Development of Spatial Skills through the Moholy-Nagy Visual Modules:

A Longitudinal Study

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Abstract. In the age of digital imaging, spatial skills seem to have increased their status in education. Geometry tasks were included in the 2012 Programme for International Student Assessment (PISA) in mathematics (OECD, 2012, 2013) and their positive correlation with achievement in science and technology disciplines were repeatedly proven in STEM (Science, Technology, Engineering, and Mathematics) education research. This chapter presents results of the development of visual-spatial skills after the completion of Moholy-Nagy Modules, an innovative curriculum that focuses on one area of Visual culture: Visual communication, Visual media, Environment and design and Contemporary arts in fifty percent of the lesson hours (32 art lessons of 45 minutes in Grades 5-8, ages 11-14 and 16 art lessons of the same duration in Grades 9 -11, ages 15-17). The in-depth immersion in an area of art education provided an opportunity for a focused visual literacy development and resulted in a more intensive enhancement of spatial skills. he paper begins with an overview of components of the spatial skill cluster (components of perception of and creation in space) and presents the digital, interactive diagnostic assessment tools developed for this study. Spatial perception involves the elements of visual language, including methods for creating spatial illusions; perception of spatial arrangements; orientation in real and virtual spaces based on two-dimensional (2D) images and spatial memory. Representational skills involve in 2D and three-dimensional (3D), including construction and reconstruction of changing experiences of space through time and visualization of 3D objects on the basis of 2D images. Results of the pre- and post-tests as well as background variables impacting students' performance will be discussed to show the potentials of art education in developing an area of visual literacy equally important for everyday life and hundreds of vocations and professions.

Keywords: Art education, assessment, development, spatial skills, visuospatial information processing

Visuospatial information production and processing is a basic visual skill cluster present in a wide range of everyday activities, from gardening or sewing to building self-representations on a social website. Interpreting and creating spatial information develops knowledge building and problem-solving skills and prepares for flexible retrieval and utilization of information in the world of work. Image production (both in two- or three-dimensional formats) fosters the creation of accurate mental representations (McKim, 1980; Mohler & Miller, 2009). Design and construction is associated with genetic forms of knowledge building: exploration, trial and play. The design process involves instinctive, spontaneous phases that may lead to inspiring detours and incongruences that result in the discovery of new solutions (Aden, 2016).

Visualization 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 contextualized rather than abstract (Boone, Gong & Hegarty, 2018). Representing space is traditionally considered a basic set of skills that occupied a central place in the training of the artist (Sanabria & Arámburo-Lizárraga, 2017).

In the age of digital imaging, spatial skills seem to have increased their status in education. Geometry tasks were included in the 2012 PISA assessment in mathematics (OECD, 2012, 2013) and their positive correlation with achievement in science and technology disciplines were repeatedly proven in STEM (Science, Technology, Engineering, and Mathematics) education research (Uttal & Cohen, 2012; Newcombe, 2013; Cheng & Mix, 2017, Power & Sorby, 2020). Besides Mathematics, Art and Design is mainly responsible for fostering spatial skills. Most studies dealing with the issues of the enhancement of spatial cognition come from the tertiary level of education, and the training of engineers and architects (e.g., Sorby & Baartmans, 2000; Sutton & Williams, 2007). A reason for this could be that the low level of development of visual-spatial skills, which usually remains hidden in public education, becomes evident during engineering courses. In many cases, graduation or the practice in the chosen profession becomes impossible due to the lack of fundamental skills as visualization and implementation of three-dimensional perspectives based on two-dimensional plans, projections and sections (Leopold, Gorska, & Sorby, 2001). Studies on spatial skills of students enrolled in tertiary technical training programs claim that secondary levels of education fail to develop this basic skill cluster and endanger successful technical training. This chapter discusses how spatial skills may be developed in primary and secondary school and encourages the inclusion of such programs in basic, compulsory art education (Edens & Potter, 2007).

Educational research on spatial skills is mostly conducted by experts of natural sciences or mathematics, thus there are quite few outcomes that can be used in visual art education (e.g., Tsutsumi et al., 2005; Jee et al., 2014). Art education that has been using expert agreement based on holistic judgment in the last three decades, seems to have turned back to skills research and evidence based educational planning (Madeja 2013). The best example for the “cognitive return” in the field is perhaps the *Common European Framework for Visual Literacy* developed through the cooperation of twenty-one institutions in nineteen countries (Wagner & Schönau, 2016; Kárpáti & Schönau, 2019). It provides a conceptual structure of visual skills utilizing case studies of programs fostering their development. The European Network of Visual Literacy (ENViL), the research community behind the Framework, is engaged in further exploration of the skills identified and ways of their development. Research presented in this chapter is part of this international effort to describe the developmental levels of spatial skills through online, interactive, diagnostic assessment that helps identify levels of processing spatial information in an authentic, lifelike setting. The researchers define spatial skills and show how an art and design education program, inspired by the legacy of the masters of the German arts, crafts and architecture college, the Bauhaus, may contribute to its development.

SPATIAL SKILLS AND VISUAL LITERACY

The group of spatial subskills (generally referred to as spatial skills) constitute an important domain in visual literacy. As many of these subskills require mental operations, their relation to other visual skills are emphasized in research about mental representations. Spatial perception develops mental imaging, and it enhances the development of visual perception in general (Arnheim, 1997; McKim, 1972). Interdisciplinary studies of arts and science education indicate the importance of visualization of spatial relations in solving mathematical problems. Findings indicated that the level of spatial understanding and the use of schematic drawings were significantly correlated to problem-solving performance which have implications for policy and practice. The art classroom is “an important context for developing students' spatial understanding and proportional thinking skills associated with artistic as well as mathematical ability” (Edens & Potter, 2007, p. 282).

Lubinsky (2010) advocated 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).

