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BABÁLY BERNADETT:

# SPATIAL SKILLS: ASSESSMENT OF DEVELOPMENT AND RECOMMENDATIONS FOR ART EDUCATION

Theses of PhD dissertation

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## RESEARCH OBJECTIVES

In recent decades, evaluation of results of educational interventions has become a focus of both domestic and international attention. This thematic cluster has become an independent area of research, and involves the development of more and more sophisticated assessment instruments and publications of results in high level research journals (Halász, 2004). Data driven development of teaching-learning methods support institutions to design and reach their educational goals (Csapó, 2003). The development of measurement tools that can be easily included into the everyday evaluation practices of teachers is of increased significance for special skills, where the number of objective, reliable instruments is limited or none at all. The area of visual abilities would classify as one of these, as educational evaluation is usually undertaken on a subjective basis, with the mere objective of giving school marks to the students (Bodóczky, 2000). The development of diagnostic measurement methods and the regular practice of examinations is necessary to trace the progression of visual skills and subskills. Many of these are important in the working sphere and in everyday life, the development of teaching and learning programs and methodologies increasing the efficiency of developmental activities, as well as the improvement of the social acceptance and the methodology of visual art education.

In the field of visual skills research, significant results have been achieved during the recent decades. This area has been reformed its conceptual base, content and perspective through the development of the Common European Framework for Visual Literacy (Kárpáti & Gaul, 2011; Wagner & Schönau, 2016; Kárpáti & Pataky, 2016; Kárpáti, 2018; Kárpáti & Schönau, 2019). By the appearance of digital imaging techniques, multimedia tools and online platforms, the training shifts from high art towards the visual communication of everyday life in a growing extent (Sándor, 2011). Previously, the emphasis was on creativity in visual art education, with the emergence of new techniques and the drastic increase of the number of images, the significance of skill elements necessary for the reception and processing of visual information has increased (Kárpáti, 2013; Kárpáti & Nagy, 2019). Research presented in this dissertation focuses on the investigation of visual-spatial skills that have an increased significance in all aspects of everyday visual language use. Our three main research objectives: (1) to evaluate spatial abilities with paper-based and online tests at $5^{th}$, $8^{th}$, $9^{th}$, and $12^{th}$ grades; (2) to reveal background variables that impact the development of spatial abilities (3) to define the enhancement of spatial cognition through creative, constructing tasks amongst engineer students.

## THEORETICAL BACKGROUND

The development of my theoretical framework was influenced by Hungarian visual skill tests (Séra, Kárpáti, & Gulyás, 2002, Kárpáti & Gaul, 2011; Tóth, 2013, 2014; Pataky, 2012, 2017). These studies already contain the skill components necessary for the reception and processing of visual information of digital platforms and for the application of new imaging methods. In the “Moholy-Nagy Visual Modules – The Teaching of The Visual Language of $21^{st}$ Century” project (Gaul & Kárpáti, 2018; Gaul, Havasi, Nagy, & Sándor, 2018), the construction of a modular curriculum assessed through a longitudinal school experiment, evaluated through a set of skills tests and tasks, provided the framework of my research.. Our research approach was also influenced by the program called “Developing Diagnostic Assessments” led by the Center for Research on Learning and Instruction,

University of Szeged. I have also used the framework of spatial abilities constructed on the basis of curriculum analysis and research papers about spatial cognition including test development procedures, resulting assessment instruments and their implementation (Babály, Budai, & Kárpáti, 2013; Kárpáti, Babály, & Budai, 2014; Kárpáti, Babály, & Simon, 2015; Babály & Kárpáti, 2015; Babály, 2016).

Spatial cognition is an important basic skill, connected to several prioritized areas of contemporary educational policy. One of the main research directions is the investigation of the correlations with STEM (*science, technology, engineering, mathematics*) and visual-spatial abilities. 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; Gunderson, Ramirez, Beilock, & Levine, 2012; Uttal & Cohen, 2012; Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014). Our findings suggest that the development of visual-spatial abilities 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).

