Developmental Assessment of Spatial Abilities Through Interactive, Online 2D and Virtual 3D Tasks

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Abstract

Representing space in two-dimensional form has traditionally been one of the central tasks in visual skills development because of its relevance for a wide range of professions. *Spatial skill components* (mental and physical manipulation, transformation, completion, planning, construction, etc.) *are valid indicators of the developmental level of visual skills* and therefore often used for the detection of talent. However, from the copying exercises of gypsum models of academies, through studies of old masters and careful representation of arrangements of objects with pen and pencil or paint, tasks usually require activities unrelated to real life experiences of creation and perception of space. Our research objective is *to develop authentic, lifelike tasks for practice and testing creation and perception in space*.

Multimedia applications offer a chance to evaluate creation and perception of space in an authentic, developmental setting. Two digital environments for skills enhancement and assessment are presented here: a two-dimensional online testing tool and a movable, three-dimensional virtual space. Ten to twelve-year-olds, experienced in playing interactive games, easily master the use of the *e-DIA online assessment tool* (http://edia.edu.u-szeged.hu/), and intuitively use *GeoGebra*, (http://www.geogebra.org/) the open source software that provides algebraic and graphical representations of mathematical objects and offers 3D, interactive representational facilities used in hundred thousands of classrooms. Our results indicate that both environments may be used for the assessment of spatial skills, and also have potentials for becoming authentic tools for development. This paper presents a model for spatial abilities and shows two- and three dimensional tasks for its assessment. Standardisation of tasks and verification of the structure of spatial abilities are also outlined.

Keywords: spatial abilities, online testing, digital creation, virtual learning environment

Assessing spatial skills in education: traditional and innovative methods

Representing space has traditionally been considered a basic set of skills that involved a central place in the training of the artist. One of the most ancient anecdotes about the effects of a work of art on its beholder is about the depiction of space. Two famous painters of ancient Greece competed to decide whose representational skills were superior. One of them painted a still life that turned out to be so realistic that birds flew on it to savour the fruits. The other, however, managed to cheat his colleague through depicting a curtain that this one tried to pull away, only to realise that the folds were painted. The winner managed to cheat the eye of an artist, while the other created an illusion for animals only. – The Hungarian curriculum for Art and Visual Culture, our discipline for education through art, is focused on teaching a versatile and sophisticated visual language that can be used for a variety of purposes, from self-expression through communication to representation in different styles and symbol systems – with space being a central area of experimentation and learning. In many countries, similar approaches are observable (Haanstra, 1994, Glaser-Henzer et al., 2012, Kárpáti and Gaul Eds., 2013). Our research objective is to develop authentic, lifelike tasks for practice and testing creation and perception in space that can easily be used at school and the home. This paper describes the development and piloting of two task sequences: one in two-dimensional, static format and another in virtual, three-dimensional, dynamic format, simulating real-life spatial operations.

Traditional methods of developing and assessing spatial abilities

Traditional methods of developing and assessing spatial skills at the art academies as well as architects' studios of the 19th and early 20th century involved perspective drawing, copying gypsum models of Classic works of art, studying geometric shapes and drawing floor plans and section plans. (Efland, 1999, McDonald, 2004) As an indication of the central role of spatial skills in a variety of trades and professions, geometric drawing was introduced in public education in the last decades of the 19th century, as part of the discipline of Mathematics, later also of Fine Arts. (Gittler and Glueck, 1998).

School curricula of the 20th century developed two distinct clusters of spatial abilities: *geometric construction and artistic creation*. Loosely interrelated, these two methodologies still targeted the same objective: preparation for certain professions. (Smith, 1996) A variety of tests were developed to assess perception and mental manipulation of space and it was also identified as a major component of visual talent. (Bennet, 1973, Guay, 1977, Séra, Kárpáti and Gulyás, 2002, Clark, 1989)Cognitive skills like reasoning were also found to have connections with the level of spatial orientation. (Newcombe and Huttenlocher, 2008)

Interdisciplinary studies of arts and science education indicate the importance of visualisation of spatial relations in solving mathematical problems. “Findings indicate that level of spatial understanding and use of schematic drawings both were significantly correlated to problem solving performance. Findings from this research have implications for policy and practice. The art classroom is an important context for developing students' spatial understanding and proportional thinking abilities associated with artistic as well as mathematical ability.” (Edens and Potter, 2007, 282) In a paper with the metaphoric title, “Spatial ability and STEM: A sleeping giant for talent identification and development”, David Lubinsky (2010) advocates for the integration of the development of visual culture and science disciplines. “Spatial ability is a powerful systematic source of individual differences that has been neglected in complex learning and work settings; it has also been neglected in modelling the development of expertise and creative accomplishments. Nevertheless, over 50 years of longitudinal research documents the important role that spatial ability plays in educational and occupational settings wherein sophisticated reasoning with figures, patterns, and shapes is essential. Given the contemporary push for developing STEM (science, technology, engineering, and mathematics) talent in the information age, an opportunity is available to highlight the psychological significance of spatial ability.” (Lubinsky, 2010, p. 344)

Visualisation and observation of space both play an important role in everyday life. Authentic assessment of skills used in manipulating a large car into a narrow parking space, finding our way around with the help of a map or verbal instructions, reconstructing a broken object or buying furniture to fit in a living space require tasks that are contextualised rather than abstract. Children can perform operations with three-dimensional objects from the age of 9-10. (Mohler, 2008) Time constraints and financial limitations, however, make authentic assessment difficult. Interactive computer technology may be used to support real-life procedures for enhancing spatial abilities and provide easy-to-use, inexpensive and precise methods for assessment as well.

Innovative assessment methods

The situational approach of the detection, development and assessment of visual skills seems to be a good model for space research, too. (Billmayer, 2013) Billmayer describes competencies as a set of skills, knowledge and attitudes that enable us to act aptly in specific situations that manifest a set of resources and limitations in specific circumstances. In ENViL, (the European Network for Visual Literacy)[1], we decided to scrutinize the validity of this pragmatic approach through an integration of real-life spatial problems in the Hungarian diagnostic assessment of visual skills. We describe a situation in terms of genre, content and form to be used and also indicated the visual culture community where the task was most likely to emerge.

Manipulating objects in space through two-dimensional abstractions has been accepted as a valid means of identifying spatial skills and assessing them – however, working with generations of students deeply immersed in multimedia technology, we found this solution unauthentic and idiosyncratic. Edutainment and gaming applications (like those developed by the Quest to Learn[2] project) have long been using sophisticated virtual spaces that activate skills ranging from orientation to memory, manipulation to construction. KINECT[3] transmits real movement to virtual space and thus

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1 *ENViL, the European Network for Visual Literacy* is an informal research network of art educators, founded in 2010, with 40art educators from 9 countries working on a European Framework of Visual Literacy.

