sciendo

10.2478/jbe-2019-0002

The CAD 3D course improves students' spatial skills in the technology and design education

Katona, János[1] and Nagy, KEM Gyula[2]

[1]Department of Mathematics and Computer Science,
Institute of Civil Engineering, Szent István University, Budapest, Hungary
katona.janos@ybl.szie.hu
[2]Department of Mathematics and Computer Science,
Institute of Civil Engineering, Szent István University, Budapest, Hungary
nagy.gyula@ybl.szie.hu

Abstract: *The nature of 3D ability is deeply considered, but little is known about students' learning and understandings of technology and about the meaning to become more technologically capable. We considered the spatial intelligence of first-grade engineering students, how much that improved to the effect of 18 times 45 minutes course of computer-aided 3D modeling. We consider the success of our 3D course in spatial intelligence. 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 the students in learning how to solve technology problems, and how to design objects. We offer the intellectual pleasure of problem solving through 3D problems. Our CAD course excellently improves the spatial skills of the middle third of the students. Computer-aided 3D modeling also bridges the gap for students with worse spatial ability. Dealing with students in a more differentiated way about CAD modeling would be advisable.*

Keywords: *3D modeling; Problem solving; Technology and design education; Spatial intelligence; Mental rotation test.*

1. INTRODUCTION

Teaching CAD and Geometry as a component of general 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 and about the meaning to become more technologically capable. We believe in the principle that the geometry and 3D education is the base of the knowledge of technological and designs and natural science.

Dürer said, "And since geometry is the right foundation of all painting, I have decided to teach its rudiments and principles." [38] Similarly, the geometry was taught in the ancient Greek also. The teaching of geometry decreased in 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. Has an 18 times 45 minutes computer-aided 3D modeling course any effect on it? In the spring semester of the previous academic year, with the students of our faculty, we performed an educational experiment.

2. REVIEW OF THE CONCEPT OF SPATIAL INTELLIGENCE INTRODUCTION

Most of the developed living creatures possess the ability of biological-physical space-perception. The main 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." [2]. Gardner differentiates eight types of human intelligence, one of them is spatial intelligence: ability to develop a mental model of the 3D world and to orientate and act using this model. [3] The entry on "spatial ability" Hungarian Pedagogic Encyclopedia by Séra: "The ability to perceive two and three-dimensional shapes, to be aware of the perceived information and relations, and to use them to solve spatial problems." [4], as to the general spatial ability in our study, the geometrical spatial ability requires three further skills (É. Vásárhelyi's notice):

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

Our test, which will be introduced later on, 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. [5]

Spatial abilities are a relatively constant quality of each people that may be transmitted to other abilities through cognitive processes and the change of knowledge structure and may be developed by practice and an abundance of experiences. [6] The skill development may be achieved by mastering and restructuring a declarative knowledge, or in a procedural manner [7]. 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 to developing skills. The former may be characterized briefly by the words "know what", the latter by "know how".

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. [8] Metacognitive skills usually get key importance in geometric problem solving (understanding and verifying of cognitive processes); several articles may be read on the beneficent effect of the use of taught strategy [9] [10].

Spatial abilities of men and women differ. Measuring spatial skills shows significant differences between the two genres. [11] [12]

Since spatial ability is developed mainly by experimental factors, spatial skills may be practiced and developed by suitable experiences (irrespective of the age) [13] [14] [15] [16].

Not surprisingly, spatial skills may be developed by drawing and computer-aided modeling 3D objects and by solving problems of spatial geometry [17] [18] [19] [20].

3. INTRODUCTION OF THE APPLIED TEST FOR MEASURING SPATIAL SKILLS

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, only the order of the questions and the possible answers were mixed.

The test includes 22 simple multiple-choice questions. Each question was given three or four possible answers to choose from, one is 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 exercises 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 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. (We express our thanks to our colleague Gergely Mészáros for developing the frame system and activating the students for the completion of the tests. It should be noted that the frame system has been working perfectly for years. Therefore programming errors may be practically excluded.)