Spatial skills involve many interrelated constituents of visual literacy. McKim’s three-component model of visual thinking postulates the strong interrelationship of vision, imagination and drawing.

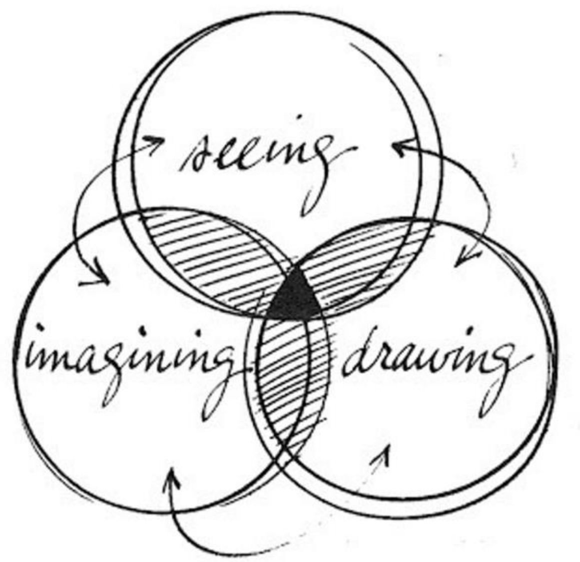

Figure 1. McKim’s three-component model of visual thinking (McKim, 1972, p.6).

McKim (1972; see Figure 1) indicated that visual thinking uses three kinds of imagery: 1) objects, pictures etc. that we see: 2) products of the mind's eye, of our imagination 3) visual representations that we create (draw, paint, sculpt, construct etc.). Advanced visual thinkers interactively utilize all three types of imagery.

> "The overlapping circles can be taken to represent a wide variety of interactions. Where seeing and drawing overlap, seeing facilitates drawing, while drawing invigorates seeing. Where drawing and imagining overlap, drawing stimulates and expresses imagining, while imagining provides impetus and material for drawing. Where imagining and seeing overlap, imagination directs and filters seeing, while seeing, in turn, provides raw material for imagining. The three overlapping circles symbolize the idea that visual thinking is experienced to the fullest when seeing, imagining, and drawing merge into active interplay" (Mckim, 1972, p.6).

This creative interplay can be observed in the solution of spatial tasks. Several research projects have proven that engaging in creative activities of visual literacy has a beneficial effect on the development of spatial skills. This effect is, however, reciprocal: spatial activities like construction or 3D representation improve visual processing in general and facilitate the performance of mental operations related to visual literacy (Leopold et al., 2001; Alias et al., 2002; Martín-Guitérrez et al., 2015; Mohler & Miller, 2009). Until the last decades of the 20th century, psychological investigations of visual-spatial skills traditionally assumed a cognitive focus, while art education concentrated on the development of creativity and self-expression, ignoring the role of this discipline in the enhancement of cognitive skills (Madeja, 2013).

However, since the 1990s, the need for a multilateral approach integrating the theoretical bases of psychology, (art) education and other areas of the study of visual literacy resulted in the new domain of *visual science* (Bertoline, 1998). In art and design education, the classic, high arts emphasis shifted towards a broader and more realistic concept: visual culture (Freedman, 2003). Ellen Winner and her associates (2006) in Harvard Project Zero, the research group that was instrumental in the cognitive assessment of results of education through art and music, suggests an assessment methodology that involves the role of the arts in developing visual literacy as well as cognitive skills.

Accountability of the discipline threatened by the continuous reduction of teaching time resulted in assessment strategies targeting an area much broader than creativity or representation; it involved several areas of visual literacy (Schönau, 2012, Madeja, 2013). The research discussed in this chapter is related to these efforts and intends to contribute to the shift of visual art education from an exclusive, high art focus towards developing visual literacy as a life skill.

Spatial Skills: Definition and Summary of Research

Visualization 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 contextualized rather than abstract. Representing space is traditionally considered a basic set of skills that involved a central place in the training of the artist. Traditional methods of developing and assessing spatial skills at the art academies and 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, 1990; Macdonald, 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, and later Fine Arts (Leopold, 2005).

SUBSKILLS OF THE SPATIAL SKILL CLUSTER

The first and iconic empirical study by Piaget & Inhelder (1967) identified natural growth in spatial skills in three stages:

1) *Recognition* of an object's closeness to others, its order in a group, and its isolation or enclosure in environment;

2) *Visualization* of three-dimensional objects and adaptation to their changing appearance from different viewpoints also when rotated or transformed in space;

3) *Visualization and mental manipulation* with the concepts of area, volume and distance in combination with those of translation, rotation and reflection.

Acting on the second and third level of spatial skills is difficult even for adults untrained in methods of visualization and mental representation of space. The reason for poor performance for the untrained is the complex nature of the solution of spatial problems that require different cognitive processes like comparison, visual memory, integration of different viewpoints etc. (Sorby, 2009). With regular art instruction, school curricula of the 20th century developed two distinct clusters of spatial skills: *geometric construction and artistic creation* (Bertoline, 1998). Loosely interrelated, these two methodologies targeted the same objective: preparation for certain professions (Smith, 1996). Representation of spatial relations were identified as a major component of visual talent (Clark, 1989). Cognitive skills like reasoning were also found to have connections with the level of spatial orientation (Newcombe & Huttenlocher, 2003).

In Table 1, the researchers summarized *two distinct approaches to spatial skills development*: *pedagogical* (skills identified for development in public education and the training of artists, architects, engineers and student of other technical professions), and *psychological* (skills definitions employed in psychological investigations). These approaches overlap, but the definition and assessment of skills show different interests and interpretations. Spatial subskills taught and assessed in education are identified on the basis of a comparative analysis of twenty-one European curricula from nineteen European countries (Kirchner et al., 2016) and an analysis of curricula and educational documents (including teachers' manuals and textbooks for students) used in Hungarian art education. The researchers verified the results of the document analysis through interviews with art education teachers and their supervisors about the presence of the subskills identified in art education practice. The resulting framework was tested through 90 paper-based art and design tasks for school grades 1-8, age groups 6-14 years (Kárpáti & Gaul, 2011; 2013). Spatial subskills in art and design education included in Table 1 are the results of these studies. Psychological approaches were identified through an analysis of spatial tests referred to in the table and related research referenced throughout this chapter.