At present, the investigation of visual-spatial abilities is an active research area, thus the available data concerning the progression and upgradeability of these skills show a dynamic growth. Researches usually confirm that regardless of the nature of interventions, spatial abilities can be effectively developed at university courses, school programs implemented in the framework of developmental projects, and also through playing computer games at home. There is also no significant difference among research results whether the various activities requiring spatial thinking are implemented in a physical space with material objects, or with the help of digital technologies. The measure of development is primarily affected by the regularity, duration, and quality of practice, and the improvements achieved by the intervention are usually persistent (Newcombe, 2010; Uttal, Meadow, Tipton, Hand, Alden, Warren, & Newcombe, 2013). The significance of electronic media in learning processes is probably going to increase in the years to come. This increase of research efforts in this area will lead to the publication of more effective, scientifically grounded learning materials, increased student motivation, development of personalized learning opportunities, thus improving skills required in the 21$^{st}$ century and making their assessment more authentic (McClarty, Orr, Frey, Dolan, Vassileva, & McVay, 2012).

Most studies dealing with the issues of the enhancement of spatial cognition mostly come from the domain of technical higher education. A background for this could be that the low level of development of visual-spatial abilities, which usually remain hidden in public education, becomes evident during engineering courses. In many cases, finishing of studies, or the practice of the chosen profession becomes impossible due to the lack of such fundamental skills as the visualisation and implementation of three dimensional perspectives based on two-dimensional plans, projections and sections (Leopold, Gorska, & Sorby, 2001; Katona, 2012). According to this, one of the major purposes of the investigation was to reveal the reasons for course failure of engineering students and the development of a remedial program to prevent dropout. As the outcomes of mental rotation, tests show excessive gender-based differences within cognitive ability researches, visual-spatial abilities are usually investigated in correlation with male and female performance. Gender-based differences, typically showing male advantages concerning strategies applied and performances are widely recognized, however there are excessive debates about the measures, types, and reasons of these differences (Bouchard & McGee, 1977; Linn & Petersen, 1985; Caplan, MacPherson, & Tobin, 1985; Goldstein, Haldane, & Mitchell, 1990; Halpern, 2004; Chai & Jacobs, 2009; Voyer, Voyer, & Saint-Aubin, 2017).

In the course of the literature review, we have discovered that spatial abilities are typically investigated in a narrow age interval, and there is only an evanescent number of longitudinal developmental studies comparing the performance and characteristics of different age groups. Although a lot of measurement tools are in use, their availability is mostly limited, and only a small number of them is suitable for educational evaluation of visual-spatial skills. Concerning the situation in Hungary, we can declare that there are few examples of investigation of visual-spatial skills in younger age groups (Kárpáti, 1992, 1995, 1996). Existing studies are usually implemented in correlation with certain subskills (Herendiné Kónya, 2007; Pataky, 2012, 2017). The lack of evaluation has a poor influence on the development of the spatial skill cluster that is indispensable both in everyday life and in the domains of employment and its consequences typically emerge in higher education or at the labour market only. A further problem is that most of pedagogical researches are conducted by experts of natural sciences or mathematics, thus there are quite few outcomes that can be used in visual art education. Educational concepts supporting the learning-teaching processes, and the construction of developmental programs for certain age groups could facilitate the targeted improvement of spatial abilities. Research presented in the framework of this dissertation aims at a precise description of the components of the spatial skill cluster and the definition of its development in periods of childhood, adolescence and young adulthood that are decisive in visual skills development.

## RESEARCH QUESTIONS AND HYPOTHESES

According to my research objectives, I have formulated questions and hypotheses in correlation with the evaluation, development and enhancement of spatial abilities, in four areas: (I.) development of assessment instruments, (II.) characteristics of spatial abilities of different age groups, (III.) background variables influencing the development of spatial abilities, (IV.) potentials of development of spatial skills.

*I. Research questions concerning the* development of assessment instruments*:*

Are the test items suitable for the evaluation of spatial abilities of $5^{th}$, $8^{th}$, $9^{th}$ and $12^{th}$ grade students? Are the psychometric characteristics of the tests appropriate? To what extent does the theoretically determined test structure match the outcomes of the empirical investigation? What type of partial constructs can be distinguished within the tests? Are the items of the background questionnaire suitable to determine the background variables targeted in the research?

*Hypotheses:*

**H1**: Children's spatial abilities can be reliably evaluated through my spatial perception tests and its psychometric properties will be appropriate.

**H2**: There are at least moderate correlations between the subskills identified and assessed within the tests.

**H3:** In the course of empirical investigations, the test will confirm the hypothetical structure of spatial skills. This structure will show correlations identical to the hypothetical model for all of the four grades.

**H4**: Within the tests, the coherence of the tasks will be primarily determined by the complexity of spatial operations. Most stable relations will be identified within the groups of elementary and complex operations.

