Spatial Skills of Preschool Children supported by Game Application

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***Abstract*—**In recent years, there has been an increasing interest in technology and its use in education. Many studies on mathematical and early mathematical competencies have been conducted in order to help establish the new field in education, pedagogy and also in science. The attitude towards how to define mathematics and how to teach mathematical competencies has been changing immensely during the last decade. Mathematical skills and spatial skills correlate with success in many areas. Comprehensive mathematics curricula targeted at preschool-aged children define knowledge in the new framework of early mathematical competencies. ICT might bring some critical benefits to early childhood education and to development of particular human cognitive abilities and skills. In the paper we focus on a research analyzing the benefits and impact of an educative multimedia application, a story-based game with contents related to visual differentiation and spatial skills, on preschool aged children's spatial skills.

***Keywords*—**Mathematical competencies, multimedia application, preschool aged children, spatial skills.

I. Introduction

THERE has always been a lack of attention in the field of spatial skills in education. Nevertheless, within last decades spatial skills have gained increasing acknowledgement as an important aspect of intellectual ability. Researches bring sufficient evidence that spatial skills are foundation for mathematical skills and their influence in human life is remarkable. Positive correlations were found between spatial skills and mathematical achievement. Moreover, spatial skills are malleable and can be supported.

It is also evident that spatial skills are already presented by small children being strong predictor for later achievements in mathematics. Thus, the importance of spatial skills as a gateway to better mathematical skills has had an increasing trend during the last decade.

Furthermore, these skills are also necessary for success in the science, technology and engineering domains. A lot of research started to focus on a new attitude to spatial skills and training which can help children not to be left behind. In this context ICT are also considered to provide new learning opportunities.

Approach to teaching mathematical skills has changed dramatically in the last decade. Newly promoted competency model involves more complex area than only acquiring of math skills and numerical rules. As mentioned above mathematical skills are strongly affected by spatial skills. ICT can bring benefits to the development of new mathematical concept- mathematical competences, where well developed spatial skills also belong.

On the other hand, the use of ICT and educational applications might present certain risks in education of preschool children where the role of ICT educational tools might be exaggerated. Therefore, we want to analyze relationship and correlations between specific variables and their impact on overall mathematical competences.

II. Current state of the field

Recent research is bringing new evidences about interconnections between domains of human thinking. New interdisciplinary research indicates relations among education, neuroscience, psychology and neurophysiology. The movement from the previous attitude, which considered mathematics mostly as counting and capability to operate with numbers is disappearing, and new concept of mathematical skills and competences is coming with changes in the life of society.

Mathematical skills and spatial skills correlate with success in many areas: chemistry, engineering, science, geology and etc. Many new science, technology, engineering and math (STEM) related positions have been emerging last years and employees and workers have to face new demands of these new job positions which require more technical and mathematical capability than the previous ones. Young children's mathematical development and proficiency has become an important predictor of later labor market success [1], [2].

An increasing number of research demonstrates that other abilities not traditionally viewed as ''mathematics skills,'' such as spatial skills and executive function skills, make significant contributions to young learners' overall mathematics performance [3]–[5]. Empirical work states that children's early competencies set the course for their later achievement, the mathematical competencies which children demonstrate at school entry are considered as the strongest predictors of their

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later school achievement [6]. Researchers bring evidences that spatial skills are essential base for later developing of mathematical skills [5], [7]–[8]. Research findings also bring the results that information and communication technologies (ICT) have the propensity to increase children’s motivation, interest and engagement in literacy and learning [9]. The use of technology is more interdisciplinary approach which can allow teachers to act primarily as coaches while children motivate themselves to grow as learners [10].

A. Malleability of Spatial Skills

Based on previous research there is evidence of malleability of spatial intelligence. The evidence of malleability is quite encouraging and the research focused on this issue has repeatedly confirmed similar outcomes in terms of possibility to enhance and support this cognitive factor by training and specific tasks [11]–[14].

Different instructional programs, concrete materials, manipulatives, visual treatments, sketching activities, technologies, computer aided-design courses, and toys are considered to be effective tools for improving individuals’ spatial skills [15]–[17].

For instance, Sorby [18] provided a review of pre-college activities in which students with well-developed spatial skills were interested. Based on researches, which he had compared and analyzed, he concluded that follow activities to develop spatial skill are: 1) playing with construction toys as a young child, 2) participating in classes such as shop, drafting or mechanics as a middle school or secondary student, 3) plying 3-D computer games, 4) participating in some type of sports, 5) having well developer mathematical skills. He described strategies that educators should adopt to develop these skills in their engineering undergraduate students such as sketching, drawing 3-D objects and using hand-held models.

He claimed, that only one semester of a spatial training course improved spatial skills, and gained exceeded up to +15 IQ points.

Uttal [8] conducted an exhaustive search in 2545 relevant studies on spatial training. He reconfirmed Sorby’s results. It was shown that overall effect size of training was mostly +7 IQ points. This result is still significant to be taken in account because this is considered a moderate effect size and indicates that spatial skills are malleable.