In the Hungarian testing study discussed, the researchers performed a factor analysis of spatial test items and identified three clusters involving spatial skills:

Spatial perception

- Perception of elements of visual language, including representational techniques and methods used for the creation spatial illusions
- Perception of spatial arrangements: interpretation of conventions of spatial representation (Two-Dimensional)
- Orientation in real and virtual spaces based on pictures, technical drawings, maps, models, everyday experiences and spatial memory

Spatial representation (Two-Dimensional)

- Knowledge and application of systems of spatial representation (Two-Dimensional)
- Representation of two and three dimensional shape characters
- Representation of changing experiences of space through time
- Reconstruction and visualization of three dimensional objects on the basis of two dimensional images

Table 1. Spatial subskills identified in in art and design education and psychology.

Spatial subskills in art and design education documents.	Spatial subskills in psychological tests.	Examples for the assessment of subskills.
1. Knowledge and application of systems of spatial representation (Two-Dimensional). • Perception of elements of visual language, including representational techniques and methods used for the creation spatial illusions.	1. Assessment of spatial perception and the use of spatial representation systems.	• Rod and Frame Test (Witkin 1949). • Water Level Test (Piaget & Inhelder, 2013).
2. Perception of spatial arrangements. • Interpretation of conventions of spatial representation (Two-Dimensional).	2. Interpretation of spatial relations by changing size and placement and interpretation of spatial relations.	• Complex Spatial Skills Test (Csíkos & Kárpáti, 2018).
3. Experiencing space, identifying spatial qualities. • Recognition and representation of two- and three-dimensional shape characters. • Interpretation of spatial structures of natural and artificial shapes detection of connections among structural elements.	3. Recognition of two and three dimensional shape characters: • Matching parts fo shapes and patterns, recognition and synthesis of forms, form equation. • Matching sections and shapes, identifying part and whole relationships. • Recognition of embedded figures. • Recognition of hidden figures. • Mental cutting.	• Embedded Figures Test (Witkin, 1950). • Hidden Figures Test (Ekstrom, French & Harman, 1976). • Paper Form Board (Quasha & Likert, 1937). • Form Equations (El Koussy, 1935). • Mental Cutting Test (CEEB, 1939). • Complex Spatial Skills Test (Csíkos & Kárpáti, 2018).
4. Orientation in real and virtual spaces based on pictures, technical drawings, maps, models, everyday experiences and spatial memory.	4. Spatial orientation.	• Spatial navigation tasks (Sandstrom, Kaufman, & Huettel, 1998; Chai & Jacobs, 2009). • Virtual navigation tasks (Andersen et al., 2012).
5. Reconstruction and visualization of three-dimensional objects on the basis of two-dimensional images.	5. Recognition of spatial relations. • Usage of technical, mechanical or engineering drawing systems. • Multiview creation, creation of isometric images. • Axonometric drawings of spatial configuration.	• Three-Dimensional Assessment Tasks (Sutton & Williams, 2007). • Complex Spatial Skills Test (Csíkos & Kárpáti, 2018).
6. Interpretation of abstract spatial representations. • Reduction and abstraction of spatial images.	Not measured in psychological tests.	• Visual communication tasks (Kárpáti & Simon, 2014).
7. Dynamic space perception: representation of changing spatial experiences through time.	7. Visualization of mental rotation, mental transformation and changing spatial relations.	• Differential Aptitude Test: Space Relation (Bennett et al., 2010). • Mental Rotation Test (Vandenberg & Kuse, 1978). • Card Rotation Test (Ekstrom, French & Harman, 1976). • Three-Dimensional Cube (Gittler & Glück, 1998). • Paper Folding Test (Ekstrom et al., 1976). • Surface Development Test (Thurstone & Thurstone, 1949). • 3D Assessment Tasks (Sutton & Williams, 2007).

Creation of new spatial objects (Two-Dimensional and Three-Dimensional)

- Design (planning of objects, buildings and spaces)
- Modelling
- Creation
- Construction

SPATIAL SKILL DEVELOPMENT AND ASSESSMENT IN THE MOHOLY-NAGY VISUAL MODULES

This longitudinal study of the development of spatial skills is part of the assessment system of the “Moholy-Nagy Visual Modules --- Teaching the visual language of the 21st century, 2016-2020” project, supported by the Hungarian Academy of Science. The name of Laszlo Moholy-Nagy, designer, photographer and media artist of world fame in the title of the research program refers to an important and, for public education, still unutilized legacy of Hungarian art education: educational theories and practices of the Hungarian masters of the German arts and crafts college, the Bauhaus. (Droste, 2019) Based on this rich repository (Van Osten & Watson, 2019) of innovative ideas, this project develops curricular modules to map four areas of the discipline called “Visual culture” of the Hungarian Core Curriculum: *Visual communication; Visual media in art education; Environmental education and design and Contemporary visual arts*. These thematic areas have different effects on spatial skills and allow for observations of optimal developmental methods for students in Grades 5-11, ages 11-17 years.