*II. Research questions concerning the spatial skills of the students:*

What kind of standards do the visual-spatial skills of the participating students represent? What characteristics can be identified concerning the spatial skills of $5^{th}$, $8^{th}$, $9^{th}$ and $12^{th}$ graders? Is there any difference in the performance level of the four grades?

*Hypotheses:*
**H5**: Results of around 50%p will be identified in the grades $5^{th}$, $8^{th}$, $9^{th}$ and $12^{th}$
**H6**: The difference between the visual-spatial ability levels of $5^{th}$ and $9^{th}$ graders will be significant, implying the advancement of $9^{th}$ grade students.
**H7**: The difference between the visual-spatial ability levels of $8^{th}$ and $12^{th}$ graders is significant, implying the advancement of $12^{th}$ grade students.

*III. Questions concerning the progression of spatial cognition and the relations of background variables:*

What background variables determine the performance shown during spatial cognition tests? Could the extent of performance differences between schools and within schools be determined? Are there any visible gender-based differences concerning the results and background variables? Do the investigated forms of activity, right- or left-handedness and colour blindness influence the development of spatial abilities? Are there any traceable coherences between school performances and test results?

*Hypotheses:*
**H8**: Due to the selection mechanisms of the school system, there will be significant differences among the institutions participating in the survey and within separate schools, concerning the performances shown during spatial ability tests.
**H9**: In accord with specialized literature, significant gender-based differences will be identified in the test results, signifying the advantage of boys.
**H10**: Weak and moderate correlations will be observed between spatial ability test performances and school marks. The strongest correlation will be observed between the test results and maths grades.
**H11**: Confirming previous research results, the popularity of action and strategic games among computer games shows significant positive correlations with the students' spatial abilities. Furthermore, we expect similar correlations between the test results and building activities as well as computer games requiring logical thinking.
**H12**: Confirming specialized literature data concerning spare time activities, sports activities, DIY construction activities, handicraft, art circles, preference for construction games and logical quizzes will have positive influence on the performances.

*IV. Questions concerning the upgradeability of spatial cognition:*

Is the development of spatial abilities with creative construction tasks still possible in young adulthood (18-23 years)? Does the learning environment have an influence on the effectiveness of development? Is it possible to determine any differences in the extent of development due to gender, university training type or secondary school background?

*Hypotheses:*

**H13**: Visual-spatial abilities can be effectively developed among 18-23 year old people with creative construction tasks.

**H14**: Different learning environments develop spatial cognition with different efficiency. Construction in a real environment helps to develop spatial abilities more efficiently than virtual space modelling.

**H15**: There will be no differences in the extent of progression according to gender, specialisation or secondary school background.

## INVESTIGATION OF VISUAL-SPATIAL ABLITIES IN THE AGE GROUP OF 10-18 YEARS - RESEARCH METHODS

*Research sample, survey structure*

Our research investigating spatial abilities is a part of the Moholy-Nagy Visual Modules of the Discipline Based-Pedagogy Research Program of the Hungarian Academy of Science. The objectives and scope of this project determined the construction and composition of the sample. Monitoring of the changes occurring in the spatial perception skills of students was conducted both in a primary- and in a secondary school age group, with the participation of 10-18 year old students Studies presented in the dissertation were conducted in two phases:

1. *In 2016-2017,* we have examined the knowledge level of the students at the beginning of the school experiment in modular curriculum design, prior to the targeted development in $5^{th}$ and $9^{th}$ grades. (We have also included students in $6^{th}$ -$8^{th}$ grades into the trial of our test samples).
2. *In 2019,* we have examined the extent of the students' knowledge level at the end of the experiment – $8^{th}$ and $12^{th}$ graders respectively. (We have also included students in $7^{th}$ and $11^{th}$ grade into the trial of our test samples).

The location of the spatial skills evaluation pilots and large-scale assessment were nine Hungarian counties Budapest and Oradea (Nagyvárad), Romania). Altogether, 19 schools participated in the surveys, whose first phase included 841, and the second 689 students. Data collection was conducted by teachers appointed by the school principal, with the cooperation of the members of the Center for Research on Learning and Instruction, University of Szeged. Data recording was implemented partly on paper, partly in the eDIA (Electronic Diagnostic Assessment System) platform. In order to ensuring objectivity, a testing guide was sent to each of the institutions. The first large sample testing was conducted at the spring of 2017, with 604 participants; the second one was conducted between October-December 2019, in which 512 children completed the tests. The background questionnaire in the large sample measurement of 2017 was implemented online, linked with the $5^{th}$ and $9^{th}$ grade spatial cognition tests.

