Development of spatial skills through 3D, online, interactive tasks

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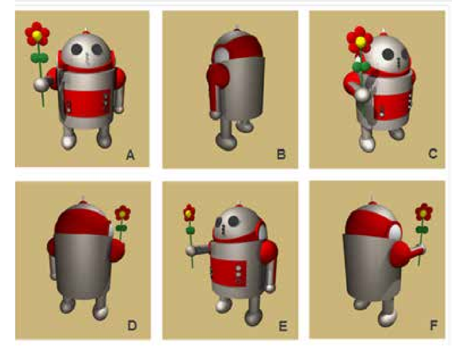

The Spatial Abilities Development and Assessment Project

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, tasks required activities unrelated to real life experiences of creation and perception of space.
This poster 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.
Multimedia applications offer a chance to evaluate creation and perception of space in an authentic setting. Research presented here compares performance in two digital environments: 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 worldwide used, open source software that provides algebraic and graphical representations of mathematical objects and offers 3D, interactive representational facilities. Our results indicate that the dynamic, 3D environment is best for skills development, while the 2D testing tool is optimal for evaluation.
Empirical studies of visual skills development has been one of the major areas of research in Hungarian art education from its beginnings in the 1880s. (Kárpáti and Gaul, 2011). Ninety tasks with a variety of creative materials were developed and tested with 5000 students aged 6-12 to test the validity of a framework of visual skills and abilities. (Kárpáti and Gaul, 2012) Through factor analysis of data, we reduced this hypothetical structure of 19 visual skills and abilities to four factors.
Spatial skills are present in three of them:

1. Spatial perception (orientation in space, experiencing space, identifying spatial qualities and interpretation of spatial structures);
2. Representation in 2D: spatial qualities and positions, creation of spatial sensations (e. g. rhythm, balance), reconstruction and abstraction;
3. Creation of spatial objects in 2D and 3D: design, modelling and construction.

We identified spatial abilities and related knowledge relevant for the age groups targeted (10-12 years, Grades 4-5-6 of primary school) and developed 62 tasks and their scoring guides and embedded them in an online testing environment, eDIA, the online, adaptive testing environment of our national competence based assessment by the Development of The Assessment of Cognitive and Affective Skills and Abilities Project.
Colourful and detailed digital images in eDIA and 3D, movable images in GeoGebra provide a much better representation of space than usual, pen-and-pencil, black-and-white task sheets. They optimally visualise complex spatial situations and facilitate easier processing.

THE EDIA INTERFACE:

Figure 11: Estimating distance in virtual space (Grades 4. and 5.)

The Interactive Spatial Skills Test

The two-dimensional, static tests were comprised of similar tasks for Grades 4-5. and 6-7., but their difficulty level was different. In this way, the same spatial ability components were assessed in both grades. (Figure 12 and 13).

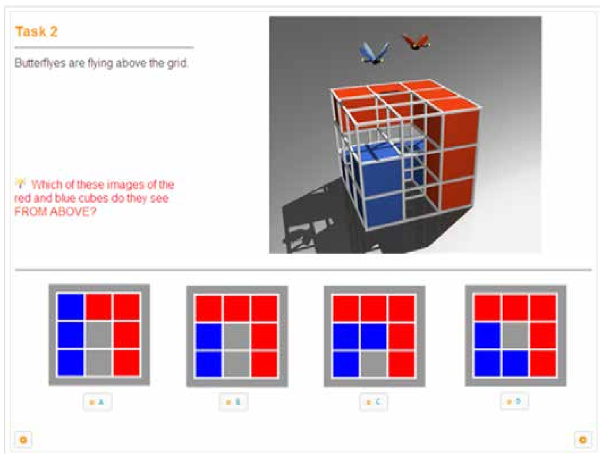

Figure 12. (to the left): Interpretation of spatial relations in 2D (Monge projection) and 3D (perspective drawing). Tasks for Grades 4 and 5.