Moholy-Nagy Visual Modules introduce a basic change in curriculum design: elective curriculum modules that provide *an in-depth acquisition of areas of visual literacy, important for life and work*. The researchers want to break with the tradition of introducing a wide range of unconnected themes, covered in a very limited number of lesson hours (at present, in July 2020: two lesson hours (45 minutes) for Grades 1- 4, ages 6-10 and one lesson hour for Grades 5-10, ages 11-16 weekly). This theme-focused curriculum design is also supported by research from the Leonardo Program, a Hungarian art education project involving 850 children in 14 school grades 5-8, age groups 11-14, that showed beneficial effects of thematically focused art education on a wide range of visual skills (Kárpáti, 1995). Thematic areas for the modules and age groups for piloting were selected through expert agreement. The 600-member professional community created by our research group, the Network for Master Teachers of Art helped us find the most important visual skills that may and should be developed in public education. The four modules and their core content in relation to spatial skills development are identified as:

1. *Visual communication* – the use of visual language for a wide range of expressive, functional and scientific purposes through digital arts, social media and traditional imaging methods. Forms of spatial representation taught involve mapping, planning, scientific imaging (dynamic and static infographics) and basics of architectural visualization. Puppetry as a form of integrated communication through visual arts and drama also contributes to spatial skills development.

2. *Visual media in art education* – introduction to photography, filmmaking, animation, and multimedia. Spatial skills are developed through scenography, stage design, and development of layers of animation, photographing and filming in different spatial settings. (Figures 2 & 3)

3. *Environmental education and design* – an integrative theme with a potential to reach out to STEM (Science, Technology, Engineering and Mathematics) and introduce STEAM (with Art included). All projects in this module involve

research related to the design task that involves retrieving and, with teacher support, processing relevant science, technology and engineering information. Spatial skills development involves developing axonometric representations and floor plans, modelling and (in secondary school level), designing and constructing objects and spaces.

4. *Contemporary visual arts* – integrates creation in and perception in contemporary art genres. Educating an open and flexible audience for the contemporary art scene is also an important objective. Spatial skills are developed through designing and participating in performances and happenings, creating art objects, artistic microspaces and land art.

Each Moholy-Nagy Visual Module covers approximately fifty percent of the discipline-based teaching content. Experimental schools were selected on the basis of experiences in innovation of their art teachers. They have an average and below average infrastructure and a community of students who do not specialize in art. Art teachers selected a module in September 2016, and supplemented it with curriculum contents tailored to students' interests and the sociocultural needs of their school. Modular curricula were realized in longitudinal school projects implemented within three academic years, from 2016 until 2019. Members of the research team, including five young art teachers from different parts of the country who earned their PhD degrees and six mid-career educators, success-fully applied for professional upgrade (higher teacher status) through researching the realization of the curriculum modules.

Experimenting teachers and those partici-pating in dissemination activities unanimously welcomed the *modular curriculum design* --- building blocks that teachers could integrate in their art programs that provided them with opportunities for in-depth skills development and the realization of the art project requiring time to unfold. Pre- and post-competence tests (executed in 2016 and 2019) proved that focused, intensive development in one visual area had generated "transfer effects" and developed visual skills equally or better than those learning programs that taught about various visual genres, techniques and themes for short periods. The model offered educational policy makers a valid, evidence-based curri-culum design option. As Hungarian curricula are not piloted before becoming a research-supported compulsory document, the tried and tested teaching programs provide a model for future educational innovation in art education.

Figure 2. Representing spatial relations in photography. Girl, Grade 7, age 13 years.

Figure 3. Creating sand animation. Boys and girls, group work. Grade 5, age 11 years.

SAMPLE AND ASSESSMENT TOOLS

The majority of spatial skills tests are two-dimensional, paper-based tasks requiring mental activities unlike real-life situations. Spatial construction skills, for example, are measured through the completion of isomorphic images, where developmental levels are defined by the number and complexity of elements that the images contain. Such task sequences are tedious to complete, lack creative problem-solving options and may yield inferior results. Spatial skills are typically investigated in a narrow age span, and there is only an evanescent number of longitudinal developmental studies comparing the performance and characteristics of different age groups. Time constraints and financial limitations, however, make authentic assessment difficult. Although a lot of measurement tools are in use, their availability is mostly limited, and only a small number of them are suitable for educational evaluation of visual-spatial skills. Researchers intended to remedy this situation and assess spatial skills in a longitudinal research design through tools that represent life-like situations and are available for teachers (in Hungary and abroad) in an easily accessible, interactive online system that provides immediate feedback (see tasks in Figures. 4-7).

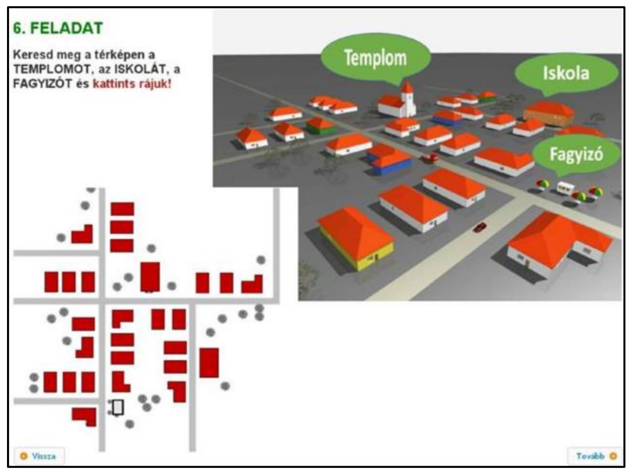

Figure 4. Spatial orientation task from eDia, the online Hungarian testing environment. (Grade 5). Text on the task screen: “Find the church, the school and the café on the map, and click on them to indicate your choice.”

Students came from different sociocultural areas of Hungary, from the capitol city to small villages. The Moholy-Nagy Visual Modules were introduced in 5th and 9th Grades respectively and taught in the course of three school years in fifty percent of the lesson hours allocated for Visual Culture, the Hungarian name of the discipline of art education. Time for the realization of the experimental curriculum objectives was limited (32 hours yearly in Grade 5-8, 16 lesson hours for Grades 9-11), thus development could not be lucrative. Still, in an experimental and control group based assessment design, the researchers could show the benefits of intensive, modular way of visual skills development. In 2016-2017, the research group took the pre-tests and the background questionnaire prior to the developmental project, in Grade 5 (age 11 years, 167 boys and 168 girls) and 9 (age 15 years, 106 boys and 109 girls). In 2019, the researchers examined the extent of the students' knowledge level at the end of the experiment in Grade 8 (age 14) and 11 (age 17) respectively.