*Development of measuring tools*

During our large sample measurements, we used four test versions. Their development was implemented according to our previous (2013-2014) research results, the outcomes of testing conducted in 2016 and 2019 as well as the reflections of experts and practising art teachers. Students of Grade 5, 8, 9 and 12 received a similar set of test items, that varied mostly in their difficulty level.

The tasks targeted four clusters of spatial skills: (1) visualization, (2) reconstruction of space (only in Grade 8-12), (3) spatial orientation, (4) mental rotation. Our measurement tools contained knowledge elements included in the curriculum of the discipline called Visual Culture, psychology test items and also spatial problems encountered in everyday life. School curricula are represented in the tests by contents related to spatial cognition and interpretation, as well as the knowledge of spatial representation systems and conventions (e.g. Monge projection system, engineering drawing). The presentation of lifelike spatial problems was linked with the investigation of the subskill of spatial orientation. Item types that resemble psychological test items represent mental manipulations. In order to be able to investigate the changes occurring in the students' abilities in the time span of 8 years, we have added anchor-items to all age related tests.

In the course of the development of our tasks, we had to be aware that our tests should function properly both on a paper basis and in the online assessment system (eDIA). The sample tasks with solutions included in front of each assignment type are important facilitating features of our test, as they make the interpretation of the tasks possible on a purely visual basis, without textual explanations. The initiation of all four tests was conducted on a platform where the students could practise reply functions, and were introduced to the correction possibilities of faulty solutions. Another advantage of the use of eDIA platform was, that the students and teachers participating in the survey received immediate feedback about the performances. Results were displayed in a percentile form at the end of the test solution process.

The questionnaire applied in the large-scale survey of 2017 primarily targeted background variables that previous research revealed as important for the development of spatial perception. The questionnaire contained 10 questions and 32 items. We asked for the demographic data of the students (e.g. age, gender) before they solved the tasks, and the rest of the questions followed the completion of the test. Open-ended questions were not provided, due to the limited time frame. Most background questions were multiple-choice items. These questions helped answer some of the research hypotheses, e.g. the effect of various visual activities on spatial abilities. Besides the questions most frequently used in literature, we also collected information considered relevant in connection with this study (e.g. about learning results of the students, their opinion concerning the test, right- or left-handedness, colour-blindness etc.).

## INVESTIGATION OF VISUAL-SPATIAL ABLITIES IN THE AGE GROUP OF 10-18 YEARS – RESULTS

According to the results of the testing studies, we can determine that the tests we have developed provide an opportunity for the reliable measurement of Hungarian students' visual-spatial abilities in a wide age span (Table 1). The tests included anchor-items, thus making the comparison of the performances of certain age groups, as well as the levels of development from age 10 until youth (ages 18-23). The survey can be easily conducted at school classes, and the automatic evaluation of the outcomes also helps their integration into everyday educational practice. The data provide instant feedback about the efficiency of the learning processes, thus promoting the recognition of problems and the planning of necessary interventions.

The inner consistency of the tests was verified along the values of item omission reliability and item-test correlation (Pearson correlation coefficient). According to data, our tests have appropriate inner consistency, and all of our assignments contribute to the determination of spatial intelligence to a significant extent. Correlation coefficients imply medium and strong relations between the subskills in each case. The strongest correlational values are revealed between visualisation and spatial

orientation in every age group, the strong correlation between them is also confirmed by the correlation values between the different assignments. Reconstruction and mental rotation subskills were examined with fewer test items, so the lower correlation coefficient values concerning the whole of the test and the different subskills probably result from this.