2 Quest to Learn home page: http://q2l.org/

3 Official KINECT home page: http://www.xbox.com/hu-HU/kinect/

provides authentic orientation experiences. The Leonar3Do[4] software enables users to manipulate in real space and create 3D images that can be shown through a 3D printer as sculptures or objects. Manipulation in virtual space is being employed at the Harvard Mental Imagery and Human Computer Interaction Laboratory[5] where a spatial aptitude test is developed using Virtual Reality and Augmented Reality solutions.

Our methodological objective is to integrate these digital solutions in educational assessment in the visual arts. We employ digital technology in two forms: first, we provide students with a personalised, flexible, online practicing and testing environment that uses two-dimensional (2D) tasks. Second, we offer three-dimensional (3D) software solutions that provide authentic methods for creation, manipulation and perception of space in a dynamic virtual environment. In this paper, we give a brief account of our first results comparing these two- and three-dimensional evaluation methodologies.

The Spatial Abilities Development and Assessment Project

Empirical studies of visual skills development have been a central area of research in Hungarian art education from its beginnings in the 1880s. (Kárpáti and Gaul, 2011). At the current National Assessment of Visual Literacy, ninety tasks in a variety of creative media were developed and introduced to 5000 students aged 6-12 to test the validity of a framework of visual skills and abilities. Through a factor analysis of data, we reduced the hypothetical structure conceived by twelve leading art educators, originally consisting of 19 visual skill items, to 4 clusters that provide a realistic framework for curriculum innovation. (Kárpáti and Gaul, 2012) Spatial skills are present in three of them:

1. *Spatial perception*
    - Orientation in space
    - Experiencing space, identifying spatial qualities

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[4] Official site of the Leonar3do software: http://leonar3do.com/

[5] Maria Kozhevnikov's Mental Imagery and Human Computer Interaction Laboratories at Harvard University and at the National University of Singapore investigate the neural mechanisms of visual/spatial imagery. http://www.nmr.mgh.harvard.edu/mkozhevnlab/

- Interpretation of spatial structures, longitudinal and cross sections

2. *Spatial representation (2D)*
    - Representing spatial qualities based on visual perception
    - Representing positions in space (2D)
    - Creation of spatial sensations caused by the organisation of visual elements (e. g. rhythm, balance)
    - Representation of changing experiences of space through time
    - Reconstruction of space
    - Reproduction of space, abstraction
3. *Creation of spatial objects (2D and 3D)*
    - Design
    - Modelling
    - Creation
    - Construction

The table below shows how spatial skill components are integrated in Hungarian curricula of "Art and Visual Culture" and "Mathematics". After the identification of spatial abilities and related knowledge relevant for the age groups targeted by these curricula, (10-12 years, Grades 4-5-6 of primary school), we developed 62 tasks and their scoring guides and embedded them in our national online testing environment, eDIA.

Table 1 Spatial skill components in Hungarian curricula by grades

Skill component	Explanation	Gra-de	Examples - Mathematics	Examples – Art and Visual Culture
1. Decode and use systems of spatial representation (2D)	Application of repre-sentation systems to interpret spatial relations.	4	Axonometry, representation of planes	Monge-projection, axonometry, perspective
2. Analyse and use conventions of spatial representation (2D)	Application of repre-sentation conventions to interpret spatial relations by changing size, hue, placement etc.	4	Observe and represent parts and interrelations of plane figures (side, peak, opposite, adjacent)	Representations of positions and directions (e.g. up-down, ahead-behind, right-left, foreground-background) and size differences

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3. Experience space, identify spatial qualities	Recognition and representation of shapes. (2D, 3D)	4	Characteristics of cuboids and the cubes	Visualise concave-convex, positive-negative, open-closed, simple-complex, regular-irregular qualities
4. Design and construction of spatial objects (2D)	Solving space composition and design problems, interpret spatial concepts in 2D	4	Formation of planes, conditions of (un)equality	Projection drawings, section planes, ground plan, front elevation, layout
5. Design and construction of spatial objects (3D)	Solving space composition and design problems, spatial concepts in 3D	4,5		Construction and analysis of models, design objects, sculptures, origami
6. Orientation in space	Orientation in real and virtual spaces based on pictures, technical drawings, maps, models, everyday experiences and spatial memory.	5,6	Computation of the surface of spatial objects, analysis of their structure and observation of changes due to modification of components	
7. Reconstruction of space	Reconstruction and representation of 3D objects from 2D pictures.	6,7	Representing a shape based on its floor plan	Identifying floor plans of buildings and explaining the function of spatial solutions
8. Spatial sensations caused by the organisation of visual elements	Analysis of the spatial effects of different compositions.	6,7		Rhythms caused by the repetition of elements, balance sensations (stable vs. unstable compositions)
9. Basic elements of visual qualities	Graphical techniques and methods, which can be used by creation spatial illusions.	6,7		Light-shadow effects, texture-facture, colouring, contrast
10. Interpretation of spatial structures	Structures of natural and artificial shapes, connections	5,6	Measures of volume and cubic capacity; overlap,	Longitudinal and cross sections, part and whole relations

	among structural elements.		intersection.	
11. Reduction and abstraction of space	Interpretation of abstract spatial representations, reduction of spatial forms and relations.	6,7	The interpretation of sphere geometry, a map	Map symbols, traffic and other spatial orientation signs
12. Dynamic space perception	Representation of changing experiences of space through time.	6,7	Mental rotation	Change of viewpoint, movement phases, mental rotation, animation, video

eDIA in art education

In order to show the beneficial effects of art education on the development of cognitive and affective skills utilised in science and technology education as well as in everyday life, and identify visual skills as important and assessable components of education, we joined the *Development of The Assessment of Cognitive and Affective Skills and Abilities Project* of Szeged University, Hungary. In the first phase of its *Visual Literacy Sub-Project*, we developed and piloted a set of paper-based and digital tasks and piloted them in primary schools. Later, the best tasks were included in eDIA, the *online, adaptive and interactive testing environment* of the project that provides an easy-to-use, freely available for all Hungarian schools testing environment. Characteristics of eDIA:

- Diagnostic assessment of competences in three main domains (reading, mathematics, science) and further fourteen cognitive, affective and psychomotor skills and competences)
- Online, adaptive and motivating testing environment
- Free and easy availability for schools for development and assessment all over Hungary
- Immediate, personalized feedback on knowledge and skill levels of learners
- Tests and tasks for student aged 6-12 (Grades 1-6 , ISCED level1)
- Wide variety of item types with sound, image, video and animation

– Response in different forms (e.g.: marking, clicking, colouring and rearranging images, entering text, pairing text and picture)
– Below, a sample task shows how the system supports authentic visualisation of spatial tasks often encountered in everyday life.