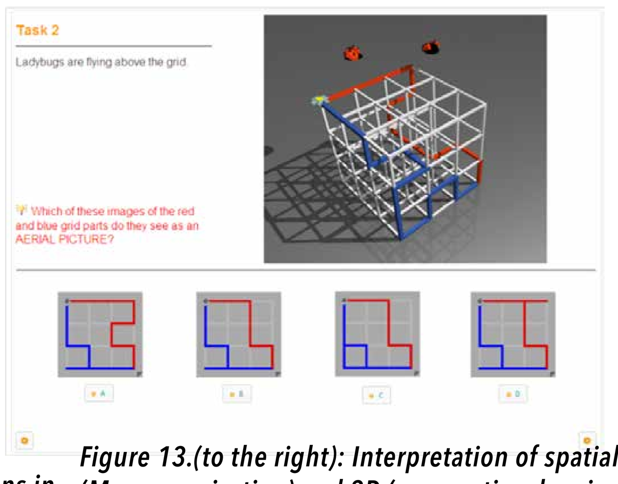

Figure 13.(to the right): Interpretation of spatial relations in 2D (Monge projection) and 3D (perspective drawing). Tasks for Grades 6 and 7.

General features of the eDIA (Electronic Diagnostic Assessment System):

1. – Diagnostic assessment of competences, Centre for Research on Learning and Instruction, University of Szeged (3 main domains, like reading, mathematics, science and further 14 cognitive, affective skills and competences)
2. – Online, adaptive and motivating testing environment
3. – Free and easy availability for schools for development and assessment all over Hungary
4. – Immediate, personalized feedback on knowledge and skill levels of learners
5. – Tests and tasks for student aged 6-12 (Grades 1-6 , ISCED level1)
6. – Wide variety of item types with sound, image, video and animation
7. – Response in different forms (e.g.: marking, clicking, colouring and rearranging images, entering text, pairing text and picture)

GeoGebra SOFTWARE INTERFACE

- Dynamic Geometry System
- GNU General Public License
- Interactivity
- Dynamic display
- Replay of the constructions steps of editing
- Create new tools
- Python and JavaScript support
- CAS computer-algebraic support
- 4.x → 2D displaying
- 5.0 Beta → 3D displaying

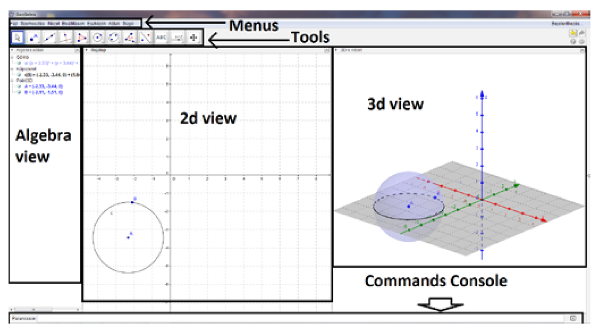

Figure 1: The GeoGebra interface

USERS OF GEOGEBRA

62 languages	1700000 online study material
190 countries	900.000 visitors / month
122 GeoGebra research institutions (in 82 countries)	400.000 downloads / month
43 developers	6,2 million downloads in 2011
200 translators	5,5 million users in schools on tablet PCs

A MODEL FOR SPATIAL ABILITIES

1. Space conversion (transformation, manipulation)
2. Interpretation of the mechanism and structure of spatial objects (and their conversion)
3. Perception of spatial positions
4. Usage of space imaging systems
5. Space reconstruction

Factor analysis was performed on 13 tasks for Grades 6 and 7. The inter-task variance of the factors was 60,82. Based on communality values, five spatial ability factors were identified (Table 1):

- C1: Perception of directions, changes of viewpoint: it is needed for most spatial operations as it guides spatial orientation and mental rotation.
- C2: Perception, without interpretation of spatial structures and shape characteristics (strongest correlations are negative values).
- C3: Mental transformations: strongest correlation with mental folding and reconstruction, and negative correlation with the recognition and interpretation of static spatial situations.
- C4: Change between modalities (two- and three-dimensional representations): positively correlates with matching Monge projections with images in perspective.
- C5: Interpretation of spatial structures and shape characteristics (strongest correlations are positive values).