*Table 1 Reliability values for the tests for Grades 5, 8, 9 and 12*

| *Grades* | *N* | *Number of items* | *Cronbach-alpha* |
|---|---|---|---|
| 5th | 342 | 10 | 0,83 |
| 8th | 254 | 15 | 0,88 |
| 9th | 262 | 13 | 0,86 |
| 12th | 215 | 15 | 0,91 |

In the course of empirical investigations, the inner structure of our tests were identical to the hypothetical model. The correlation system revealed by the cluster analysis is also identical to several visual-spatial models described in specialized literature. The coherence of the assignments on one hand was determined by the classification according to the subskills revealed by previous studies (Lohman, 1979; Linn & Petersen, 1985; Carroll, 1993; Maier 1994; Voyer, Voyer, & Bryden, 1995; Quaiser-Pohl, Lehmann, & Eid, 2004; Sutton & Williams, 2007), and the items on visualisation, reconstruction and spatial orientation constitute a unique group in each of the tests. Besides the type of spatial operations, their complexity also had a significant effect on the stability of the inter-item connections within the tests. In connection with item complexity, and difficulty, our assignments may be classified into two groups, identified by Séra et al. (2002) as "*recognition and manipulation*", Tóth (2013) as "*primary and complex operations*". According to our investigations in 2013-2014, we have proven that the visualisation of the test items has a significant impact on performance (Babály & Kárpáti, 2015). Our present assessment confirmed our previous results, representing spatial problems into lifelike contexts. The figurative nature of the illustrations increased the number of successful solutions, especially at lower grades. Altogether, our empirical data support our theoretical model and also Hungarian and international research, which confirms the validity of the hypothetical skill-subskill construct our tests were built on.

Our hypotheses concerning the assessment instruments are typically confirmed by our research data. Psychometric indices show that spatial abilities of 10-18-year-old students could be reliably evaluated through online tests (H1). Our tests confirm previously hypothesised inner structural consistencies (H3). Medium or strong correlations exist between skill structure studied (H2). Our hypothesis about the coherence of test items within the tests is primarily determined by the complexity of spatial operations is only confirmed by the test results of 5$^{th}$ graders (H4). Cluster analyses suggest that the classification of subskills (the type of spatial operation) and the complexity of operations are both responsible for cluster formation and strong coherence among test items.

We have formulated three hypotheses about the characteristics of spatial skills of students. Since our previous investigations covered only primary school students (Grades 4-8, ages 10-14), the evaluation of secondary school students' skill levels caused some problems during test development. A further problem was that there were significant performance differences at the same grades within schools of different educational quality. Upon the compilation of our tests, we intended to cover the widest

possible range of skill levels through our test items, by large-sample measurements our preliminary test result expectations were about 50%p at every grade. The outcomes imply that the difficulty of the tests of 5th and 8th graders is appropriate, grade averages were about 50%p. At grades 9 and 12, the students performed better that expected, which probably is a consequence of sampling (including schools that scored high in all educational indicators). By more appropriate sampling, we would have received lower performance averages. However, this assumption can only be confirmed or rejected through further investigations. The relatively high deviation values point at the significant differences between the students' skill levels, while also confirming the appropriate differentiating effects of our tests. Thus, our hypothesis concerning test results was only partially confirmed, as 5th and 8th grades stayed in the range of 50%p, however 9th and 12th grades achieved results over 60%p (H5).

Our investigation confirmed the assumption that spatial problems related to lifelike situations and visualisation both improve efficiency. The complexity of shapes, the figurative or abstract characteristics influenced the success of solution to a great extent. In some cases, it had a higher level of determination than the complexity of spatial operations. The fact that the highest rate of solutions in every age group was identified with the orientation assignments related to spatial problems of everyday life, can be attributed to lifelike problems and / or detailed, colourful visualisations. Besides primary school age groups, formal details of the test items also had a strong impact on the performances of 9th grade students, and they lost their significance only by 12th graders. Assignments requiring reconstruction and assuming an allocentric viewpoint proved to be the most difficult tasks of the tests. According to previous research, the development of the ability to mentally visualise spatial relations from perspectives independent of the actual viewing angle of the beholder is observable already at age seven (Piaget & Inhelder, 1956). Our research showed that this activity may be difficult even for older children. (Séra, 2002; Hegarty & Waller, 2004). Our results also show the issues of stepping out of egocentric perspectives. A rather high percentage of students are not able to form a precise mental visualisation about the image from a viewpoint other than their own. Poor performance observed in reconstruction tasks confirmed my expectations, as a series of operations consisting of several stages had to be solved by creating mental images and integrate them. The tasks having the lowest rate of solutions proved to be suitable to differentiate on higher spatial ability levels, thus helping to identify students with outstanding talents.