Interactive, digital assessment increases student motivation, provides personalized learning opportunities and thus improves skills required in the 21st century (McClarty et al., 2012). The measure of development of spatial skills is primarily affected by the regularity, duration, and quality of methodological practice. Improvement achieved by the developmental intervention is usually persistent (Newcombe, 2010; Uttal et al., 2013). The assessment tools were based on the skill descriptions and evaluation strategies of researchers quoted in the section on the definition of spatial skills. The intention of the researchers was to cover as many subskills as adequate for the cohorts to be tested. Several versions were developed and piloted in the classroom as well as through individuals whose eye tracking data revealed that information on test items was adequate and understandable. To assure professional validity, out tests were criticized by art educators and teachers of mathematics, who gave useful insights about the text and images of the tasks, the scope of knowledge covered and the age-related levels of performance to be reflected in the scoring system.

The tests were developed and administered in the Electronic Diagnostic Assessment System (eDia) developed by the Research Group of the Hungarian Academy of Science and Szeged University. The eDia system mediates a wide range of item types through high quality visualizations and many interactive options. Sample items help students understand the way a task should be interpreted. The system provides voiceover for slow readers and immediate feedback after the completion of the tests. The eDia testing system, available free of charge to all Hungarian schools, makes it possible for teachers to monitor learners' development continually, to indicate areas that need further development and thus support individualized instruction (Csapó & Molnár, 2019).

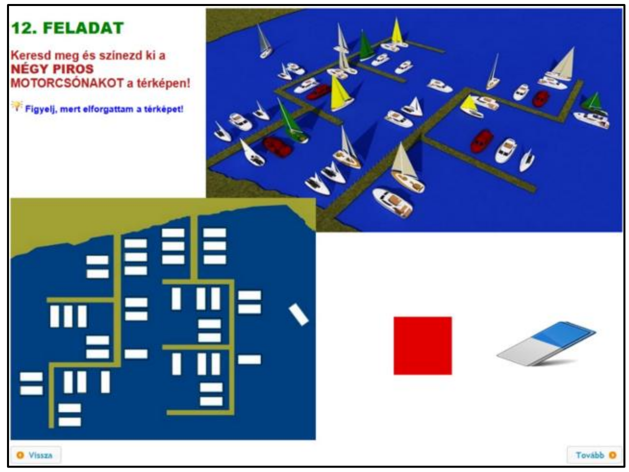

Figure 5. Spatial orientation task from eDia, the online Hungarian testing environment (Grade 8). Text on the task screen: "Identify the three red motorboat on the map and paint them to indicate your choice."

The researchers developed tasks based on children's everyday experiences that covered major content areas of the art education curriculum. Test items represent typical art education tasks in a more authentic setting including perception and interpretation of spatial relations (e.g., structure vision, observation of whole-part relationships, see Figures 4 & 5). The use of representational conventions (e.g. linear perspective and Monge projection) are also included. From the spatial subskills that psychological tests measure, mental rotation was included (see Figures 6 & 7). In the test, mental manipulations appear in isolation (elementary operations) and in sequences (complex operations). The researchers wanted to find out how the representational quality of test items (e.g., formal character or color) influences successful solution. Further, they represented spatial relations through easily recognizable, figurative tasks and also through abstract, geometric tasks. When designing the tests, the researchers hypothesized that task difficulty would be influenced by the types of operations, their complexity and the abstraction level of representation.

The researchers developed different test versions for the pre- and post-tests and included anchor items to make comparison of developmental levels more accurate. In the course of the longitudinal assessment, 4 anchor items (tasks measuring the same spatial skills in pre- and post-tests) were included to compare the results of the students who attended Grade 5 during the pre-test in 2016/17 and Grade 8 during the post-test in 2018/19. Tests for secondary school students also included 8 anchor items for Grade 9 during the pre-test in 2016/17 and Grade 11 during the post-test in 2018/19.

In 2017, the researchers added a questionnaire to the pre-test that provided data about background variables that, according to previous studies, influence both the natural growth and school-based enhancement of spatial skills. A background questionnaire was taken during testing, as part of the online task sequence. Therefore, a complete set of questionnaires for the whole sample was taken. Data collected:

- basic information about students (age, gender, school grade).
- types and frequency of internet use (to identify potential obstacles for online testing).
- favorite computer games (in order to identify games that involve spatial orientation).
- frequency of using image processing software.
- preferred free time activities (to detect those related to spatial operations, like ball games).
- motivation to take the test (likeability of the items).

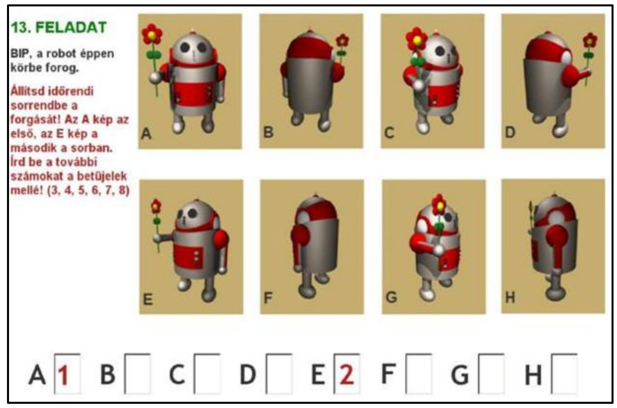

Figure 6. Mental rotation task with figural shape from eDia, the online Hungarian testing environment. (Grade 9) Text on the task screen: “Roby the robot picked a nice flower and is now turning around to show it to everyone. Try to sort pictures in the order of his turning movement. I started numbering: picture A is phase 1, picture E is phase 2. Write the other numbers in the brackets below the pictures!”