General features of the GeoGebra software

GeoGebra (http://www.geogebra.org/) is an open source software used worldwide, 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. Thousands of volunteer developers broaden the range of applications daily. It is open-source and can be installed on any platform that is suitable to run Java. Perhaps Its basic functions can be learned by anyone with minimal computer skills in a couple of hours. Therefore, teachers often use them for practice and testing as well. However, its application for art education still has 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: Visual Culture – the Hungarian school discipline for art education.

TASK SNAPSHOTS

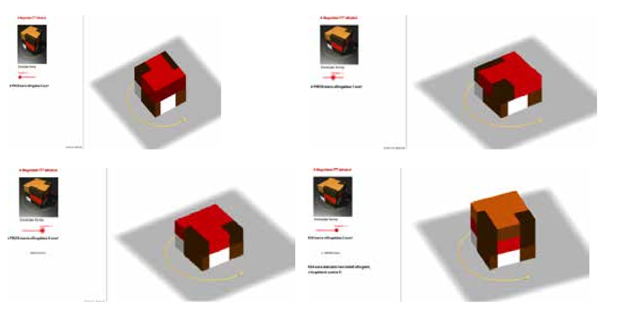

Figure 6: Rotating an image while solving a spatial perception task

HOW TO USE THE DYNAMIC TESTS

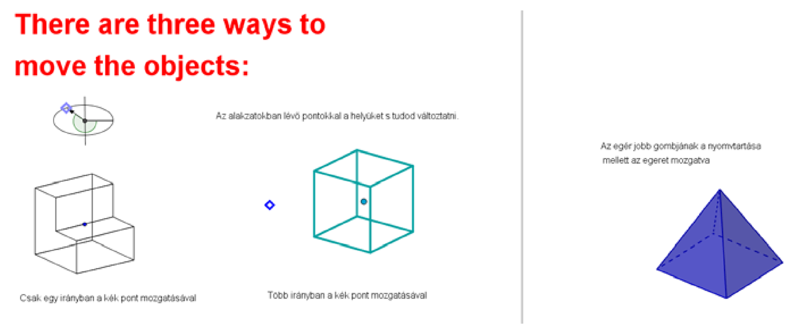

Figure 2: Three ways to move a GeoGebra image

THREE WAYS TO MOVE A GEOGEBRA IMAGE

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