The investigation of the development of visual-spatial abilities was an important and timely research objective, as previous studies provide few information about the changes occurring between 10-18 years of age, especially concerning primary school age groups. At the surveys conducted in 2017 and 2019, we have examined whether a significant difference could be confirmed between the spatial ability levels of primary- and secondary school students, implying the advantage of the older age group. According to the outcomes of the 2017 survey, the difference between the visual-spatial abilities of 5th and 9th graders is clearly traceable, 9th grade students performed significantly better at each of the four anchor items. (H6). We have also verified the rate of deviations concerning the subskills, which confirmed the advantage of secondary school students in each of the three cases. The differences between the two grades were significant, concerning the items of mental rotation and spatial orientation, despite the fact that most of the test items of 9th graders were more difficult. The testing studies conducted in 2019 provided similar results, the performance difference at $p<0.001$ level was significant to the advantage of older age group at each of the eight anchor items (H7). Better performance of the students in 12th grade is also characterized through the results achieved at the four subskills. Our statistical analysis indicates that the stronger performance of secondary school students is significant in each spatial components, in spite of the higher difficulty levels of the tests. Although

previously we have assumed that the performances of 8th and 12th graders will be closer to each other than those of the 5th and 9th graders, the average results in of subskills and the final score of the tests show a correlation contradictory to that.

The analysis of the total sample comparing the performances of the students between 10-18 years, we have only included those test items of the four grades that had at least one equivalent pair in the tests of any other grade. The grade averages, calculated from the tests with decreased item count implied the continuous progression of visual-spatial abilities in the investigated age interval. Altogether, we had eight assignments that appeared both in primary and secondary school tests. The results of these showed the pronounced separation of the two age groups, demonstrating significantly higher spatial ability levels of secondary school students. Due to the performances shown on the 17 assignments that were considered equivalent and the increase of test averages, we can assume that the visual-spatial abilities of the children can be effectively developed in every age group within the eight years period studied.

The purpose of the investigation of the background variables and test performance correlations was to find the factors that have the greatest effect on the development of visual-spatial abilities. We have done detailed analyses concerning school related and gender related differences. We have compared the participating institutions in the subsamples of primary and secondary schools. In advance, we have assumed significant performance deviations among schools in the course of spatial ability tests, which was confirmed by each survey conducted in the four grades. The second part of our hypothesis was directed towards selection mechanisms within certain schools. However, significant performance differences between classes only occurred in case of two primary schools. Thus, our hypothesis concerning school quality affection spatial performance was only partially confirmed. In summary, our data imply that the differences among institutions are of greater extent than the ones within them (H8). The presence of selection mechanisms in domestic public education system is also confirmed in connection with other ability tests (Tóth, Csapó, & Székely, 2010; Molnár & Csapó, 2011). According to our outcomes, we can declare that neither primary-nor secondary school education can compensate the significant differences in the visual-spatial abilities of 5th and 9th graders appearing as institutional characteristics, thus these are still present in the same extent in 8th and 12th grades at the end of the educational cycle.

Concerning test averages, we have expected a significantly higher performance of boys in every age group. This hypothesis was only confirmed by the 5th grade surveys; in grades 8th and 9th, the performance of boys and girls was almost identical, and although in 12th grade, boys achieved better results than girls, the difference was not significant (H9). Concerning genders, we can determine that our statistical data confirm the stronger performance of boys, also, we can only present significant differences on the level of test averages, subskills and items in favour of them. Our outcomes are in accordance with Hungarian and international research results, which regularly present data about the higher performance indices of spatial abilities of boys (Bouchard & McGee, 1977; Moffat, Hampson, & Hatzipantelis, 1998; Halpern, 2004; Séra et al., 2002; Chai & Jacobs, 2009; Voyer et al, 2017). Our research also further confirms the other results of previous studies. An important one among these is that gender-based differences are inconsistent, and typically of small extent. They are only observable with certain subskills (Kail, Carter, & Pellegrino, 1979; Caplan et al., 1985; Linn & Petersen, 1985; Okagaki & Frensch, 1994; Miller & Halpern, 2014). In our own research, the data concerning the extent of gender-based differences also fluctuate from grade to grade, for example in respect of test averages, or items on spatial orientation, where the better performances of boys and girls alternate. Our background questionnaire also confirms the fact that it is the boys who are more intensively involved

in the activities developing spatial skills (Halpern, 2000; Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005; Quaiser-Pohl, Geiser, & Lehmann, 2006; Spence, Yu, Feng, & Marshman, 2009; Yılmaz, 2009; Reilly, Neumann, & Andrews, 2017).

