FORMATIVE ASSESSMENT USING THE "THINK ALOUD" METHOD FOR THE DEVELOPMENT OF EXECUTIVE FUNCTIONS AND MATHEMATICAL PROBLEM-SOLVING ABILITY

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Abstract

Executive functions are a group of higher cognitive abilities that allow individuals to program, control, and direct their behavior and thought towards a goal. The construct of executive functions conceptually resembles to of metacognition and self-regulation, as the three terms describe the ability to monitor and control behavior. Several studies have shown that executive functions are strongly related to mathematical skills and the mathematical problem-solving ability, yet only a few educational interventions have been designed and implemented to improve executive functions through the process of solving mathematical problems. This study aims at investigating the contribution of the "think aloud" method to improvement executive functions by solving mathematical problems. For this purpose, an intervention program was designed and implemented. This program was based on two important educational approaches, the teaching of cognitive strategies through personalized intervention and the "think aloud" method. Seventy two school-aged students participated in this study; thirty six of themreceivedthe intervention program which lasted for 12 weeks. The results demonstrated that students improved their ability to solve mathematical problems showing that the "think aloud" method can be an important educational tool for the development of students' metacognitive awareness and self-regulation of learning. Nevertheless, although their executive functions did not appear to improve through this program, it was shown that students developed their ability to use them more effectively when carrying out cognitive work.

Keywords: Executive functions, school-based intervention, mathematical problem-solving, "think-aloud" method

1. INTRODUCTION

The purpose of this article is to present an intervention program for the cultivation of the executive functions of school age students through a formative assessment when dealing with mathematical problems. Executive functions are superior cognitive skills that allow individuals to plan, control and direct their behavior and thought towards a goal (Garon, Bryson, & Smith, 2008; Jurado & Rosselli, 2007; Miyake & Friedman, 2012). According Zelazo and Müller (2002), executive functions are psychological processes that are involved in the conscious control of the individual's thinking and behavior especially in solving a problem (Zelazo & Frye, 1998). The unifying model of Miyake and his associates (Miyake et al., 2000) has extensively been used in the literature According to this, executive functions are interrelated yet discrete capabilities. Three basic functions are recognized: a) updating or working memory, which is the ability to hold and at the same time cognitively process the information, provide feedback and use it in performing cognitive works, b) inhibition or inhibitory control, relating to the ability to hold back automatic thoughts, behaviors and impulses and c) mental shifting or cognitive flexibility, which allows shifting attention flexibly to modify the way of thinking and adapting behavior to new stimuli or unexpected changes (Diamond, 2014; Miyake & Friedman, 2012; Miyake et al., 2000).

1.1Executive functions in education

The importance of executive functions for the students' smooth adaptation to the school environment as well as for the attainment of high learning goalshas attracted research attention(Best, Miller, & Naglieri, 2011; Blair & Razza, 2007; Jacob & Parkinson, 2015). Several studies have shown that executive functions are significantly developed during school life, when they participate in a structured and demanding learning environment (Duncan et al., 2007; Fuhs, Nesbitt, Farran, & Dong, 2014; Welsh, Nix, Blair, Bierman, & Nelson, 2010). Moreover, in many studies executive functions have been found to explain students' performance in the areas of reading, writing and mathematics(Best et al., 2011; Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Bull & Scerif, 2001; Clements, Sarama, & Germeroth, 2016; Fuhs et al., 2014; Jacob & Parkinson, 2015).This relationship has been shown to be stronger with mathematical ability, and each executive function seemed to be related with distinct mathematical abilities in different ways(Bull & Lee, 2014; Clements et al., 2016; Latzman, Elkovitch, Young, & Clark, 2010; Viterbori, Traverso, & Usai, 2017). The relationship between executive functions and mathematical skills can be explained by the fact that solving mathematical problems requires higher cognitive and metacognitive abilities(Bryce, Whitebread, & Szűcs, 2015; Clements et al., 2016; Cragg & Gilmore, 2014; Roebers & Feurer, 2016; Viterbori et al., 2017).Mathematical skills are complex in structure and continue to develop by acquiring more and more mathematical knowledge(Agostino, Johnson, & Pascual-Leone, 2010; Fuhs et al., 2014; Roebers & Feurer, 2016).

An important research issue in the area of executive functions was concerned with the possibility of their cultivation through educational programs(Diamond, 2012, 2013, 2014; Diamond & Lee, 2011; Serpell & Esposito, 2016). However, the majority of these programs aimed at preschool children, while a small number of such programs were designed for primary and secondary education (Diamond & Lee, 2011; Dias & Seabra, 2017; Lynn Meltzer, 2010; Otero, Barker, & Naglieri, 2014).The results concerning the potential enhancement executive functions through school-based programs have been ambiguous. According Bodrova and Leong (2001)for instance, implementation of educational programs significantly improved the children's executive functions, while other studies have failed to achieve similar results through educational interventions (Blair & Raver, 2014; Clements et al., 2016).This article presents an intervention program designed and implemented toprimary school pupils for the development of their working memory, inhibition control and cognitive flexibility through mathematical problem- solving. The implementation of this intervention program was based on three pillars: a) teaching of cognitive strategies; 2) the implementation of the "think-aloud method" (Ericsson & Simon, 1993)and 3) the problem-solving model(Polya, 2004). The three pillars of the intervention program are briefly presented below.