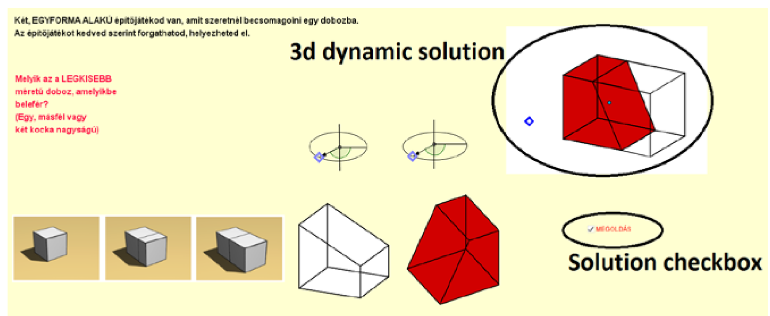

Figure 3: Sample task in GeoGebra

THINKING PROCESS LEADING TO THE SOLUTION

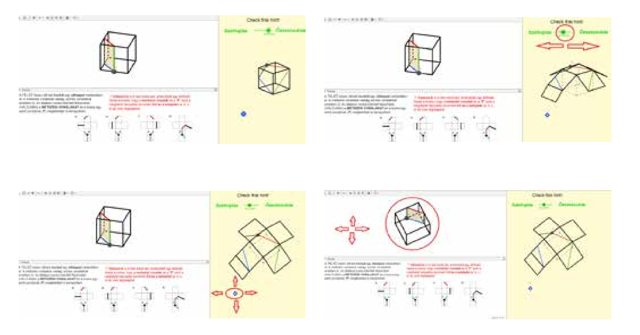

Figure 5: Thinking process leading to a solution

Tasks

TYPES OF TASKS

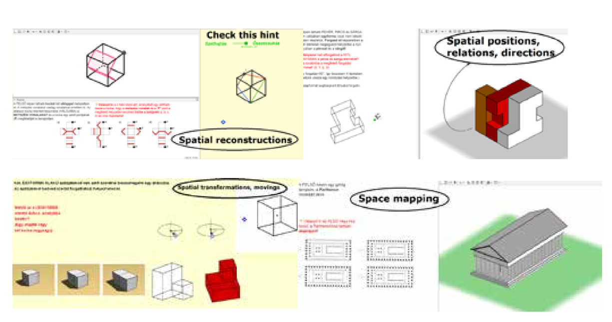

Figure 4: Types of tasks in GeoGebra

SAMPLE TASKS FROM THE EDIA ONLINE TESTING ENVIRONMENT

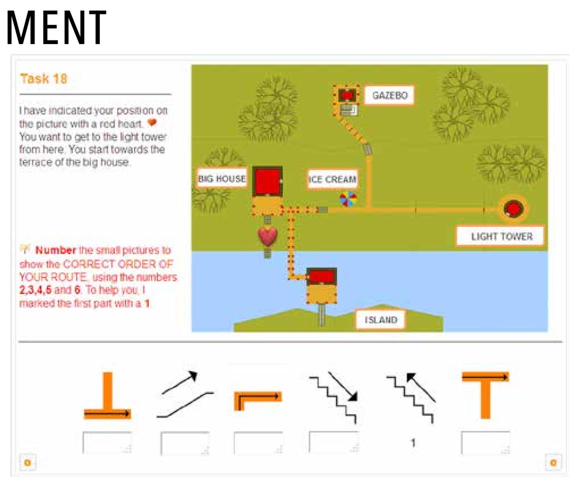

Figure 20: Spatial orientation based on maps and pictograms (Grades 6 and 7)

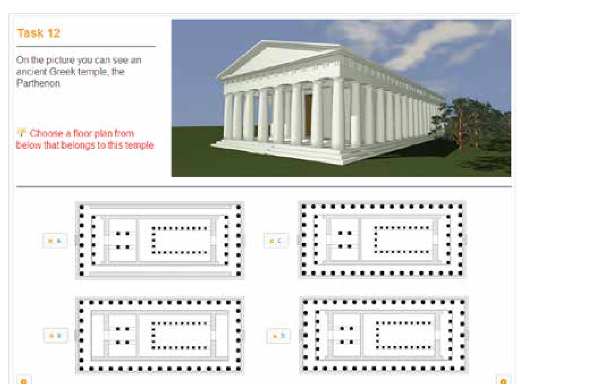

Figure 21: Reconstruction: matching the image of a building with its floor plan (Grades 6 and 7)

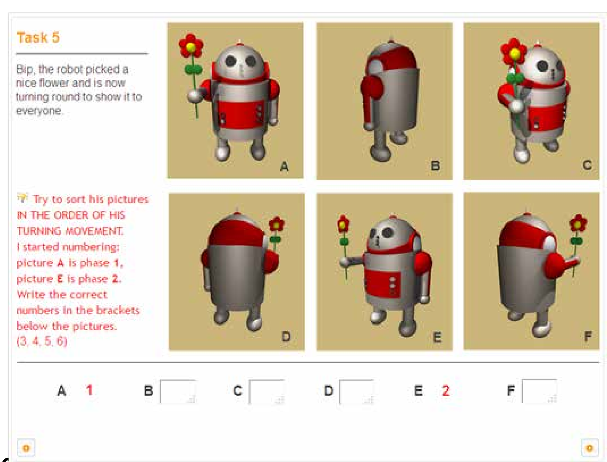

Figure 22: Mental rotation (Grades 4 and 5)

Results - GeoGebra Tests

Figure 7 below shows 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-alfa coefficient is 0,513665600158327; the Cronbach's Alpha Based on Standardized Items is 0,458514422030235. Taking the students' number in the pilot into consideration these values are normal.