Our empirical data confirm our hypothesis concerning the correlations of spatial ability test performances and school marks. There are weak and medium correlations between the test results and the marks received in various subjects. Similarly to our previous studies, the spatial ability test performances of 5th and 9th graders show the strongest relation with maths marks (H10) (Kárpáti et al., 2015). Our outcomes confirm previous research that, to various extent in different age groups, there are certain types of activities that support the development of spatial abilities. Most studies confirm the positive effects of action computer games (Feng, Spence, & Pratt, 2007; Boot, Kramer, Simons, Fabiani, & Gratton, 2008). Our survey does not confirm this correlation in any of the grades, which can also be attributed to the fact that different gender-based preferences concerning this game type could significantly distort the outcomes (in both age groups, the popularity of these games was three times higher among boys than among girls). The popularity of strategic games implies significant positive correlations with spatial cognition test performances in both 5th and 9th grades. Among ninth graders, those preferring logic and construction games achieved higher scores (H11). Our hypothesis concerning spare time activities is confirmed by our data in respect of sports- and handicraft activities, art club participation, construction and logic games , the only exception being DIY construction activities that showed no correlations with our test results (H12). Concerning forms of activity, the frequent use of construction games in childhood, and the favouring of logical puzzles positively affected spatial cognition test outcomes in both age groups.

Our research confirms in multiple aspects that visual art education can have an important role in the development of spatial abilities. Besides the positive effects of participation in art clubs and handcrafting sessions, the frequent use of image editing software products also improved spatial cognition test results in 9th grade. The significance of building and constructing activities concerning the development of visual-spatial abilities receives special attention in Hungarian art education curricula, as emphasized in several studies. This is also confirmed by our own research (Kárpáti, 1992, 1995; Hewitt, 2001; Richardson, Jones, Croker, & Brown, 2011; McKnight & Mulligan, 2012; Nath & Szűcs, 2014; Pataky, 2012, 2017).

## EFFECTS ANALYSIS OF A VISUO-SPATIAL SKILLS DEVELOPMENT PROGRAM BASED ON CONSTRUCTION ACTIVITIES - METHODS

### *Composition of the sample and assessment instruments of developmental program*

Participants of the experiment were 1st and 2nd grade students of the Ybl Miklós Faculty of Architecture and Civil Engineering of Szent István University (n=299). The programs of study that the students engaged in iwere Architecture (n=225) and Civil Engineering (n=74). The experiment was conducted during three semesters, and the development programs were tested with the participation of 122 students altogether. Our control group consisted of 177 students, who visited traditional freehand drawing courses.

The effects of the developmental program was tested with a pre- and post-testing design. The assessment instruments employed was the Spatial Skills Test by Séra, Kárpáti and Gulyás (2002). The tests were taken on paper, during 50 minutes periods. Every participant had the chance to solve the

tasks in arbitrary order. The interpretation of the spatial operation tasks was aided by examples. Correlations of visual-spatial information processing and problem solving were revealed by a questionnaire, recorded observation and the analysis of visual documentation. In the last semester, the participants were required to lead a working diary, which complemented our research with further valuable data.

*Description of the training*

The development experiment was conducted along three semesters, namely the autumn and spring semesters of 2014/2015, and the spring semester of school year 2017/2018. The seminar involved 13 face-to-face sessions, in the framework of 2 periods weekly. The primary purpose of this research was to determine the efficacy of the development of visual-spatial abilities through creative construction tasks, and by solving design problems. The theoretical framework of the developmental program was STEAM education: the integration of Science, Technology, Engineering, Arts and Mathematics. We employed the creative problem solving methodology of arts education for skills development. Since in the course of pre- and post-testing I employed traditional instruments of spatial ability testing, focusing on cognitive aspects (mental manipulation), the effects of the program could also demonstrate far transfer.

In the control group, we developed the students' visual-spatial abilities according to the traditional curriculum, incvolving freehand study drawings. Students mainly solved two-dimensional spatial visualisation assignments through graphic techniques (e.g. reconstructions based on Monge projection).

In the experiment group, we used the project method, organizing the tasks around a design issue. Four programs were tested in the course of the research, each of them representing changes along different parameters. In the Experimental Groups 1 and 2, we determined the spatial problems to be solved, the techniques to be implemented along the task solution process, and the steps for solving the tasks. The students completed a set of tasks containing three-dimensional modelling in both groups, but they worked in different study environments. In Group 1, the works were created in real, while in Group 2 in virtual environment. The program was piloted during the autumn of 2014/2015 academic year and was repeated in a similar form, applying minimal substantive changes during the spring semester, with new students involved. In Groups 3 and 4, the students also completed spatial problems related to three-dimensional modelling. However, they had the opportunity to individually determine the subject, the steps of task solution and the materials and instruments to be used.