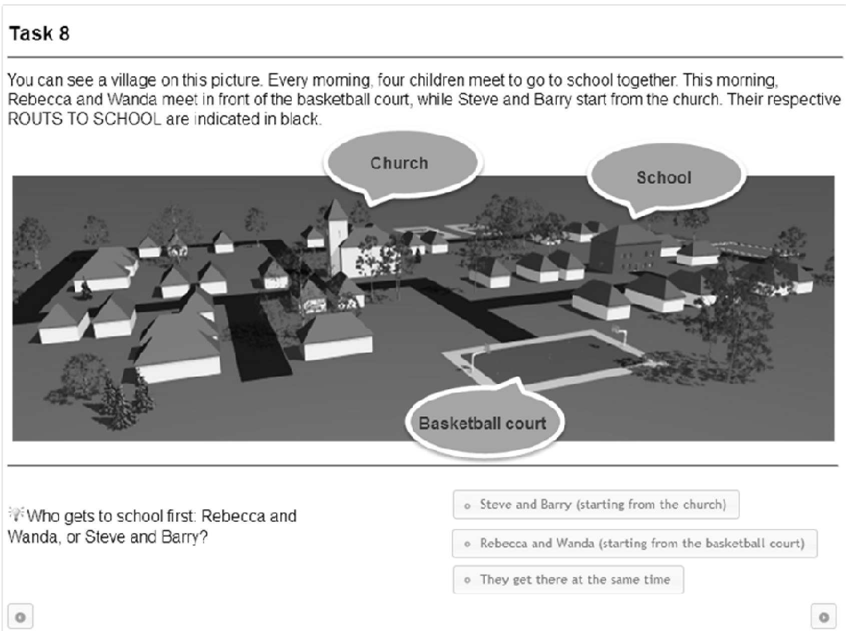


Figure 1 Estimating distance in virtual space (Grades 4. and 5.) A task from eDIA, the online, interactive Hungarian testing environment. (Screenshot, July 2014)

The spectacular visual appearance of the tasks of eDIA makes it an enjoyable visualisation tool that makes it easier to comprehend spatial problems than black-and-white, abstract axonometric projections in traditional paper-based tests. During electronic assessments, students work in a testing environment that resembles social web sites as well as gaming applications. Usage studies show that they can orientate in the menu without effort. In the “Art and Visual Culture” task package, we always provide practice items that show manipulation options and also a voiceover for slow readers. Digital images provide a life-like representation of space and reproduce complex spatial situations accurately.

Development of two-dimensional digital tasks, construction of online tests

Task response types in eDIA include marking, colouring and moving images, entering text, joining text and picture or forming groups of items. Cognitive skills involved in perception, design and creation are targeted simultaneously, just like in real life. Visual skills are in the focus, but other competences are also targeted, revealing the interdisciplinary significance of art education.

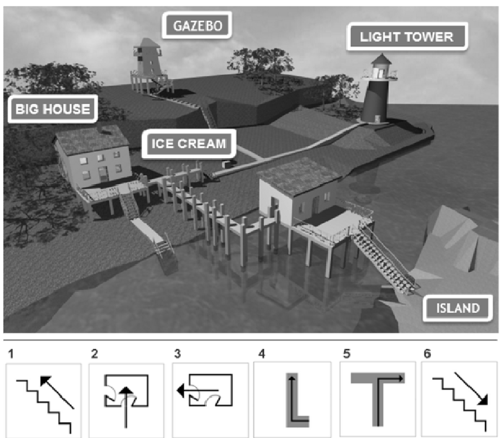


Figure 2 Finding your way around in a virtual space, using directions represented by signs (shown below). Task for 4th graders (age: 10 years)

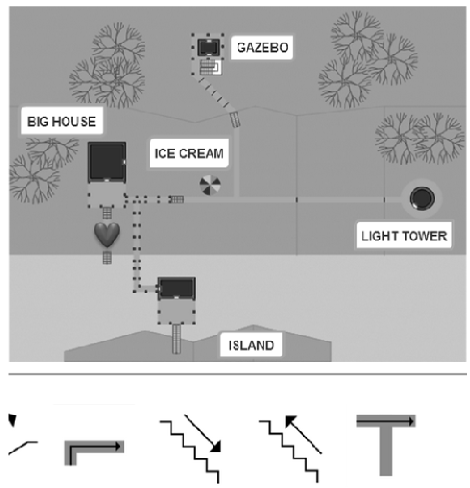


Figure 3 A more difficult version of the spatial orientation task in Figure 2 (for 6th graders, aged 12): the virtual space is depicted as a map, directions represented by signs.

In the eDIA testing environment, results of the discipline called “Art and Visual Culture” may be compared with four core disciplines (Mathematics, Mother Tongue, Science and Foreign Languages) as well as eleven other areas of studies (including Music and Media Arts) to reveal correlations cognitive, affective and psychomotor gains resulting from education through art. In its final form, the eDIA-system will monitor personal development, and offer tasks for individual skill enhancement based on previous results. Art teachers may thus design individualised teaching-learning processes that supports talent development and caters for special needs (like mental or psychomotor deficits) at the same time.

As our research objective was to provide a useful tool for art and mathematics educators for teaching and practice, not just testing, we designed tasks focusing on one or a few skill elements only. (Tasks activating a wide range of skills tend to hide merits as well as deficiencies). To improve content validity, we analysed test items of current psychological measures of spatial abilities as well as Hungarian curriculum objectives and related educational content to reveal important skill components that should be present in our developmental assessment tasks. (An example: we included mental rotation and transformation because it is a standard feature in intelligence tests and are also considered basic for understanding primary geometry). Young adolescents (aged 10-13) have rarely been examined in this area, so we had to make adaptations of existing task types. (For example, for any single task, mental rotation is required in one direction only, and abstract shapes were replaced by pleasing images.) (Figure 4)

Our tasks target four clusters of spatial skills:

1. *Spatial positions, relations, direction*: here students are invited to orientate in a virtual space that imitates a real-life, built environment. To solve spatial problems they have to perceive distances, sizes of objects and determine their position in this space compared to the objects. (See Figure 1-3 for examples).
2. *Comprehension of structures of three-dimensional shapes*: cognition of spatial shapes and their concave-convex extensions, perception of covered bulks, observation of regular-irregular spatial structures, comprehension of connection among structural elements. These skills are basic for a wide range of vocations and professions. If detected early, deficiencies can be developed with success.
3. *Spatial reconstruction*: students have to recognise three-dimensional spatial situations visualised in two-dimensional images (projection drawings, section planes, ground plans, front elevations and pictograms).
4. *Spatial transformation and manipulations*: this cluster requires mental operations like cutting, rotation, removal, mirroring, assembly and construction. (See Figure 4 for example)

Figure 4 Images showing movement phases from a mental rotation task.(Tasks for Grades 4-7)

Sample and testing procedure

We piloted the first version of the tests with 161 students, almost equally distributed between Grades 4, 5 and 6, (students of 10, 11 and 12 years of age) in the capitol city and a small country town in May 2013. In the second piloting phase, in October 2013, we worked in two schools (252 students from Grades 4, 5 and 6.) For about half of the groups, tests were administered online, using the eDIA testing environment, for the other half, on paper, using PowerPoint presentations to show the tasks and answer sheets to collect responses.