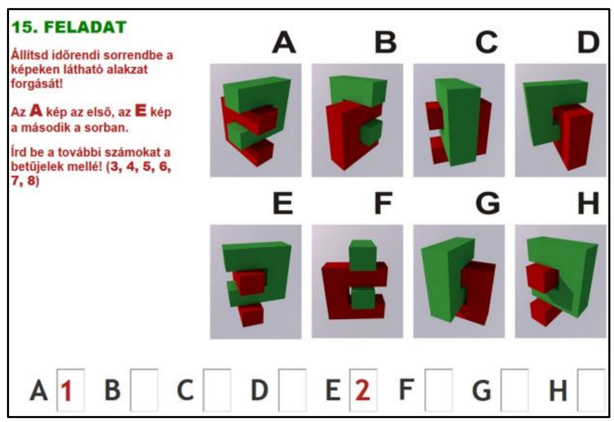

Figure 7. Mental rotation task with abstract shape from eDia, the online Hungarian testing environment for Grade 11, age 15 years. (“Try to sort pictures in the order of turning movement. I started numbering picture A is phase 1, picture E is phase 2. Write the correct numbers in the brackets below the pictures. (3, 4, 5, 6, 7, 8)”).

RESULTS

Data from the 2017 and 2019 testing cycle proved that the spatial skills tests were valid and reliable, and the development of the subskills could be assessed using them, in Grades 5, 8, 9 and 11 (see Table 2).

Table 2. Spatial subskills assessed through the tests.

Spatial subskills	Description of tasks in the test.
Visualization	Imagination of objects from different viewpoints.
Reconstruction of space	Mental modelling of three-dimensional objects based on two-dimensional representations.
Spatial orientation	Orientation in space based on models and maps that imitates a real-life, built environment. To solve spatial problems associated with relationships between objects (position, direction, distance, size).
Mental rotation	Arranging phases of a rotating object in a correct visual order.

Reliability values increased in parallel with the number of tasks in the test (see Table 3). Correlation coefficients show medium and strong values in all four tests (r_5=0.42-0.74, r_8=0, 0.50-0.74, r_9=0,48-0,70, r_{12}=0.51-0.75), indicating that all items have a significant effect on the final test score.

Table 3. Reliability values for the spatial skills tests (Grades 5, 8, 9 and 11).

Grades	N	# of Items	Cronbach-Alpha
5th	335	10	0.83
8th	249	15	0.88
9th	261	13	0.86
11th	215	15	0.91

Secondary school students scored higher than what the researchers presumed in the test (with all items considered) (Grade 9, pre-test: 60,89%p, Grade 11, post-test: 69,58%p). This result indicated successful development in all four modules. The relatively high deviation values, however, point at the significant differences between the students' skill levels, while also confirming the appropriate differentiating effects of the tests (see Table 4).

The complexity of shapes and the figurative versus abstract character of the test items largely influenced the success of solution. In some cases, it had a higher level of determination than the complexity of spatial operations. This study confirmed the assumption that spatial problems related to authentic, lifelike situations and featuring attractive visualization are motivating and improve student performance. The highest number of good solutions in every age group are related to spatial problems of everyday life. These tasks also have detailed, colorful visualizations. In primary school age groups (Grade 5 and 8, ages 11 and 14) and also in the youngest group in secondary school (Grade 9, age 15), the quality of the visualization of test items has a strong impact on the performances. In the post-test, the performance of 11th graders was already unaffected by the quality of the visualization, their spatial concepts became more abstract and solid.

In Table 5, we compared results of Grades 5, 8 and Grades 9, 11 of the same type and difficulty level. The grade averages, calculated from the tests with decreased item count implied *continuous progression of visual-spatial skills in the investigated age interval.* Post-test results showed *significant increase of performance of the experimental groups* compared to the control groups. Primary school students participating in the experimental program between Grades 5 and 8, ages 11 and 14, developed 5.59%p more than those of the control groups ($t=2.35$, $p<0.02$). In the secondary school, pre-tests showed an advantage for the experimental group. However, the difference grew significantly as a result of the Moholy-Nagy module programs: experimental classes developed 6.93%p more than their same-age peers in the control groups.

The discussion in the next section focuses on the results of the primary school grades 5 (age 11 years) and 8 (age 14 years). Table 6 shows the development of spatial skills resulting from the educational interventions in the four Moholy-Nagy Visual Modules. The comparison involves test items of the same difficulty level for all age groups. In Module 1, Visual Communication, development is significant ($t=2.53$; $p<0.02$). In Module 2, Visual Media, development is observable, and almost significant ($t=1.96$; $p=0.052$). In Environmental Education, the training program focused on 2D tasks (the representation of spatial relationships) and development was insignificant. In Module 4, Contemporary Arts, the experimental group was reduced, due to high achieving students leaving primary school after Grade 6 (age 12) to attend 6-Form secondary school. The researchers did not observe significant spatial skills development.

Table 4. Test results for Grades 5, 8, 9 and 11 (ages 11, 14, 15 and 17 respectively)

Grades	N	# of items	Mean (%p)	Standard Deviation	Minimum (%p)	Maximum (%p)
5th	335	10	53.36	29.80	0	100
8th	249	15	52.18	28.49	0	100
9th	261	13	60.89	28.47	0	100
11th	215	15	69.58	29.42	0	100

Table 5. Results of the same tasks in the pre-test (Grades 5 and 9, ages 11 and 15 years) and the post-test (Grades 8 and 11, ages 14 and 17 years)

Grades	N	# of items	Mean (%p)	Standard Deviation	Minimum (%p)	Maximum (%p)
5th	335	9	54.58	29.39	0	100
8th	249	9	58.27	31.39	0	100
9th	261	11	66.53	24.52	0	100
11th	215	11	70.66	29.28	0	100