Average results of the static test (71.21% with 0,16 standard deviation) and the dynamic test (72.83% with 0.13 standard deviation) clearly indicate that the static and dynamic tests are equal in difficulty level.
Figure 3 shows the results by tasks. 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.

On Figure 4 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.

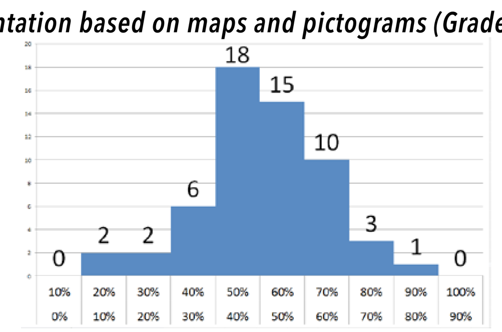

Figure 7: Student performances in decimal intervals (N=57)

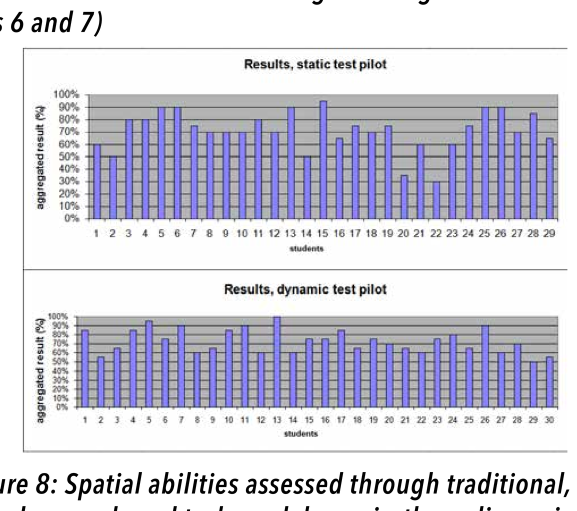

Figure 8: Spatial abilities assessed through traditional, two-dimensional, paper-based tasks and dynamic, three-dimensional tasks in GeoGebra (N=59)

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 2 provides a summary of the results of the tests and shows how differences in results in the two testing environments.

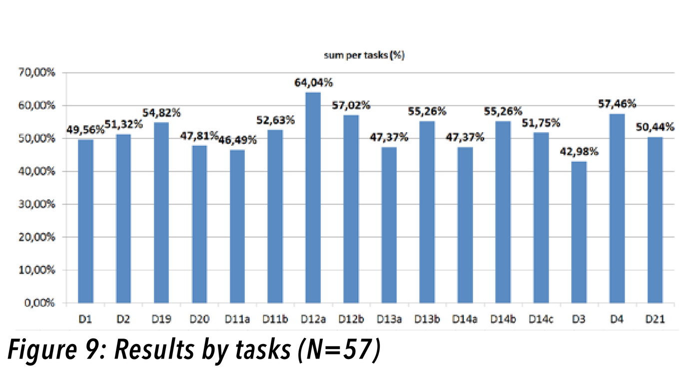

Figure 9: Results by tasks (N=57)

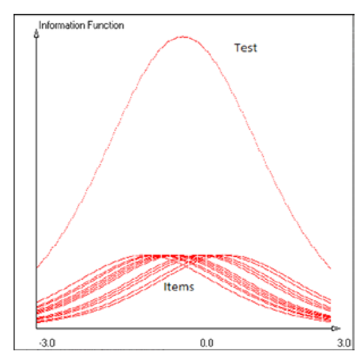

Figure 10: Ability character curve (N=57)

Results - 2 D Tests

Results of the Interactive Spatial Abilities Test – a two-dimensional, static task sequence – are shown on Figure 23. (Number of students in the sample 988) 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 23)

Student performance was significantly different in the grades tested. Figure 24 shows results of the age groups and illustrates differences in difficulty level between the two test versions in Grades 4-5. and 6-8. Figure 25 shows the relative frequency distributions in Grades 4-7. (In Grade 8, only 10 students were tested.)