After these pilots, spatial skills of a national sample of 633 students from Grades 4, 5, 6, 7 and 8 (ages 10-14 years) from 14 schools were assessed with the corrected measuring instruments between March and June 2014. (The sample included 163 students from 4th Grade, 161 students from 5th Grade, 104 students from 6th Grade, 195 students from 7th Grade, and 10 students from 8th Grade.) Test version A for Grades 4-5, (ages 10-11 years) contained 11 tasks and test version B for Grades 6-8, (ages 12-14 years) contained 13 tasks. Time for the solution was recorded and one testing process was planned to involve a maximum of one lesson hour (45 minutes). This large sample was used to define optimal time limits: students completed the tests in *20 minutes on average*. In the Student Background Questionnaire, family background, left or right-handedness, learning performance and participation in formal and informal learning opportunities of art, design, mathematics and sports was also recorded and used in consecutive analyses (to be reported in a separate paper.). We invited participating teachers to report their experiences with the tests. According to their remarks and on-site experiences of external evaluators, the tests are motivating for students, authentic and reliable for teachers and therefore, they may be used for skills development as well as assessment in art education. In comparison to the duration of even the simplest perspective drawing task, our new spatial skills testing instrument proved to be a motivating and comprehensive assessment method to define the developmental level of a wide range of spatial skill components.

Results

Results of the Interactive Spatial Abilities Test – a two-dimensional, static task sequence – are shown on Figure 5. Test solutions (in percentage points) are between 4% and 100%. Average achievement is 55,54 percentage points, with a deviation of 19,71. Results show a normal distribution, although average performance is slightly above the desirable 50 percentage point level.

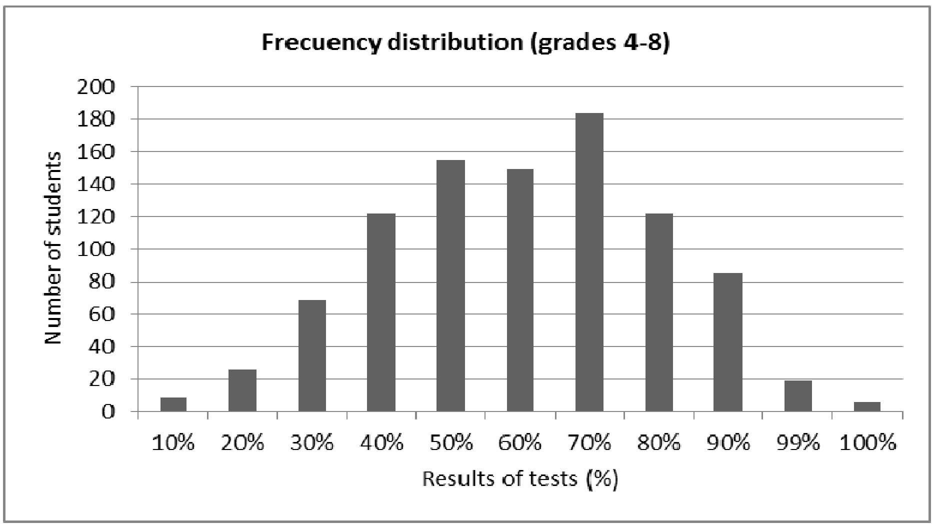


Figure 5 Absolute frequency of results (Grades 4-8, N=946)

Student performance was significantly different in the grades tested. Figure 6 shows results of the age groups and illustrates differences in difficulty level between the two test versions in Grades 4-5 and 6-8. Most of the results fall between 50 – 63 %, with no significant differences among schools. (Figure 7)

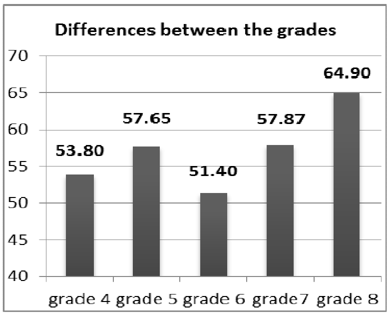


Figure 6　Average performance of Grades 4-8(in percentage points) (age groups 10-14, N=946)

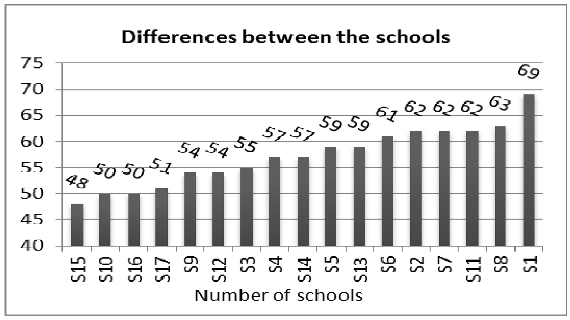


Figure 7　Average school results (in percentage points) (Grades 4-8, N=946)

Students easily solved spatial problems that they encounter in their everyday life, like estimating distances and orientation using map. The mental operation tasks seemed simpler if they were associated with recognizable shapes. Most of students found spatial operations with abstract geometrical forms too difficult. The development of cognitive skills (e.g.: analyzing, comparing, abstraction capability) influenced the performance of students. In general, the tests of varying difficulty items are capable assess spatial abilities of children differentially. (Figure 8)

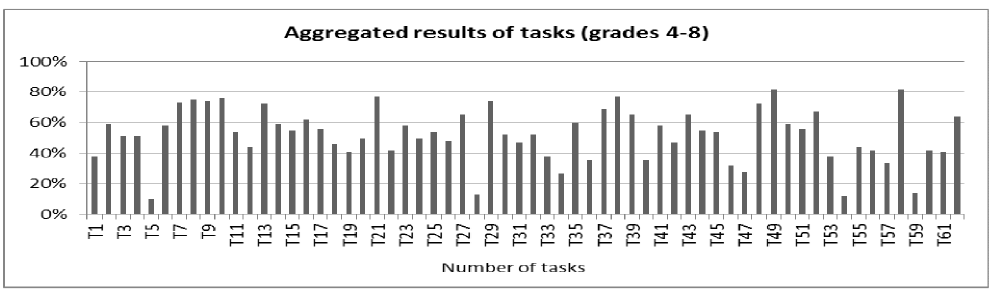


Figure 8　Results of the 62 tasks in the eDIA tests (N=988)