Tests were to be completed 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 questions 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 the usual "Mental Cutting Test"-type, also usual "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 exercises requiring a sequence of spatial actions:

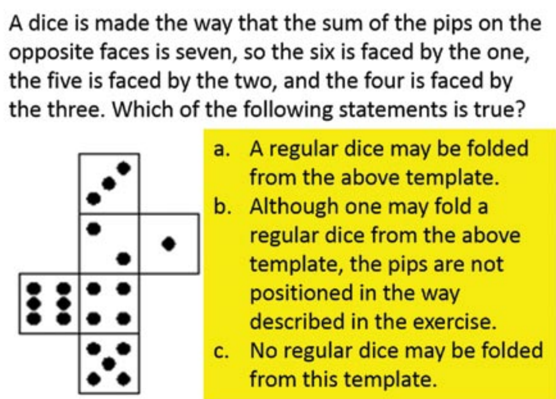

Figure .1 Conceptual folding and the opposite side examination

In this exercise, a conceptual 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:

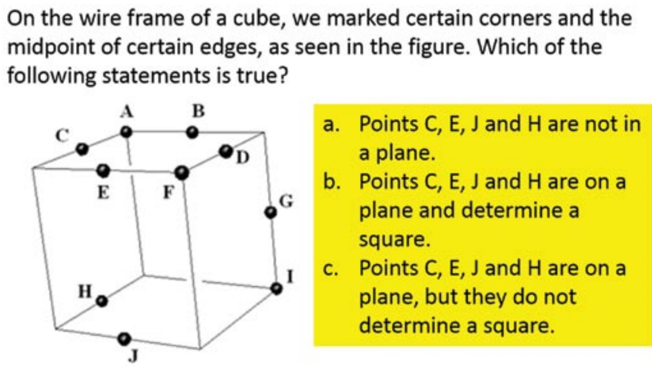

Figure 2. This question expects the routine steps of problem solving

This exercise expects the student the routine 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
- Recognizes the attributes of the plane figures, that included in the question.

The above figure includes more points marked than referred to in the question because the same figure 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.

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 increase in the complexity of operations to be accomplished mentally, the way it was published in [21-31]. Another more rarely applied type of exercise in Figure 3:

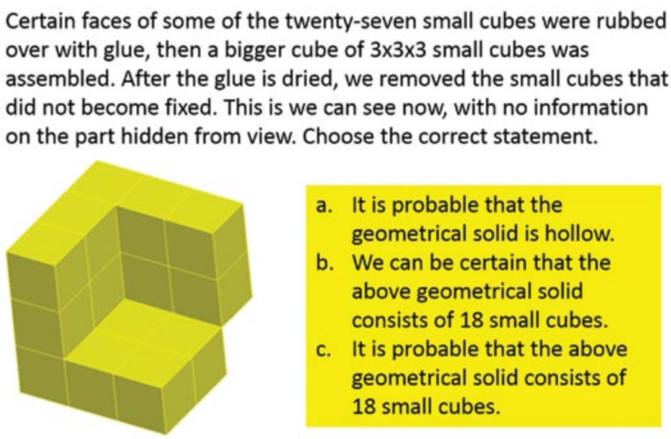

Figure 3. The next strategy gives a fast answer.
It is certain that nine small cubes are missing, so only the last one is the right answer

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

4. ABOUT SUBJECTS OF THE TEST

The testers were an 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 given 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.)

At the beginning of the semester, the entering test was completed by 120 students; unfortunately, by the end of the semester, this diminished to 31. This fact can be explained by the following: a part of the students simply "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 the 'excellence' mark.

Therefore, they were not motivated in completing the test. As regards the comparison, we could consider only those who wrote both tests. This 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.

5. DEVELOPING SPATIAL INTELLIGENCE BY 3D-MODELLING

The entering test was followed by a semester of computer-aided modeling within the subject of Technical Computing 2. The subject has continuous examining, so it results in a practical grade. Three hours in the computer lab per week and the examining also takes place in the computer classroom. 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, in which spatial intelligence was developed by programs including exercises requiring two and three dimension and mental transformation. [32] We aspired to the diversity of the exercises, 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. [33]

In the first half 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 exam 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 intelligent learning, referential relationships evolve between the concurrently developing mapping of visual and verbal information, that would enable the penetrability between the two systems. [34] By applying this, we outline the exercise to our students in several ways, and if he or she cannot proceed independently, we help him or her interactively with resolution sketch, video tutorial, tangible, actual 3D model. [35]
In the following figures, some types of exercises of the course are illustrated:

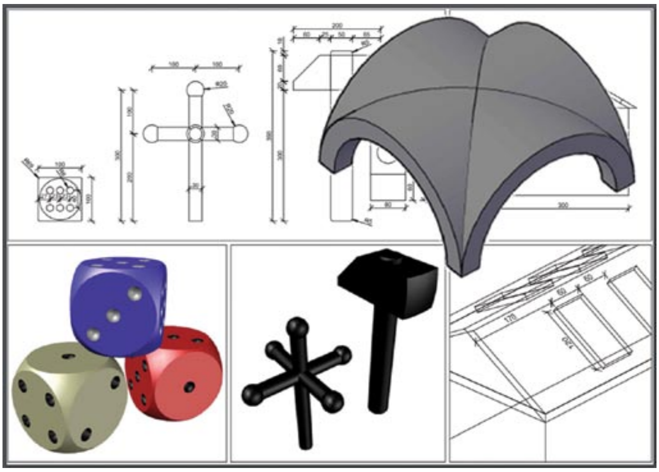

Figure 4. The dice is the intersection of a cube and the sphere tangential to each edge of the cube. Thus it rolls through it also stands solidly on its bottom face when it stops. To draw the other models is simpler.

The first solid model is a dice on the left in Figure 4. The intersection of a cube and the sphere tangential to each edge of the cube, thus it rolls through it also stands solidly on its bottom face when it stops. When preparing the pips (dots), it is advisable to work with transformations (mirroring, rotation, arraying), so not each of the 21 pips has to be designed separately. These solid-state operations can be practiced when preparing the following model (cross (quadripartite) vault): union, subtract, intersect. The command "shell" may also come in handy; this one leaves only the outer surfaces of a solid.

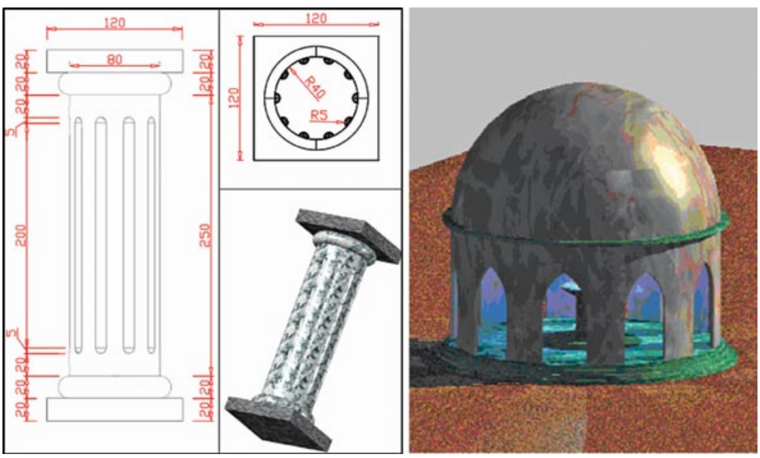

Figure 5. These two drawings are the most important parts of the course. On the right, we show only the rendered model.

The third (a column) on the left side of 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 to use her or his ability to create a new object.

6. 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 test is presented in Table 1 and Figure 7, 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:

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.

32% of the students made less than 13 credits in the first test though improved at least five credits. There were some who improved 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 none 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 not be considered neither an improvement nor a deterioration that may be a result of a simple 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 in getting acquainted with mental operations. [36] [37]

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

Table 1.

First, it is favorable that the spatial ability of the majority of engineer candidate students is good 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.

