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STIMULATION OF EXECUTIVE FUNCTION 'SHIFTING' IN TEACHING MATHEMATICS

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ABSTRACT. *Executive functions are mental processes which manage, control and organise human cognition. They represent the fundamental level of mental functioning. The research team from the Faculty of Education, University of Presov is designing a comprehensive program for stimulation of executive functions of pupils aged 9-10 years within the APVV project scheme. Three executive functions: inhibition, working memory and shifting were specified to be stimulated by the program. Mathematical component of the program is focused on stimulating and reinforcing pupil's executive functioning on the background of mathematical curriculum. This paper provides an outline for designing tasks aimed at stimulating the executive function of shifting. Shifting is the ability to switch fluently between multiple sets of cognitive operations. The authors also propose the guidelines for assessing and interpreting the performance of pupils in such tasks.*

KEY WORDS: *Executive Functions, Primary Mathematics, Cognition, Teaching*

CLASSIFICATION: *C32, Q32, U92*

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Introduction

Child's ability to learn as well as the ways to enhance child's cognitive functioning and devising efficient tools to develop child's thinking have become the area of interest, in recent years, not only for psychologists but also for teachers. In a constructivist approach to mathematics different mathematical concepts and their representational models are progressively developed in the minds of every pupil [4]. Such mathematics should be understood as a process of constructing knowledge; a specific cognitive activity aimed at developing thinking. The traditional scope of school mathematics offers many ideas for designing activities which build upon knowledge construction and thus develop cognitive functions and processes.

Developing cognitive functions has a considerable influence on the ability to learn. The above mental functions are referred to as executive functions. Specific level of executive functioning is a prerequisite for the ability to learn. Executive functions are mental tools involved in processing the contents of a school subject [5].

Findings in neuropsychology and behavioural sciences, researches into artificial intelligence and information processing as well as the theory of processing information indicate that it is useful to examine the processes of learning from the cognitivist perspective, the domain in which *executive functions* play a key role [5]. Executive functions represent the fundamental level of mental functioning in that they control and organise the interaction of cognitive functions [7]. Executive functions, in relation to cognitive functions, should be perceived as mental processes which manage cognitive functions.

The research team from the Faculty of Education of the University of Presov is trying to design a battery of tasks aimed at stimulating a selected range of executive functions in pupils aged 9-10 years as one of the aims within the project of APVV scheme. The battery

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of tasks is designed within the primary math curriculum. The individual tasks are gradually elaborated and structured so as to develop a comprehensive stimulation program. Stimulation program in mathematics is meant to be a set of tasks, stimuli and activities designed to stimulate and reinforce mental processes which involve one or more executive functions on the background of mathematical curriculum.

Based on the findings of this project the following three executive functions were specified for the stimulation program. They are: inhibition (attention control), working memory and cognitive flexibility (shifting). The set of tasks developed to stimulate working memory was presented in the article [6].

This paper deals with the design for a stimulation program aimed at stimulating the executive function of *shifting*. The shifting is the ability to switch fluently between multiple sets of cognitive operations. This function is necessary for flexible thinking and action, since it enables to change flexibly the perception and execution of a number of divergent mental operations when solving a problem. Opposite to shifting is so called perseverance, i.e. a rigid adherence to the established way of reacting irrespective of any alternation in the requirements resulting from the situation or task. The tasks on shifting are based on switching between at least two different solutions performed practically at the same time on an identical set of elements or they can include switching between the different criteria for a solution. Since the difficulty of "switching" is positively associated with the reaction time, it is appropriate to include the speed rate when increasing the difficulty of such system.

Several examples of shifting tasks used for testing pupils' executive functioning are described in the literature. For example, St Clair-Thompson & Gathercole [8] introduced *the plus–minus task*. It consists of three lists of 30 two-digit numbers pre-randomized without replacement. On the first list the participants were instructed to add 3 to each number. They were told to complete as many as possible within 2 minutes. Within the same time limit, on the second list, the participants were instructed to subtract 3 from each number, and on the third list the participants were required to alternate between adding and subtracting 3 from the numbers. The cost of shifting was then calculated as the difference between the number of correct answers given in the alternating list and the average of those in the addition and subtraction lists within the given time periods.

Another example of shifting task, introduced in [8], is *the local–global task*. It is a sets of figures in which the lines of a global figure (for example, a triangle) are composed of smaller local figures (for example, squares). On one list, participants were instructed to record the number of lines in the global figure (that is, one for a circle, two for an X, three for a triangle, and four for a square). They were instructed to complete as many as possible within 2 minutes. Within the same time limit, on the second list participants were instructed to record the number of lines in the local figure, and on the third list participants were required to alternate between recording the number of lines in the local figure and recording the number in the global figure. The cost of shifting was then calculated as the difference between the number of correct answers given in the alternating list and the average of those in the local and global lists within the given time periods.