Correlations between the whole test and individual tasks fell between 0,208 and 0,549. All tasks correlated significantly with the total score. The best indicators of spatial skills level are tasks about orientation in space. Pairwise correlation is strongest between tasks evaluating the same skill component. (Table 2)

Table 2 Correlations of tasks with test results (Test version B for Grades 6-7, N=270)

Correlations

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	SUM
T1	-	,150*	,039	-,028	,082	-,054	,119	,057	,118	,073	,137*	-,012	,092	,208**
T2	,150*	-	-,016	,019	,083	,041	,064	,209**	,233**	,148*	,112	,098	,011	,413**
T3	,039	-,016	-	,223**	,049	,126*	,033	,140*	,220**	,228**	,091	,105	,016	,429**
T4	-,028	,019	,223**	-	,044	-,012	-,029	,121*	,008	,055	,031	,113	-,030	,276**
T5	,082	,083	,049	,044	-	,081	,188**	,201**	,237**	,287**	,090	,098	,132*	,458**
T6	-,054	,041	,126*	-,012	,081	-	,074	,101	,105	-,006	,065	,109	,119	,375**
T7	,119	,064	,033	-,029	,188**	,074	-	,127*	,006	,053	,005	,040	,105	,359**
T8	,057	,209**	,140*	,121*	,201**	,101	,127*	-	,228**	,272**	,075	,176**	,147*	,467**
T9	,118	,233**	,220**	,008	,237**	,105	,006	,228**	-	,388**	,091	,182**	,109	,549**
T10	,073	,148*	,228**	,055	,287**	-,006	,053	,272**	,388**	-	,135*	,132*	,091	,465**
T11	,137*	,112	,091	,031	,090	,065	,005	,075	,091	,135*	-	,067	,111	,285**
T12	-,012	,098	,105	,113	,098	,109	,040	,176**	,182**	,132*	,067	-	,139*	,475**
T13	,092	,011	,016	-,030	,132*	,119	,105	,147*	,109	,091	,111	,139*	-	,397**
SUM	,208**	,413**	,429**	,276**	,458**	,375**	,359**	,467**	,549**	,465**	,285**	,475**	,397**	-

* Correlation is significant at the 0,05 level

* Correlation is significant at the 0,01 level

Correlations between background variables and test results were only significant within one class or school, but these same correlations were insignificant in the whole sample. For example, end-of-term school achievement (average grades) from Mathematics, Grammar and Foreign

Language showed significant correlations with test results in one school, but not in the whole sample. In further studies, we will have to investigate the reason for this and identify any factors likely to distort test results. Other studies and the recently published results of the Programme for International Student Assessment (PISA, 2012) have repeatedly shown that grades given at schools have little relevance for competence development levels identified by valid assessment instruments. (Csapó, 2004, 2008) Grading habits of teachers may have been responsible for the irrelevance of school grades for spatial skills performance level in our case as well.

Factor analysis was performed on 13 tasks of the eDIA test version B (for Grades 6 and 7), and on 11 tasks of the eDIA test version A (for Grades 4 and 5). The inter-task variance of the factors of test version B was 60,82. Based on communality values, five spatial ability factors were identified (Table 3):

1. C1: Perception of directions, changes of viewpoint: it is needed for most spatial operations as it guides spatial orientation and mental rotation.
2. C2: Perception, without interpretation of spatial structures and shape characteristics (strongest correlations are negative values). This factor shows the importance of cognitive skills, developed mainly by the disciplines of Mathematics (Geometry) and Art and Visual Culture in interpreting spatial relations).
3. C3: Mental transformations: this factor shows the strongest correlation with mental folding and reconstruction, and negative correlation with the recognition and interpretation of static spatial situations.
4. C4: Change between modalities (two- and three-dimensional representations): this factor positively correlates with matching Monge projections with images in perspective.
5. C5: Interpretation of spatial structures and shape characteristics: strongest correlations are positive values, emphasizing again the importance of cognitive skills involved in the perception of space.

Table 3 Component Matrix of test version B: communal values of tasks (Extraction Method: Principal Component Analysis, 5 components extracted; N=270)

	Component				
	C1	C2	C3	C4	C5
T21	,251	,475	-,308	,271	,426
T22	,392	,253	-,309	,303	-,330
T47	,413	-,526	-,029	,024	,348
T48	,192	-,608	-,094	,041	,412
T49	,539	,161	,041	-,498	,071
T45	,235	-,104	,624	,269	-,150
T46	,262	,398	,334	-,371	,386
T50	,581	-,044	,062	-,052	-,113
T51	,649	-,029	-,202	-,027	-,307
T52	,651	-,068	-,279	-,252	-,113
T53	,314	,125	-,090	,559	,298
T42	,401	-,224	,286	,201	-,225
T32	,331	,267	,491	,160	,091

The inter-task variance of the factors of test version A was 62,95. Based on communality values, four spatial ability factors were identified (Table 4):

1. C1: Perception of directions, changes of viewpoint. (This component is identical to the "C1" of test version B)
2. C2: Interpretation of spatial structures and shape characteristics. (This component is identical to the "C5" of test version B)
3. C3: *Estimating distance in virtual space:* this factor shows strong correlation with only one task.
4. C4: Mental rotations: this factor shows the strongest correlation with mental rotation, and negative correlation with the recognition and interpretation of static spatial situations. (This component is similar to the "C3" of test version B)

Table 4 Component Matrix of test version A: communal values of tasks (Extraction Method: Principal Component Analysis, 4 components extracted; N=309)

	Component			
	C1	C2	C3	C4
T1	,224	,431	-,312	,568
T2	,586	,154	-,004	,082
T6	,319	,608	,089	-,493
T25	,282	,684	,177	,143
T7	,564	-,122	,056	,405
T3	,571	-,268	,281	,133
T4	,521	-,229	,277	,209
T8	,344	-,023	,605	-,211
T9	,686	-,180	-,208	-,166
T10	,672	-,061	-,239	-,286
T11	,469	-,128	-,525	-,197

No significant differences were found between paper based and web based test results with regard to group average, maximum score, scope and deviation. This finding, however, needs further verification as in the few studies comparing web-based and pen-and-pencil tasks, online test have been found more difficult. A possible explanation may be the enhanced quality of digital imaging of later tests. Sutton et al. (2007) developed a psychometric test to measure understanding of three-dimensional concepts represented in drawings. Reliability coefficients were high for both paper- and web-based methods, but participants solving digital tests produced consistently lower overall scores. This result may be explained by the differences between the average level of digital competence of students between 2007 and 2013. Another explanation may be, however, the quality of visualisation of the tasks: in eDIA, as customary for 21. century virtual learning environments, high level visualisation options are readily available.