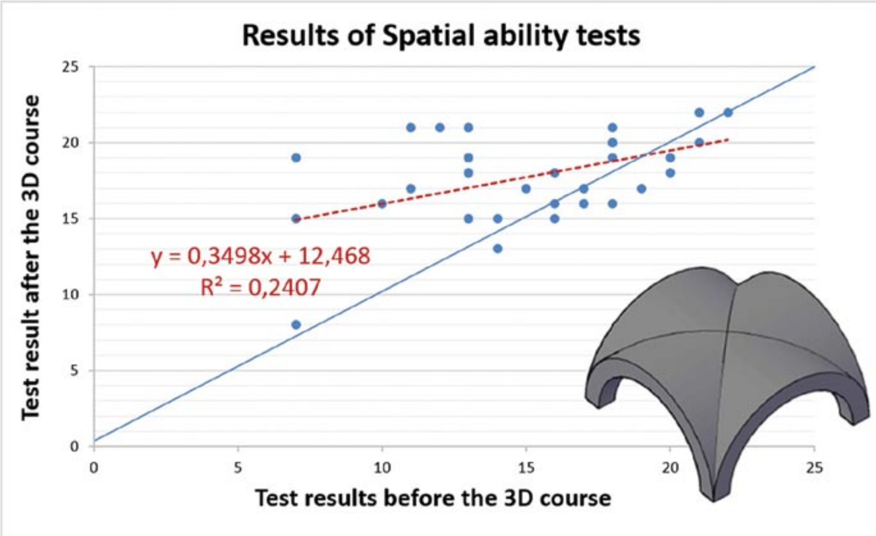

Figure 6. The graph contains the results of the same test after the 3D course against the result of the test before the 3D CAD course. The result of id 1 and id 3, and similarly id 10 and id 19 are the same; the corresponding points cover

each other on the graph. Hence, we can see 29 points instead of 31.

Students belonging to group 2 may be characterized 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 adequate 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 minimum 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" 9 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 is guaranteed 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 really 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 for three months. The members of the control group did not attend any course that would develop their spatial skills. What we wanted to know was how the knowledge of the exercises solved in an earlier test influences the second completion of the test. The results of the control group are included in the following table 2 and chart.

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

Table 2.

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.

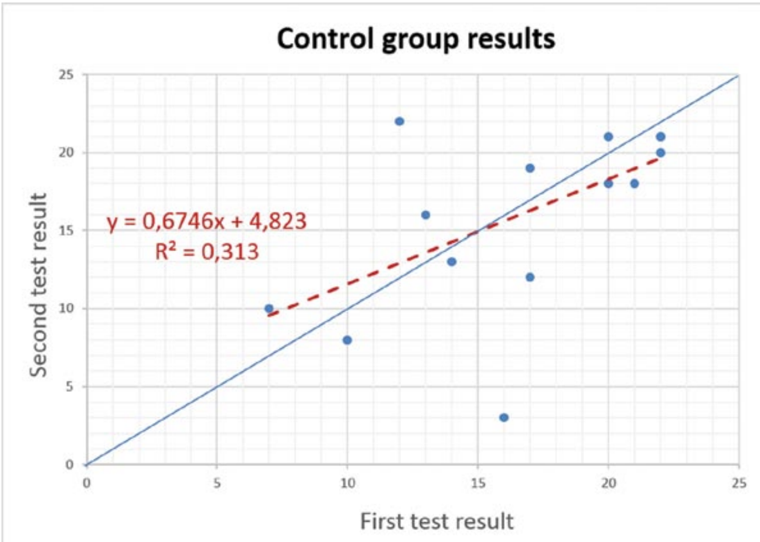

Figure 7. The graph shows the second test results of the members of the control group against their first test results. The result of id 1 and id 4, and similarly id 2 and id 5 are the same; the corresponding points cover each other on the graph. Hence, we can see 13 points instead of 15

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.

7. CONCLUSIONS

The described training process and the related test resulted in the following outcomes:

- According to the test, 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 worse 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 to get more exercises.

What could we do in order to improve spatial abilities 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.

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. 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 theoretic 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. Then, it is worth to return to the actual three-dimensional space. It is then worth to rethink, model, create, build, and turn a Rubik's cube.

Courses of spatial geometry that create models by 3D software programs; also assist the development of spatial intelligence of our students and the expansion of their creativity on a grand scale. Of course, reaching and 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 as were mentioned in [38-43].

Acknowledgments

We express our thanks to our colleague Gergely Mészáros for developing the frame system and activating the students for the completion of the tests. We thank for the support of our Faculty and the Ybl Foundation of Basic Research and Basic Education.

REFERENCES

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

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

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

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

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

[6] **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.

[7] **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.

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

[9] **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.

[10] **Robert J. Sternberg & Talia Ben-Zeev** (2001) Complex Cognition. The Psychology of Human Thought. ISBN: 9780195107715 Oxford University Press Inc. New York

[11] **Alam H.** Schoenfeld Mathematical Problem Solving ISBN-13: 978-1493305995, ISBN-10: 1493305999, Academic Press Inc. (London) Ltd.