Table 6. Results of spatial development by modules in primary school (Grades 5, 8)

Modules	Grades	N	Mean	Standard Deviation	t-test		Cohen-d
					I*t*I	p	
Control Groups	5th	94	58.83	29.26	t=0.14	p=0.893	
	8th	61	50.09	38.42			
Visual Communication	5th	68	46.40	27.55	t= 2.53	p=0.013	0.46
	8th	54	59.47	29.29			
Visual Media in Art Education	5th	65	46.67	27.51	t= 1.96	p=0.052	0.35
	8th	61	56.47	28.64			
Environmental Education and Design	5th	24	59.26	31.71	t= 0.54	p=0.591	
	8th	18	53.70	34.35			
Contemporary Visual Arts	5th	91	68.99	26.48	t= 0.27	p=0.791	0.05
	8th	58	70.12	23.38			

If developmental results of spatial subskills are analyzed, the effects of all the four modules are observable. Spatial orientation was developed significantly by Module 1, Visual Communication, (t=2.84; p<0.01), and there was substantial improvement in visualization (9.42%p) and mental rotation, too (1.02%p). Module 2, Visual media produced similarly high developmental effects in all three subskills (visualization: 7.88%p; spatial orientation: 10.76%p; mental rotation: 8.35%p). Module 4, Contemporary Arts affected mental imaging most (11.01%p) (see Figures 8 & 9).

Module 1 of the teaching experiment, Visual Communication was most successful in developing spatial skills. Here, operations of spatial perception and mental manipulation in space were included in several tasks. Students produced paper sculptures and maps in the form of relief or digital collage and they made three-dimensional models of objects and buildings. In the school where students achieved the best developmental results (16.34%p), large scale installations were also created. In Module 2, Visual Media in art education, where photos, animation and video films were produced, spatial skills development was also remarkable. In this module, space-related tasks included creating puppets and scenery for animation films, producing figures for clay animation, and arranging feature films, where the movement of actors had to be directed in real space (see Figures 10 & 11).

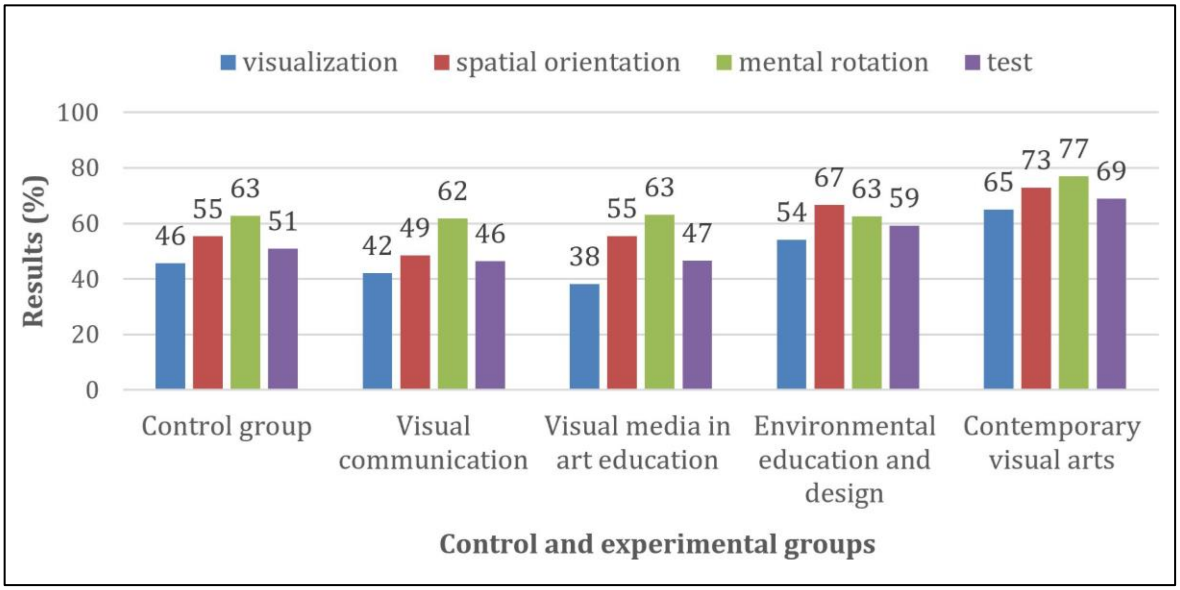

Figure 8. Results by components in the control and experimental groups (Grade 5).