A lot of different training methods (e.g., playing video games, practicing spatial tests, or taking an engineering graphics courses) improved spatial skills. Variety of training methods can substantially improve spatial skills. To summarize, the available evidence indicates that spatial skills can be improved, and they have impact on performances in STEM learning. [19]– [20].

There are several studies concerning the development of spatial skills over different ages. For instance, in above mentioned research Sorby was conducting study in which he involved adults. Most of other studies also involved adults, secondary school or university students. Only small body of studies focused on younger children from 6 to 10 years old [21]. Studies involving preschool children are still very rare and mostly focused on finding what sub-factor of spatial ability appears in infants [17]. Therefore, we concentrate on investigating malleability of spatial skills through the use of ICT in preschool age in our research.

B. Links between spatial and mathematical skills

Spatial skills are critical for mathematical performance as previous researches show. Authors state in [7] that *The relation between the spatial ability and mathematics is so well established that it no longer makes sense to ask whether they are related.* According to a factor analysis by [22] the significant spatial predictor of mathematical ability changes during kindergarten, 3rd, and 6th grades. There might be an explanation that acquisition of different mathematical skills across grades relies on different types of spatial expertise. Golinkoff states in [23] that strengthening of spatial-mathematical links with age is consistent with a causal chain of events whereby spatial skills provide a foundation for mathematical learning. *The relation between spatial and mathematical skills may appear to strengthen over time because children with good spatial skills use them as they acquire new and more advanced mathematical skills.* [23]

C. Spatial skills links to achievement in STEM

Spatial skills are necessary for success in the science, technology, engineering and math domains. Recent research indicates that spatial skills play a unique role in predicting which students pursue STEM-related careers. Wai, Lubinski and Benbow [24] found on a large nationally representative sample (n ~ 400,000) that spatial skills assessed in high school predicted which students would enter a STEM career 11 years later.

Although some educational systems already started to focus on development of spatial skills deliberately, there is still a lack of such activities. Some researchers call for more active attitude and faster implementation of different supporting means of spatial skills in the classrooms. There is still a lack of specific knowledge of how spatial thinking may be best infused across curricula and how to optimally incorporate new technologies in order to enhance better results of children [17].

III. Research Study

A. Problem Statement

The paper reports the pilot study of our research investigating influence of new technology, specifically use of tablets with particularly developed educational game application ADAM, on children´s spatial skills development. The research is part of a doctoral study research focusing on cultivation of early mathematical competencies with the use of digital technology.

B. ADAM application

Game Application was developed in Unity environment. It can be run on touched screen devices, tablets, PC and interactive boards. The ADAM game application is designed as the comprehensive story in which a child participates by playing to fulfill the main tasks. The game is divided into 17 tasks which contain wide variations of subtasks. Each task has subtasks which are divided into low, medium, and high level based on set up criteria of difficulty. There are principles of adequate challenge that help a child to be motivated for trying out the challenging or difficult tasks. For instance, the comprehensive story has a narrative guide which gives instructions, the results and provides a child with the feedback to the chosen solution. Furthermore, different subtasks of each task with gradually increasing difficulty level are shown to a child by every playing session. The difficulty level of subtasks is than automatically adjusted according to child´s previous results in playing.

The ADAM application enables to collect data of child´s achievement in every task, namely data following the quality of responses, time spent on a task solving and working speed.

There are particular parameters influencing level of spatial skills included in the application. The parameters such as spatial orientation and position are incorporated in specific tasks. Also parameters of pattern comparing, pattern exploration and parameter of composing and decomposing of geometric shapes are involved. The last parameter embedded in specific tasks is transformation (reflecting, translating and rotating of subject).

The principles of effective and affective learning are also used and were incorporated in ADAM application. According to the results of children the game shows child a subtask of adequate level. There is a score logarithm set up which either goes for more difficult level or decreases the level if a child fails a few times. There is a principle of adequate challenge that should help keep a child being motivated for trying demanding task.

Very clear evidence about children´s spatial language and their relations to their spatial skills and thus mathematical skills have been provided in recent researches [25]-[26]. According to this fact, the whole story has a narrative guide which gives a child instruction using terms which are connected with spatial skills and with early mathematical skills (seriation of orders, directions, prepositions, terms like bigger, smaller, equal, nothing, order, compare etc.), says the feedback to each task. In the case a child fails, the correct solution (with the help of animations) is provided to him.

C. Purpose of the Study

The main objective of our research has been to find out to what extent the game application ADAM has impact on the level of spatial skills. Differences in performance in particular domains between boys and girls were also subject of our interest.

D. Objectives of the Study

The objectives of the study are as follows:

- To assess the current level of spatial skills.
- To find out to what extent the game application ADAM has impact on level of spatial skills.

