Architectural Design, 84(5), 74-79. Special Issue on "Empathetic space: The computation of human-centric architecture," C. Derix & A. Izaki (Eds.).

Sternberg R. J., & Ben-Zeev T. (2001) *Complex Cognition. The Psychology of Human Thought.* ISBN: 9780195107715 Oxford University Press Inc. New York

Schoenfeld, A. H. (1985) *Mathematical Problem Solving* ISBN-13: 978-1493305995, ISBN-10: 1493305999, Academic Press Inc. (London) Ltd.

Eliot, J., & Fralley, J. S. (1976). *Sex differences in spatial ability.* Young Children, Vol. 31. pp. 487-498.

McGee, M. G. (1979). *Human spatial abilities: Sources of sex differences.* Praeger Publishers, New York.

Newcombe, S. & Frick, A. (2010) *Early Education for Spatial Intelligence: Why, What, and How.* Mind, Brain and Education Vol. 4. No. 3. pp. 102-111.

Sorby, S. A. (1999) *Developing 3D Spatial Visualization Skills. Engineering Design Graphics Journal*, Vol. 63. No. 2. pp. 21-32.

Mohler, J.L. (2008) *A Review of Spatial Ability Research.* Engineering Design Graphics Journal Vol. 72. No. 3. pp. 19-30.

Lean, G. & Clements, M.A. (1981) *Spatial Ability, Visual Imagery and Mathematical Performance.* Educational Studies in Mathematics Vol. 12. pp. 267-299.

Mohler, J.L. & Miller C.L. (2008) Improving Spatial Ability with Mentored Sketching. Engineering Design Graphics Journal Vol. 72. No. 1. pp. 19-27.

Kirby J. R. & Boulter D. R. (1999) *Spatial ability and transformational geometry.* European Journal of Psychology of Education. Vol. 14. No. 2. pp. 283-294.

Olkun S. (2003) *Making Connections: Improving Spatial Abilities with Engineering Drawing Activities.* International Journal of Mathematics Teaching and Learning, Vol. 2003 April.

Sorby S.A. (2007) *Developing 3D spatial skills for engineering students.* Australasian Journal of Engineering Education, Vol. 13. No. 1. pp. 1-11.

Danos X, Barr R, Górska R & Norman E: *Curriculum planning for the development of graphicacy capability: three case studies from Europe and the USA* European Journal Of Engineering Education Vol. 39 , Iss. 6,2014

Babály B., Budai L. & Kárpáti A. (2013) *A térszemlélet fejlődésének vizsgálata statikus és mozgó ábrás tesztekkel.* Iskolakultúra, Vol. 2013/11. pp. 6-19.

Eliot J. (1987) *Models of Psychological Space.* Springer-Verlag New York Inc.

Lohman, D. F. (1988) *Spatial abilities as traits, processes, and knowledge.* In R. J. Sternberg (Ed.), Advances in the psychology of human intelligence (Vol. 4, pp. 181–248). Erlbaum Lawrence Associates Inc. Hillsdale-New Jersey

Clark, J. M. & Paivio, A. (1991). *Dual coding theory and education.* Educational Psychology Review, Vol. 3. No. 3. pp. 149-170.

Robert, M. & Chevrier, E. (2003) *"Does men's advantage in mental rotation persist when real three-dimensional objects are either felt or seen?"* Memory & Cognition Vol. 31. No. 7. pp. 1136-1145.

Prensky, M. (2007) *Digital Game-Based Learning.* Paragon House Edition, St. Louis

Oei, A. C. & Patterson, M.D. (2013) *Enhancing Cognition with Video Games: A Multiple Game Training Study.* PLoS ONE, Vol. 8. No. 3.

Janelle, D. G., Hegarty, M. & Newcombe, N. S. (2014) *Spatial Thinking Across the College Curriculum: A Report on a Specialist Meeting,* Spatial Cognition & Computation, 14:2, 124-141,

Nagy, Gy. (2017) Developing Problem-solving Skills. Mathematics Competition 29 (2), 26-41

Bölcskei, A., Kállay-Gál, Sz., Kovács, A. Zs. & Sörös, Cs. (2012) *Development of Spatial Abilities of Architect and Civil Engineer Students in the Light of the Mental Cutting Test*, Journal for Geometry and Graphics, Volume 16 (2012), No 1, 97–109.

Velichová, D. (2002) *Geometry in engineering education.* European Journal Of Engineering Education 2002. 27,3,

Starkey E, Toh C. A. & Miller S. R. (2016) *Abandoning creativity: The evolution of creative ideas in engineering design course projects.* Design Studies,47, 47-72

Chang, Y. (2014) *3D ‐ CAD effects on creative design performance of different spatial abilities students.* J. Comput. Assist. Learn. 30, 397‐407.