Dynamic visualisation in GeoGebra

All four special skill clusters may best be observed during action in real space – but how can we integrate such experiences in a testing environment? The solution of this crucially important issue of authenticity was the inclusion of the GeoGebra dynamic mathematics software in the battery of testing tools.

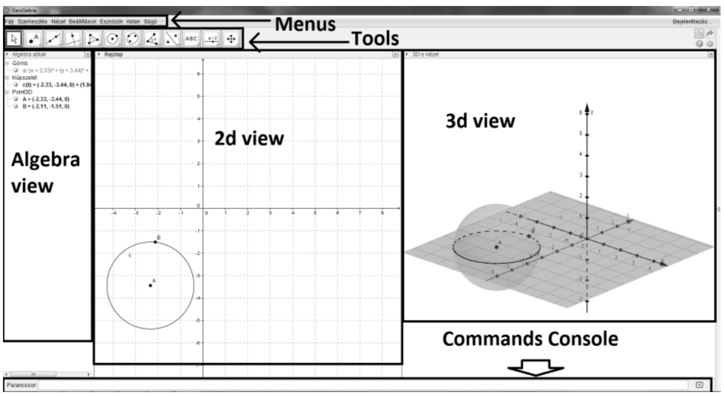


Figure 9 The GeoGebra interface

General features of the GeoGebra software

GeoGebra (http://www.geogebra.org/) is a free to use, adapt and develop (open source) software that provides algebraic and graphical representations of mathematical objects and offers 3D, interactive representational facilities. This dynamic visualisation software was created by Markus Hohenwarter and originally intended for use in secondary level science and mathematics education. It is available as an open source application and can be installed on any platform that is suitable to run Java.

Today, the software is available in 62 languages and used in 122 institutions of 190 countries. With more than 45000 online study materials available, about 5.5 million copies of the software were being used in schools in 2012. Thousands of volunteer developers broaden the range of applications daily. Its success is due to the fact that it is open-source and can be installed on any platform that is suitable to run Java. Perhaps the most important advantage is its ease of use. Its basic functions can be learned by anyone with basic computer skills in a couple of hours. Therefore, teachers often use them for teaching and testing as well.

However, its applications for art education still have to be discovered. One of the objectives of our research project is to utilise these perfect visualisation functions in the area that may benefit from it most: “Art and Visual Culture”, the Hungarian school discipline for art education.

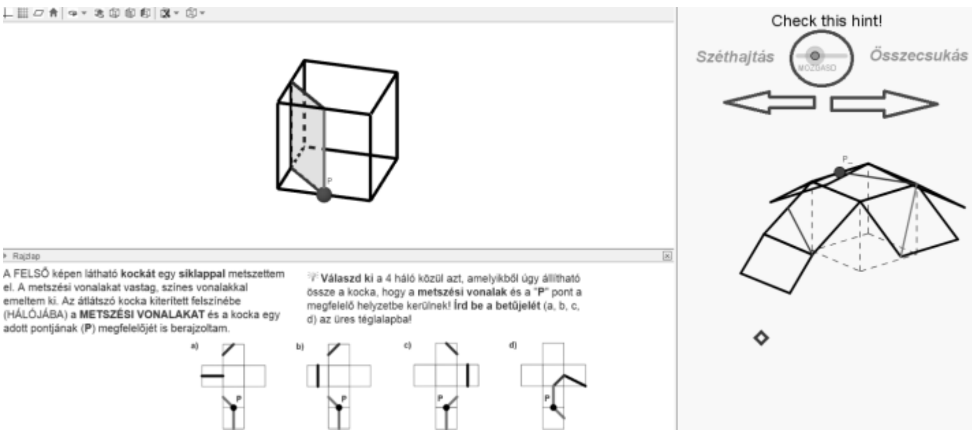


Figure 10 Practice spatial task in the GeoGebra software environment.
(Dynamic functionalities of GeoGebra are optimally used to support mental imagery.)

Its latest version, GeoGebra 5.0 includes 3D functionalities and is ideally suitable for digital creation in space. Perhaps the most important feature of this version is that it connects different representations of objects with their geometric display and algebraic description. GeoGebra is a dynamic system because users get a virtual design kit with the program that enables them to visualise any spatial problem. Unlike drawing images on paper, the initial objects (points, straight lines, etc.) can be freely moved while the objects dependent upon them move along with them based on their geometrical connections. (Figure 9) Thus, students practicing mental rotation can actually rotate a linear representation of a cube and see its shape changing according to the change of perspective. *Discovery learning* at its best, the system can also be used for testing the level of spatial perception.

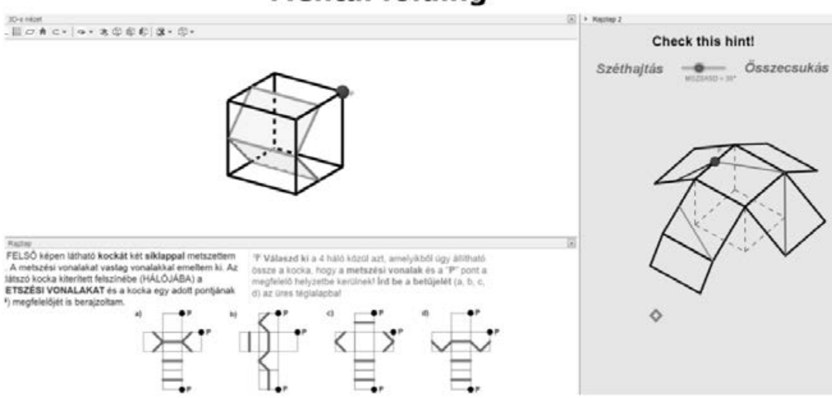
Tasks

There are *three ways to move a GeoGebra image*:

1. vertical motion
2. moving around a point
3. 3D rotation with the mouse (right click)

The figure below shows some of the task types for the assessment of most frequently tested spatial manipulations: mental folding, identification of spatial positions, relations and directions, transformation and reconstruction. These complex activities are facilitated by the dynamic visualisation option of GeoGebra: the possibility to rotate the image on the screen and thus examine it from a variety of viewpoints.