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

[13] **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.

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

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

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

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

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

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

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

[21] **B. Babály, L. Budai & A. Kárpáti** (2014) Developmental Assessment of Spatial Abilities Through Interactive, Online 2D and Virtual 3D Tasks. Guo Ji Yi Shu Jiao Yu Xue Kan = The International Journal Of Arts Education 12: (2) pp. 94-124.

[22] **B. Babály & A. Kárpáti** (2016) The impact of creative construction tasks on visuospatial information processing and problem solving. Acta Polytechnica Hungarica 13:(7) pp. 159-180.

[23] **B. Babály & A Bölcskei** (2017) Analysis and Comparison of the Three Spatial Tests: MRT, MCT and HSAT Biuletyn Polskiego Towarzystwa Geometrii I Grafiki Inzynierskiej / Journal Of Polish Society Of Geometry And Engineering Graphics 30: pp. 9-15.

[24] **A. Bölcskei & J. Katona** (2015) Experiences in the Development of Digital Learning Environment Studies Of The University Of Zilina Mathematical Series 27:(1) pp. 3-10.

[25] **A. Bölcskei, A. Zs. Kovács & D. Kusar** (2013) New Ideas in Scoring the Mental Rotation Test Ybl Journal Of Built Environment 1:(1) pp. 59-69.

[26] **A, Bölcskei Sz. Kállay-Gál, A. Zs. Kovács & Cs. Sörös** (2012) Development of Spatial Abilities of Architect and Civil Engineer Students in the Light of the Mental Cutting Test. Journal For Geometry And Graphics 16:(1) pp. 97-109.

[27] **B. Babály & A. Kárpáti** (2015) A téri képességek vizsgálata papír alapú és online tesztekkel Magyar Pedagógia 115:(2) pp. 67-92.

[28] **B. Babály, L Budai, & A. Kárpáti** (2013) A térszemlélet fejlődésének vizsgálata statikus és mozgó ábrás tesztekkel Iskolakultúra: Pedagógusok Szakmai-Tudományos Folyóirata 23:(11) pp. 6-19.

[29] **A. Zs. Kovács & L. Németh** (2014) Development of spatial ability according to mental rotation test at SKF and YBL. Ybl Journal Of Built Environment 2:(1) pp. 18-29.

[30] **A. Zs. Kovács** Central axonometry in engineer training and engineering practice Teaching Mathematics And Computer Science 12:(1) pp. 17-28. (2014)

[31] **A. Bölcskei, A. Zs. Kovács** (2012) Az Ybl Miklós Kar építész hallgatóinak térszemlélet mérése MCT segítségével Debreceni Műszaki Közlemények 2012:(2) pp. 35-44.

[32] **John Eliot** (1987) Models of Psychological Space. Springer-Verlag New York Inc.

[33] **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

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

[35] **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.

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

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

[38] **Gy. Nagy** (2003) Tudományok katalizátora. Magyar Tudomány 48 : 11 p. 1455

[39] **J. Katona** (2005) Improving students' three-dimensional eyesight by CAD models pp. 195-199. , 5 p. In: Lehoczky, László; Kalmár, László (szerk.) microCAD 2005 International Scientific Conference Miskolc, Magyarország: Miskolci Egyetem Innovációs és Technológia Transzfer Centrum,

[40] **A. Bölcskei &; J. Katona** (2012) Efforts in Descriptive Geometry Education and Their Result pp. 381-389. , 9 p. In: Ratko, Obradovic; Radovan, Stulic (szerk.) 3rd International Scientific Conference moNGeometrija 2012 Novi Sad, Serbia : University of Novi Sad, Faculty of Technical Sciences

[41] **B. Babály, A. Bölcskei, L. Budai;** A Kárpáti & J. Katona, (2013) Virtual learning environments and online assessment of spatial abilities In: Tomislav, Došlić; Ema, Jurkin (szerk.) 17th Scientific-Professional Colloquium on Geometry and Graphics: Abstracts Zágráb, Horvátország : Croatian Society for Geometry and Graphics, (2013) pp. 6-7.2 p.

[42] **Gy. Nagy** (2015) A problémamegoldás megismerésének magyar módszere. Matematikai Lapok 21 : 2 pp. 44-56. , 13 p.

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