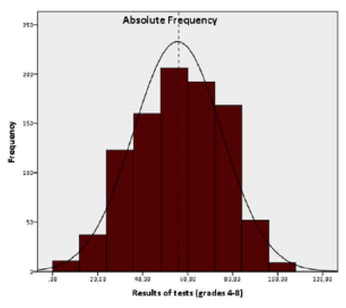

Figure 23: Absolute frequency of results (Grades 4-8, N=988)

Before starting task design, an analysis of existing spatial ability tests was undertaken and a comparison of alternative art education textbooks and curricula was also performed. We selected skill components that appeared as output requirements in Hungarian art education curricula and featured in widely used, valid spatial ability testing instruments. 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, as on Figure 17.)

Conclusions

No significant differences were found between paper based and web based test results with regard to group average, maximum score, scope and deviation. This result, however, needs further verification as in the few studies comparing web-based and pen-and-pencil tasks, digital test have been found more difficult. 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. With GeoGebra, we were able to provide a virtual environment that was as familiar and easy to use for students, as traditional tools.

Future research

Phase two of our project will involve the correction of the system of tasks both for Spatial Abilities and Visual Culture, development of new items for Art Appreciation as well as Environmental Culture, and introduce them to a representative population of Hungarian 6-12-year olds. We intend to reveal spatial manipulation strategies through the employment of eye tracking tools.
Another major issue to 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 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, cf. 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 (art and mathematics) education. Our testing processes not only model, but also directly involve creative and design practices as we confront them in real life, interlinking assessment, education, and (self)improvement.

Sample and testing: GeoGebra tests

Is a 3D virtual reality environment an equally authentic tool for testing spatial skills as traditional, paper-and pencil, 2D tests? (mérettel, színnel kiemelve – a továbbiakban is, ha ezt a Kiemelés formátumú szöveget látod.) To explore this problem, a pilot study with 112 students (55 static and 57 dynamic testers), and 6th grade students has been carried out in May, 2014, in a primary and secondary vocational school situated in a small country town in Hungary. (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.
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 duration was necessary for the majority of students. In the static test, the fastest student finished in 12 minutes, while the slowest needed twice as much time and completed the task in 25 minutes. All groups have seen the tasks on their computer (in PowerPoint), and their solutions had to be recorded on paper.
The 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.

Sample and testing procedure to the Spatial Skills tests

We piloted the first version of the tests with 161 students, almost equally distributed between Grades 4, 5 and 6, 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 both piloting phases, art educators and teacher trainers helped us fine tune the tests. Difficult or confusing images were corrected and task descriptions shortened or made more explicit.
After the pilots, a national sample of 633 students from Grades 4, 5, 6, 7 and 8 (ages 10-14 years) from 14 schools were tested 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, 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. In comparison to the duration of even the simplest perspective drawing task, our new Interactive Spatial Abilities Test proved to be a motivating and comprehensive assessment method to define the developmental level of a wide range of spatial skill components.

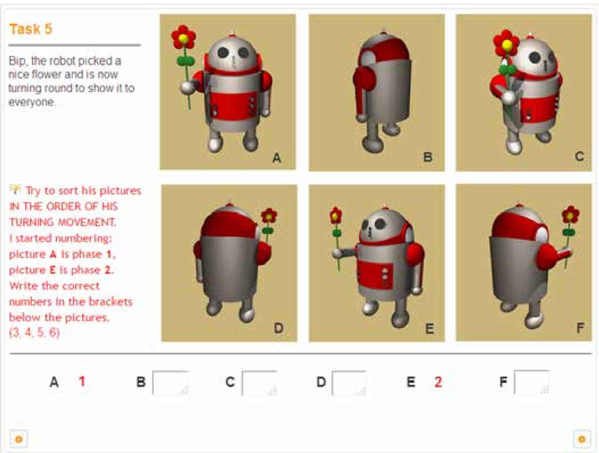

Figure 17: Images showing movement phases from a mental rotation task. (Tasks for Grades 4-7.)