Mental folding



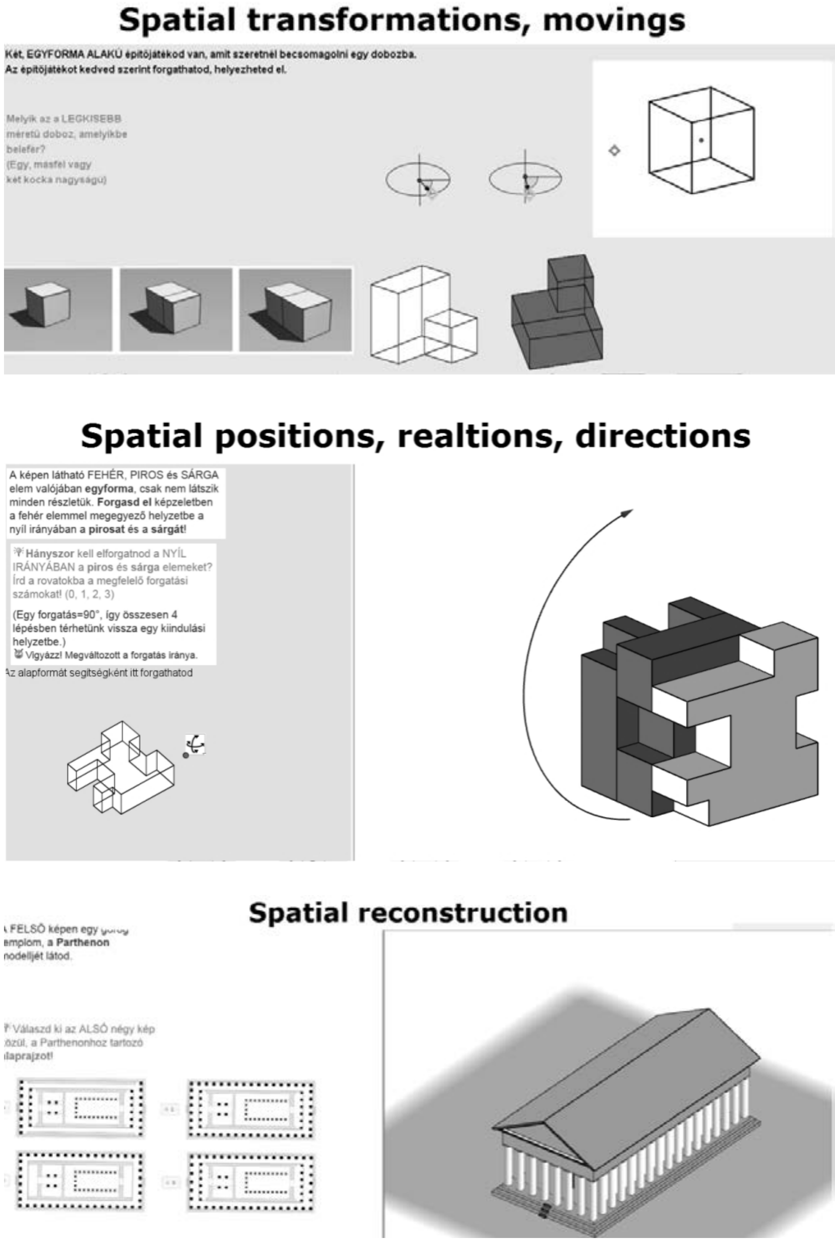


Figure 11 Types of tasks in GeoGebra

Pilot study: assessing spatial abilities through 2D, paper-based tests and GeoGebra

If we want to disseminate tasks developed in the GeoGebra environment in schools, we have to prove that *a 3D virtual reality environment an equally authentic tool for testing spatial skills as traditional, paper-and pencil, 2D tests.* Therefore, two pilot studies with both environments was conducted with 178 students in June 2013 and May 2014, in a primary and secondary vocational school situated in a small country town in Hungary. The first sample included 59 students aged 12 from 6th Grade (29 static and 30 dynamic testers), the second included 112 students, also from 6th Grade (55 static and 57 dynamic testers). The infrastructure and student performance of this educational institution equals the national average. We have selected 11 tasks from the test database that were available both as static (2D) and dynamic (3D) versions. Dynamic tests were shown in the GeoGebra environment. Static tests were presented on the computer screens (in PowerPoint), and solutions had to be recorded on paper.

Students had maximum 45 minutes to complete the assessment. *Time required to solve the static and dynamic tests differed significantly.* In the dynamic version, this amount of time was necessary for the majority of students. In the static test, the fastest student finished in 12 minutes, and even the slowest student needed only 25 minutes to complete the task. Apparently, students needed time to get accustomed to the GeoGebra environment, but once it was accomplished, they performed the same way as in the traditional testing environment. However, this pilot was conducted at a school where software applications (including GeoGebra) are regularly used. Large-scale national studies will show if and how far digital literacy influences test results.

The most interesting methodological aspect of our pilot was the task sequence that we could develop both in 2D and 3D formats. These were the five spatial skills we focused on:

– Space conversion (transformation, manipulation)

- Interpretation of the mechanism and structure of spatial objects (and their conversion)
- Perception of spatial positions
- Usage of space imagery systems
- Space reconstruction

Through a comparative analysis of results in the two-and three-dimensional environment, we wanted to find out, *which environment is better to assess (and later also develop) these skill components*.

Results

Figure 12 and 13 below shows attained scores in decimal intervals and also indicates how many students are in the given intervals. On the graphs we can fit the Gauss-curve. The distribution of the results is suitable. Cronbach's coefficient is 0,51; the Cronbach's Alpha Based on Standardized Items is 0,45. Taking the students' number in the pilot into consideration these values are normal.

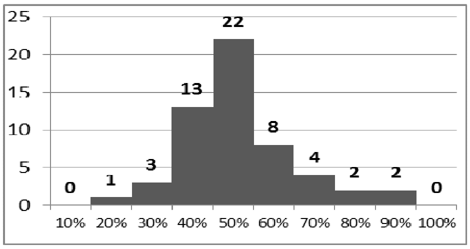


Figure 12 Student performances in the static test (N=55)

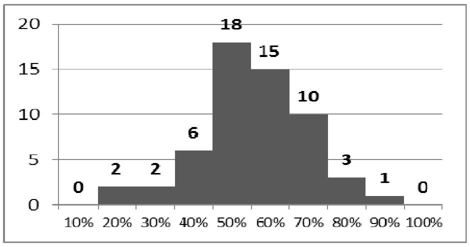


Figure 13 Student performances in the dynamic test (N=57)

Test solutions (in percentage points) ranged from 80,43% and 17,39%. *Average results* of the dynamic test was 51,56% with 0.1339 standard deviation. Figure 14 and 15 provides a summary of the results of the same items in the static and dynamic tests. They show how differences in results in the two testing environments and clearly indicate that *the static and dynamic tests are equal in difficulty level, both are reliable assessment measures.* Contrary to assumptions by critics of dynamic testing applications, the dynamic test was not too easy to solve because of the in-built rotation option.

The dynamic test could not be done through mindless manipulation and guesswork.