The *Wisconsin Card Sorting Test* (WCST) was designed by D. A. Grant and E. A. Berg [2]. The new manual of WCST is described in [3]. It operates with a series of cards identified by three dimensions: colour, shape and number. Four key cards are placed in front of the child, each with a different shape (triangle, star, cross, or circle), different numbers of shapes (one, two, three, or four), and different colours (red, green, yellow, or blue). The child is asked to pick up the first card from a pile of cards and match it to one of the key cards by arbitrary criteria (colour, shape or number). If the child matches the card

by the correct sorting criteria the child should continue sorting subsequent cards by the same dimension. If the matching dimension was incorrect, the child should match the next card by a different dimension, in an attempt to identify the correct one. When the child has maintained the correct sorting dimension for 10 consecutive trials, the matching criteria is changed without explicitly telling the child. It is the child's task to use the feedback to determine that a previous matching criteria that was correct is now incorrect and that a different matching criteria needs to be used. This procedure continues until the child completes six category changes or runs out of cards (total = 128 trials). Results from the WCST show that the main difficulty for children with lower level of mathematical ability is with inhibiting a learned strategy and switching to a new strategy [1].

Stimulation Program: Mathematical Traffic Lights

Following is a proposal for the stimulation program called Mathematical Traffic Lights inspired by Wisconsin Card Sorting Test [2]. Such stimulation program can be applied within teaching mathematics to automate basic connections in mental arithmetic. It is aimed at developing skills in the range of basic mathematical operations with natural numbers. The emphasis is on stimulating the executive function - shifting. It utilises visual presentation and other possibilities made available by ICT and visual educational technologies especially the dynamics of animation (stimulation program can be prepared as a PowerPoint presentation on an interactive whiteboard, or, if the school is sufficiently equipped, it may be posted on website for pupils using tablet). The stimulation program consists of four modules (M1) - (M4) with their modifications.

(M1) This module is designed for a frontal work with pupils as a math warm-up. The basic scheme is as follows:

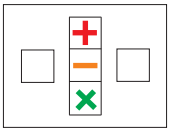

Figure 1

The numbers are inserted into the empty boxes and the tasks are activated by switching a "traffic light". Pupils gradually solve a set of tasks (the number of tasks is arbitrary by the teacher).

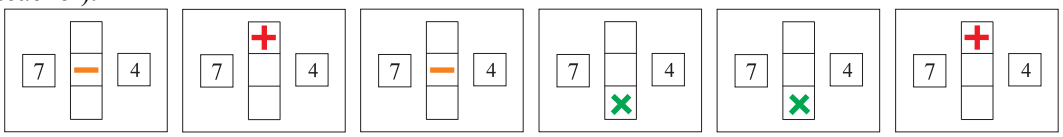

Figure 2

In the next set of tasks the colour of the sign which indicate the operation is changed. In the last set of tasks switching traffic lights is combined with a changed pair of the numbers.

Further modifications of the basic scheme may look like this:

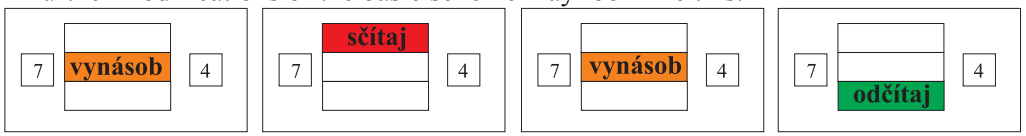

Figure 3

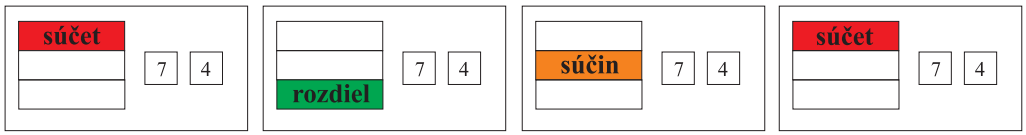

Figure 4

(M2) The module can be used in frontal work with pupils as a math warm-up. The basic scheme is as follows:

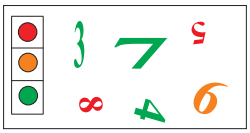

Figure 5

The pupil's task is to name the numbers of the same colour which appear on the traffic light. In the first set of tasks the numbers remain the same only the traffic lights are switched over. In the next set of tasks switching over the traffic lights is combined with changing the numbers. Modifying the above scheme we obtain mathematical exercises aimed at developing basic mathematical operations with natural numbers. The basic scheme is the following:

Figure 6

The pupil's task is to multiply the numbers of the same colour that appears on the traffic light. In the first set of tasks the numbers remain the same only the traffic lights are switch over. For example:

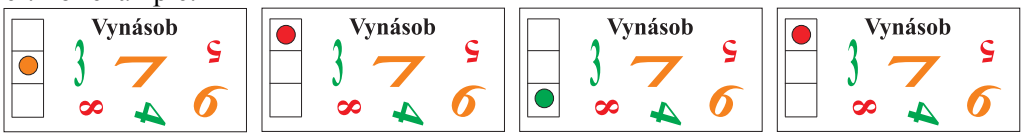

Figure 7

In other tasks the colour of the numbers is switched simultaneously with the change in the traffic light by which we always obtain new pairs of the same colour. Finally, the pupils are presented a set of tasks in which the numbers are changed. Further modifications of this scheme can be obtained if the operation is changed or a geometric figure is included or using two traffic lights while switching between colours and characters which denote the operation and so on. The basic scheme may look like this:

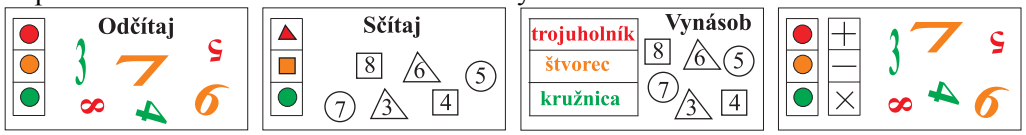

Figure 8

(M3) This module is designed for individual work with pupils. The basic scheme is as follows:

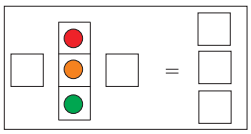

Figure 9

The numbers are inserted into the empty boxes. The task is specified by switching traffic lights, for example:

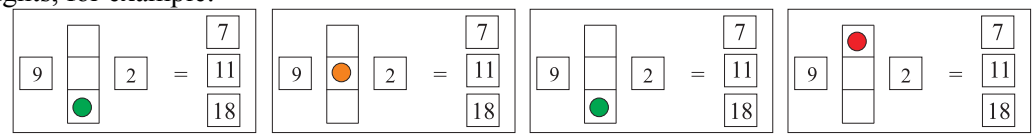

Figure 10

Each colour is assigned to one of the operations $+, -, \times$ (e.g. red $+$, green $\times$ and orange $-$). After the traffic light is on, a pupil selects one of the numbers in the right column after which he is given a feedback whether he had chosen the right or wrong number. The pupils' task is to determine which operation is assigned which colour. The pupil can be informed in advance that each colour represents one operation, but the legend is not disclosed.

The most challenging modification of this scheme is when switching the traffic light is combined with the change of the number at the same time.

Pupil's performance can be interpreted in two ways.

1. The pupil is given thirty tasks in three rounds, ten tasks in each round. After each round the legend is changed and the student is informed of that. The aim is that the pupil identifies the legend and adopts (switches to) a new rule. Pupil's achievement is assessed on the basis of the number of correct answers, whereas only the last five tasks in each round are considered. The first five tasks in each round serve as calibration so that the pupil is left room to detect a rule.
2. An appropriate time limit is set in advance. The task is then presented to pupils. When the administrator sees that the pupil discovered the rule and determined the right solution in, say, four consecutive tasks, the rule is changed. Performance of the pupil is then assessed by the number of discovered rules within the set time limit.

(M4) The basic scheme is as follows:

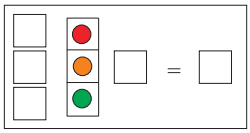

Figure 11

The numbers are inserted into the boxes and the tasks are given by switching over the traffic lights, for example:

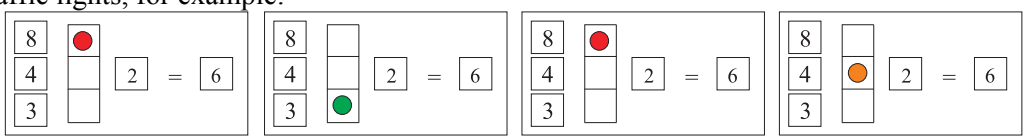

Figure 12

Like in the module (M3), each colour is assigned one sign of operation $+, -, \times$ and the pupil is not familiar with the legend. The pupil selects one of the numbers in the left column and after each choice he learns whether the chosen number was right or wrong. The pupil's task is to discover which colour denotes which operation $+, -, \times$. Performance of pupils can be interpreted by any of the two methods outlined in the module (M3). The more demanding modification of this module can be obtained when switching over the traffic light is combined with the simultaneous change of the number.

Conclusion

The paper presents the proposed set of tasks intended for stimulating the executive function "shifting". The stimulation programs Mathematical Traffic Lights and PIN Code [6] are designed as basic schemes focusing on arithmetic content area. The authors' intention is to adapt both stimulation programs to other content areas of mathematical curriculum and to expand the range of stimulation programs to incorporate other executive functions.

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