Sample solutions and explanations facilitate the interpretation of tasks. (Figure 18-19).

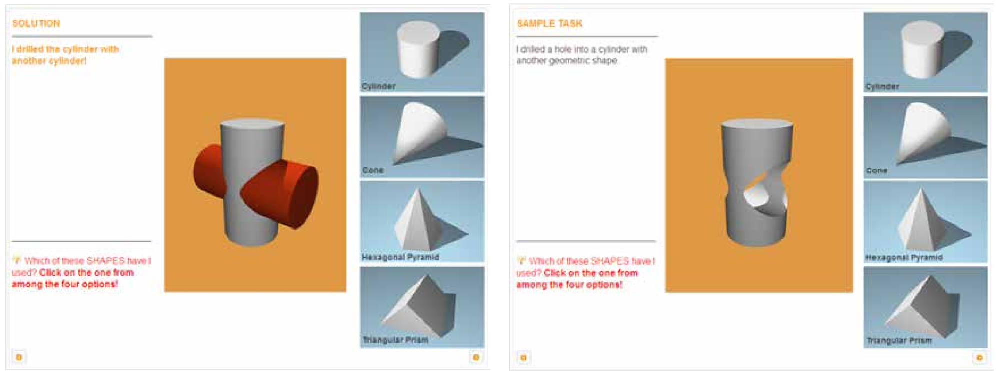

Figure 18 (on the left): Sample task for the recognition and interpretation of shapes. (Grades 6 and 7).

In most of the tasks, students solve spatial problems that they encounter in their daily lives. They have to find their ways using maps and pictograms, (Figure 14), judging distances (Figure 11), or matching floor plans with the perspective drawings of well-known buildings (Figure 15).

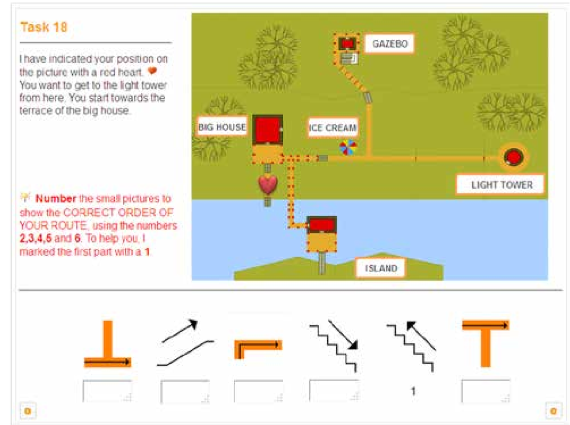

Figure 14: Spatial orientation using maps and pictograms (Tasks for Grades 4-7.)

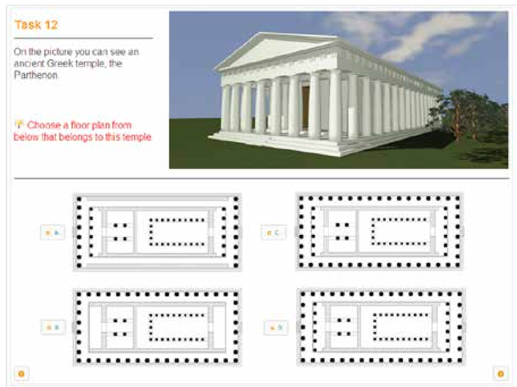

Figure 15: Mental reconstruction of a spatial image: finding the right floor plan of a building. (Grades 6-7.)

In the test, simple visualisations alternate with those requiring complex mental operations. More difficult test items can only be solved in several steps. For example, in the task on Figure 15, changes in the sizes of building parts as they appear on a perspective drawing have to be mentally corrected to find the matching floor plan. Figure 16 shows the section of the building students have to imagine in order to find the suitable floor plan.

Figure 16: Section of the building that students have to mentally produce in order to solve the matching task on Figure 15.