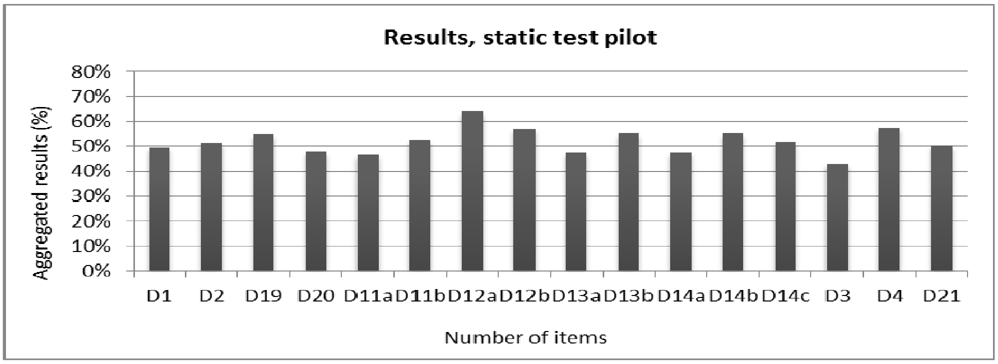


Figure 14 Results by tasks in the static test (N=55)

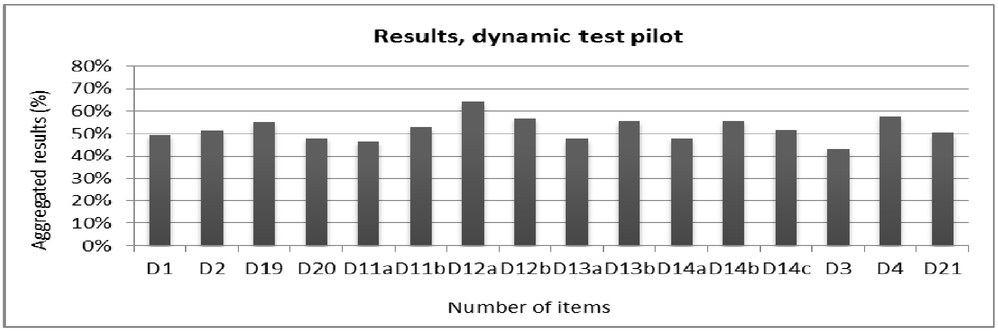


Figure 15 Results by tasks in the dynamic test (N=57)

As indicated on the diagram, task difficulty was similar in both environments. In space transformation, dynamic test results were better, while in the majority of tasks: detection of positions in space, utilisation of systems of spatial representation and reconstruction, students performed similarly in the 2D and 3D environment. Students indicated that the rotation opportunity of the whole object was confusing because of difficulties in choosing a reference point to perform the rotations required to solve the task. Due to the rotation possibility, the whole object could be rotated; therefore, the lower level was displayed in different viewpoints, which should have been compared to the positions of the other levels.

In general, students did not find any of the task types too difficult. The tasks that students found most difficult were the same in the two versions: the content mattered, not the medium. The easiest task was also the same: in the dynamic test, there was a task that could be easily done through the rotation function. Those who rotated the object right could get an immediate end result. However, this task was found easy in the static measurement, too. Both tools are appropriate for talent diagnosis, as the number of best solutions were also almost equal.

During both test versions, *text interpretation problems* repeatedly came up and task descriptions were found lengthy. (In the eDIA testing environment that we used fir the 2D tasks, hearing the explanation may make comprehension easier. In this pilot, however, we did not use voiceover.) We found that correct mathematical wording should be replaced by shorter explanations avoiding technical terms (included in the curriculum but not adequately acquired.)

On Figure 16 we can see the ability character curve. There are tasks for the -1.5 ability level students and for the 1.5 also. The whole test fits the Gauss-curve. This result indicates that the test is a valid measure.

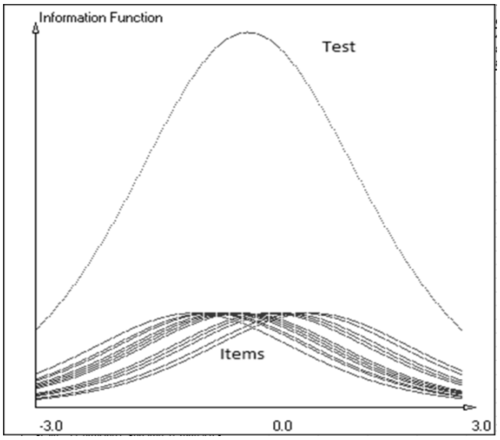


Figure 16 Ability character curve (N=57)

In this study, we did not examine transfer effects of spatial skills development. Bakker (2008) indicates that younger students (like the ones participating in our study) may not be able to comprehend all visualisation implications of spatial tasks, so such effects may not be expected. GeoGebra seems to be an ideal tool for making complex spatial images understandable through manipulation: the possibility to see the objects from different angles and thus realise the changes of its visual appearance.

The importance of visualisation skills – developed mainly by art education – seems to be getting more and more attention in psychology, too. Blazhenkova and Kozhevnikov (2010) introduces a new component of intelligence: *visual-object intelligence*, „that reflects one's ability to process information about visual appearances of objects and their pictorial properties (e.g., shape, colour and texture) it is distinct from visual–spatial intelligence, which reflects one's ability to process information about spatial relations and manipulate objects in space. visual-object ability satisfies the requirements of an independent component of intelligence: (1) it uniquely relates to specialization in visual art; (2) it supports processing of abstract visual-object information; and (3) it has unique quantitative and qualitative characteristics, distinct from those of visual–spatial processing." (Blazhenkova and Kozhevnikov, 2010, 276) The study presented here shows how much authentic, developmental assessment in art education can contribute to the detection, evaluation and further development of this important new intelligence factor.

Future research

Phase two of our project will involve the correction of the system of tasks for spatial abilities. The tests will be introduced to a representative population of Hungarian 6-12-year olds. We also intend to *reveal spatial manipulation strategies through the employment of eye tracking tools. We will also develop new task sequences related to the curriculum area of Visual Communication, Art Appreciation and Environmental Culture, major areas of the discipline "Art and Visual Culture" in Hungary.*

Another major issue of research will be the *comparison of creation with digital and* traditional *tools*. Do we lose important aspects of creation and perception if we substitute paper and pencil (or paint) with digital tools? *What is the role of multimedia in the contemporary visual language of children?* As for adolescents, we have revealed its important impact. (Freedman, Hejnen, Kallio, Karpati and Papp, 2013). A team of art teachers will use the tasks for development and diagnosis of gifts and deficits.

Comparing results of 2D and 3D spatial ability tests is one of the most important research tasks for the future. Gamification of assessment can be optimally achieved in the area of spatial ability testing if we develop reliable tasks, resembling computer game environments, with the use of 3D applications. In all our future efforts, we will focus on a synergy of everyday visual language use and synergies of art and mathematics education. Our testing processes will directly involve creative and design practices as we confront them in real life, interlinking evaluation, education, and (self)improvement.

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