## EFFECTS ANALYSIS OF A VISUO-SPATIAL SKILLS DEVELOPMENT PROGRAM BASED ON CONSTRUCTION ACTIVITIES - RESULTS

This innovative educational intervention proved that visual-spatial abilities can be effectively developed through creative construction tasks (H13). Significant progress can be achieved through the innovative tasks, professorial mentoring, and appropriate guidelines (Babály & Kárpáti, 2016a, 2016b; Babály, 2017). Participants showed almost identical performance growth during the developmental program implemented in the first semester and its two iterations in further semesters. The effect size of the development (Hedges' g 0,72) can be considered good, according to the comparison with the average effect size of the 217 spatial skill-development programs (Hedges's g 0,47) investigated in the

meta-analysis of Uttal et al. (2013). The successful completion of test assignments was not influenced by the fact, whether the correct answer had to be marked or drawn. The source of difficulties was item visualisation: assignments without visually displayed reply options provided weaker results.

The rate of development proved to be independent from gender, university programs (Architecture or Civil Engineering) and related studies at secondary school (H15). There were no traceable differences between those who solved their tasks through modelling in real or virtual environments, therefore our hypothesis concerning this variable proved to be incorrect (H14). A multitude of research confirmed that modelling, constructing activities develop spatial skills more effectively, than drawing (e. g. Kárpáti, 1992; Katona, 2012). Our outcomes reinforce this point of view: significant differences in development were only traceable between the experimental and control groups using two- and three-dimensional visualisations.

The outcomes of the background questionnaire highlight the motivational power of creative construction activities, whose potential could be used in the field of development of visual-spatial abilities to a greater extent. Experimental attitudes and creative approaches to problem solving through integrating STEAM domains are professional expectations towards future engineers at present, therefore, this result should not be underestimated (Bequette & Bequette, 2012; Yakman & Lee, 2012). The skills development methods of arts education could also result in attracting women into science, engineering and technology professions struggling with labour shortage where their participation is significantly underrepresented.

## CONCLUSIONS AND FURTHER RESEARCH DIRECTIONS

We successfully fulfilled our major research objective concerning the evaluation and development of visual-spatial abilities. The assessment instruments we developed have been proven valid indicators of developmental levels of spatial performance are valid and reliable tools for revealing the developmental stages of 10-18 year old students and are freely available for all Hungarian schools. Technology-based testing supports the work of teachers, and can be easily integrated into everyday evaluation practice. The development of such tools is especially important in the field of visual art education, where the currently used holistic form of evaluation is neither suitable for tracing the development of certain ability elements, nor does it yield useful data for the development of pedagogical strategies necessary for their enhancement (Bodóczky, 2000; Kárpáti & Gaul, 2011; Kárpáti et al., 2015).

The analysis of the outcomes points at areas in the need of further research. With our measuring tools, we aim to extend the scope of subskills with accurately described developmental levels, while at the same time we consider the involvement of 6-10 years age groups as well to provide an overview of the genesis and development of this important skill cluster. Although the increased quantity of visual information emphasizes the significance of visual literacy necessary for reception and processing, further research will decide if the evaluation of certain construction subskills of visual-spatial skill cluster can be evaluated through similar online tests. Certain parts of the studies presented in the theoretical chapters, as well as our own investigation suggest that the development of visual-spatial and other cognitive skills may be closely related. The investigation of these correlations could constitute a new direction for visual arts education research. Our background questionnaire helped identify which activities promote the development of spatial cognition most. We have identified the circle of activity forms requiring more detailed or methodically different investigations. This last study reported was conducted among university students and it confirmed that visual-spatial abilities can be effectively developed using the methods of arts education. Recently, lesson hours for Visual Culture,

the discipline for visual arts education has been decreased again in Hungarian public education. The number of lesson hours is limited to one session per week in Grades 5-10, and 45-minute sessions are highly inadequate for the development of skills through art and design practice. Apart from the skills study agenda, the major educational policy objective of my research was to reveal the significance and the numerous and varied development impacts of visual-spatial thinking, and thus support educational efforts aiming to increase the prestige and accessibility of visual art education at schools.

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