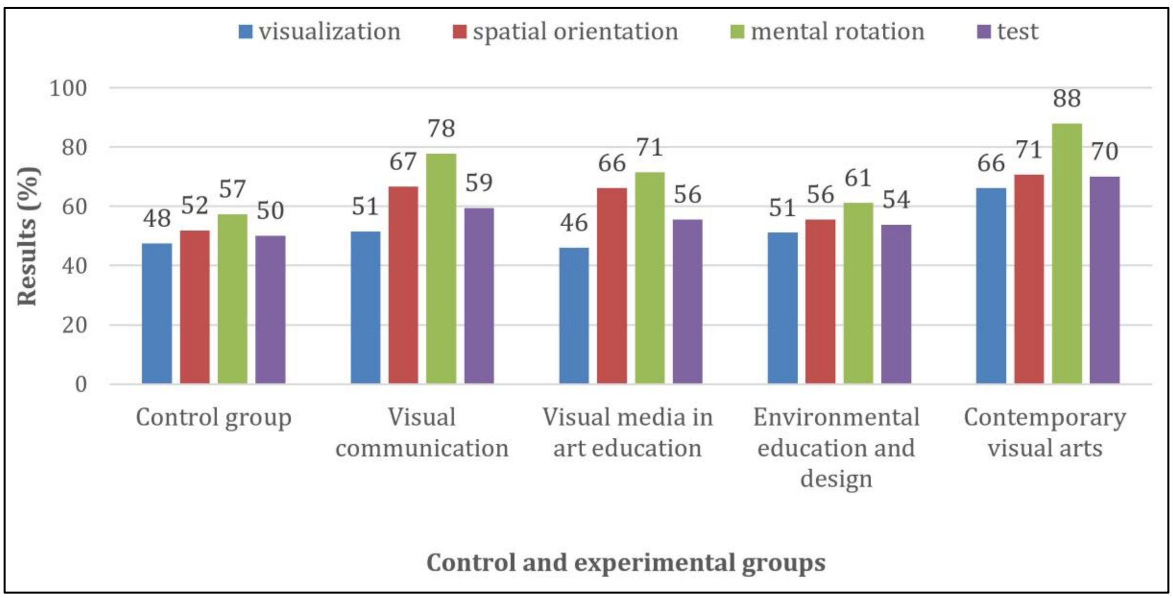

Figure 9. Results by components in the control and experimental groups (Grade 8).

Figure 10. Representing spatial relations through photomontage. Boy, Grade 5, age 11 years.

Figure 11. Projection of self-made images on the body. Performance. Boy and girl, Grade 6, age 12 years.

It was expected that Module 3, Environmental education and design will be most effective in the development of spatial skills, but in primary school, this was not the case. The curriculum involved the solution of spatial problems, but students were supposed to work predominantly in two-dimensional media, and produce representations of spatial arrangements (e.g., drawing, cube truncation and section view). These results suggest that tasks in three-dimensional (like building and construction or creation of objects) are most effective in the development of spatial skills. Regrettably, these activities that are time-consuming and rarely included in traditional curricula. In two of the Moholy-Nagy Visual Modules on communication and media, where three-dimensional tasks constituted a substantial part of the curriculum, focused on the development of spatial skills. In the module on environmental culture, primary school students achieved lower results, while secondary school students with a curriculum based on predominantly three-dimensional construction and design tasks, developed significantly.

Module 4, Contemporary visual arts was realized in two schools that produced widely differing results. Students of School 1 scored 70,89%p on the pre-test and only 62,32%p on the post-test, while students of School 2 started with 66,67%p in Grade 5, and achieved 75,24%p at the post-test, in Grade 8. Here we are facing school based performance differences that is, unfortunately, a characteristic feature of Hungarian education, also revealed by PISA assessment (OECD, 2012; 2013). These differences in development with the same developmental program shows that school-based differences like socio-economic status of students and class size have to be considered when designing and realizing a developmental program.

CONCLUSIONS

Spatial cognition is an important basic skill, connected to several prioritized areas of contemporary educational policy as it is necessary for hundreds of vocations and professions as well as everyday activities from driving a car to furnishing a home. One of the main research directions is the investigation of the correlations with STEM (Science, Technology, Engineering, Mathematics) and visual-spatial skills. The studies published on the subject confirm that spatial skill tests are suitable for the identification of talents in the fields of mathematics, technology, and natural sciences (Clarkson & Presmeg, 2008; Wai, Lubinski, & Benbow, 2009; Lubinski, 2010; Lyons et al., 2018; Uttal & Cohen, 2012; Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014). Findings of research reported here has proven that the development of visual-spatial skills can have significant benefits on STEM areas, so our opinion is that investing spatial skills in relation to other cognitive and affective domains as well as creativity is important (Yilmaz, 2009; Sorby, 2009; Newcombe, 2013).

Previous research suggests that educational interventions involving construction activities positively affect spatial skills. Even learning deficits may be revealed and individually treated in early childhood through construction game based tools (Richardson et al., 2011). In a research project using open-ended construction tasks for studying spatial problem solving skills, McKnight and Mulligan (2012) found that construction toys activate intuitive, informal modes of knowledge acquisition and thus reveal the levels of differentiated thinking. Ferrara et al. (2011) developed spatial skills through free play with building blocks, guided play and play with prefabricated constructions. All these interventions resulted in the development of the skills targeted. These authors also found that spatial skills development positively impacts learning achievement in mathematics and science

Assessing visual skills is challenging but necessary to decode abundant visualizations to be found in most spheres of life. The big “A” in STEAM, (Science, Technology, Engineering, Arts and Mathematics), the expanded model of STEM, the Arts seem to have a significant role in supporting girls and women to successfully pursue their studies. The online, interactive tasks are being developed for skills development, not only testing, with an easy and free-of-charge access from all primary and secondary schools of our country.

Spatial skills are not only developed at school. Several free-time activities play a significant role in their enhancement, and boys seem to be encouraged to engage in them much more than girls. These activities are offered to boys more often than to girls --- and the results are more developed spatial skills. The introduction of construction toys and edutainment versions of digital games may be beneficial --- for boys and girls alike. Tasks in the tests represent different strategies of the perception of spatial relations and the manipulation with spatial objects and images. The four clusters of tasks built on visualization, spatial reconstruction, orientation in space, and mental rotation are included in the Moholy-Nagy Visual Modules in a variety of situations and contexts. The tasks were piloted in a wide range of socio-economic areas to provide methodologies for schools facing different cultural and economic challenges.

Besides spatial tasks for development and tests for assessment, the researchers also developed similar tools on visual communication and color perception and interpretation. These were also piloted and validated for Grades 5-11, ages 6-17. The tests proved to be culture-free for European use, and some items were utilized in a survey of visual literacy organized by the Federal Ministry of Education in Germany. The major advantage of the assessment system is its diagnostic value. It covers a wide-range of subskills within a domain where teachers can design their educational interventions with a focus on the areas in need of fostering. Teachers may develop projects that target different subskills for boys and girls, visualizers and verbalizers, individuals interested in technology or skillful in rendering objects, and others who are intimidated by previous failures in representing space. Using these tools, teachers can get immediate feedback about the success of their interventions and change strategies or adapt their methodlogy if necessary. Evidence based art and design education has to be the guide in the Age of the Image.

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