IV. PILOT STUDY

A. Participants in pilot study

Preschool children from a kindergarten in the Czech Republic were participants in the pilot research. 39 children were included into the target group and they were in age from four until six years. The pilot group consisted of one experimental (No 19) and one control group (No 20).

B. Research Methodology

Assessments of spatial skills in the pilot study were conducted with the help of the standardized psychological SON-R 2,5-7 test suitable for measuring general intelligence in children between the ages of 2.5 to 7 years.

Three subtests, Mosaics, Puzzles, Patterns, of the test battery SON-R 2,5-7 were chosen.

All these subtests belong to the subtests which reflect the level of spatial relations and spatial skills. They measure abstract and concrete reasoning, spatial skills and visual perception. (Remark: The sub-tests of the SON-R 2,5-7 test are grouped into two types: reasoning tests such as Categories, Analogies and Situations and spatial performance tests such as Mosaics, Puzzles and Patterns. Perceptual, spatial and reasoning skills play role in all sub-tests. The performance sub-tests can be found in a similar form in other intelligence tests although in other tests these require verbal directions.)

In the time between pretest and posttest the developed game application ADAM as a treatment tool was used.

C. Data collection

Quantitative data were collected two times. The first collection of data was conducted in the pretest and level of spatial skills was measured in preschool children. The second collection was conducted four months after the children had been using game application. The same test battery was used as in the pretest. Both pretest and posttest data were collected during personal visits of the researcher.

Before the research and collection of data started the general parental consent for children who took part in the research, was collected. The parents were informed about the etic rules of planned research. The introduction workshop was prepared for head teacher and teachers in order to familiarize them with the ADAM tool. Twenty tablets, chargers and headphones were provided to the kindergarten.

Before the treatment phase started, the classroom environment was prepared, and teachers underwent the training. The training consisted of information about the application and its content. Teachers were instructed how to use and how to manipulate devices. The schedule of playing sessions was discussed and clarified with teachers. The teachers provided the name list of children. After randomization of the sample, each child was given their own profile in the tablet under their name and always played under given profile. It enabled researchers to evaluate the particular results in playing and performances in the game. Each child had approximately 25 play sessions in total. The experimental group used ADAM application in the time which suited to the common schedule of the classroom.

V. Results and Discussion

Focus group of the pilot study consisted of 39 children aged from 4 to 6, selected from the same class of a chosen kindergarten. Children were assigned randomly to experimental and control groups. This study was conducted as an experiment with pretest, application treatment, and posttest model.

A one-way analysis of covariance (ANCOVA) was conducted for this study. The dependent variable was the children' achievement scores in posttest and the covariate was the children' achievements scores in pretest of chosen relevant tasks of standardized battery test SON-R (Mosaics, Puzzles and Patterns).

A preliminary analysis evaluating the homogeneity-of-regression assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly. The results received from experimental and control group showed that experimental group playing with game based application achieved higher scores and performed higher in the posttest.

By the first spatial task (Mosaics) the p-value (0.002) of above ANCOVA is lower than assumed 0.05 which indicates that mosaic scores of children are having significant difference between scores of control and experimental group students in both pretest and posttest results. 31.7% ($\omega2 = 0.317$) of the total variance was accounted, which can be considered moderate effect size.

By the second chosen task (Puzzles) the p-value (0.002) again falls under the assumed significance 0.05. According to this acquired result, it's clearly evident that there is significant difference that exists between the scores of both control and experimental groups in Puzzles task. 34.6% ($\omega2 = 0.346$) of the total variance was observed, that can be considered also as moderate effect size.

In Pattern task, third variable, the p-value (0.001) is lower than assumed significance 0.05. Therefore it is concluded that scores of students, of both experimental and control groups differ significantly. 50.4% ($\omega2 = 0.504$) of the total variance was calculated. We consider such a result as large effect size because it's higher then moderate effect size value.

The experimental group achieved better results in posttest phase in all three subtests of measurement tool and scored significantly better. ADAM game application proved to influence the level of children´s spatial skills.

VI. Conclusion

Focus on the usage of technologies in school education has increased in the last years. [27] - [29]. There is a growing need to use smart and educational applications for the development of cognitive skills [30], [31]. There is a growing need to find appropriate technological resources in pre-school education. However, ICT is being promoted in pre-school education rather rarely, as there is a lack of professional work to assess the impact, benefits and also withdraws of ICT in pre-school children.

In order to analyze the impact of ICT in the chosen area of cognition and spatial skills, the educative application ADAM was created. ADAM application is conceived as a game based on psychological and special pedagogical knowledge as well as on the needs of preschool children.

The pilot study was carried out at a kindergarten for 4 months with 39 children. The comparison of the experimental and control results between pretest and posttest indicated improvement in spatial skills of the children in the experimental group.

Last month the main research carried out at one chosen kindergarten with 70 children started. It will include not only data collection concerning spatial skills, but also data about visual perception and motivation. All these aspects belong to the newly defined concept of mathematical competences.

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