1.1.1 Teaching cognitive strategies

Teaching for cognitive strategies is a type of educational intervention that can be infused within the school curriculum and enriches the learning process(Lynn Meltzer, 2010; L Meltzer, Pollica, Barzillai, & Meltzer, 2007).In the context of the present intervention, students were taught cognitive strategies for the use specific executive functions, while being encouraged to use them effectively in a variety of learning environments. Thus, students through cognitive demanding activities were trained when and how to apply metacognitive strategies in order complete their activities. Related studies have shown that this method strengthens both the pupils' cognitive abilities and their learning achievements (Iseman & Naglieri, 2011; Lynn Meltzer, 2010; L Meltzer et al., 2007).

1.1.2 The "Think- Aloud" method

The "Think- Aloud" method is type of formative assessment based on verbal interaction between the teacher and the students. It has been described as an appropriate method that requires the activation of cognitive and metacognitive skills (Charters, 2003; Fox, Ericsson, & Best, 2011; Jacobse & Harskamp, 2012; Smith & Wedman, 1988; Veenman, 2011; Young & Worrell, 2018).Following the "Think- Aloud" method, first, students were asked to describe in detail and reflect on a cognitive task while working on it.Their thinkingwas recorded in communication protocols. Through these protocols, teacherswere able to recognize the cognitive and metacognitive strategies that students initiate to complete their cognitive work, as well as students' difficulties in the use of executive functions that prevent the completion of the cognitive task(Bannert & Mengelkamp, 2008; Charters, 2003; Jacobse & Harskamp, 2012; Rosenzweig, Krawec, & Montague, 2011; Young & Worrell, 2018).

The "think aloud" method has been used extensively in the field of mathematical problem solving(García Fernández, Betts, González Castro, González García, & Rodríguez Pérez, 2016; Gidalevich & Kramarski, 2017; Montague, Enders, & Dietz, 2011; Ostad & Sorensen, 2007; Özcan, Imamoglu, & Katmer Bayrakli, 2017; Özsoy, Kuruyer, & Çakıroğlu, 2017; Vandevelde, Van Keer, Schellings, & Van Hout-Wolters, 2015). It can be implemented either through reflection questions, and/or through the teacher's verbal feedback to the pupil or in the form of an interview. Reflection questions help students to develop a dialogue with themselves by externalizing thoughts and reflecting on them, and finally to cultivate metacognitive awareness(Bannert & Mengelkamp, 2008; Ifenthaler, 2012; Özsoy et al., 2017). Verbal feedback is provided by the teacherafter the student is asked to answer metacognitive questions posed by the teacher, while cognitive strategies for mathematical problems are taught and encouraged to be applied in real mathematical contexts(Özsoy et al., 2017). The "think aloud" method allows the identification of the cognitive strategies involved in the elaboration of complex cognitive projects and the different strategies that students trigger at different learning levels(Montague et al., 2011; Ostad & Sorensen, 2007; Özcan et al., 2017). This method has been presented as an important tool for the educator to provide feedback to his students, to design effective educational interventions and to enhance mathematical problemsolving abilities as well as metacognition and self-control(Fox et al., 2011; García Fernández et al., 2016; Gidalevich & Kramarski, 2017; Jacobse & Harskamp, 2012; Vandevelde et al., 2015; M. V. J. Veenman, 2011; Young & Worrell, 2018).

1.1.3 The Problem-Solving Model

Another pillar of the intervention program described in this article is the problem solving model proposed by Polya (2004)which has been widely used in the literature (Kotsopoulos& Lee, 2012; Fuhs, et al., 2010; Lee, Ng & Ng, 2009; Passolunghi&Pazzaglia, 2005).This model includes four stages for mathematical problem-solving: a) understanding the problem, b) designing the solution plan, c) implementing the plan, and d) checking and evaluating the plan for the solution of the problem. The first stage requires the student to understand the mathematical concepts and processes that surround the problem. Duringplanning, students are asked to decide on the mathematical procedures and strategies to follow in the implementation of the plan. Finally, the students check and evaluate the accuracy of their results (Kotsopoulos& Lee, 2012; Lee, Ng & Ng, 2009;Viterbori, Traverso&Usai, 2017).

Based on aforementioned model, solving a mathematical problem can be approached as a task involving executive control (Bull & Scerif, 2001;Viterbori, Traverso & Usai, 2017; Swanson, Jerman & Zheng, 2008; Swanson & Kim, 2007).More specifically, working memory allows students to use and relate their mathematical knowledge, to distinguish information useful in solving the problem, to recognize and understand the mathematical concepts and processes required to resolve it and to represent, mentally or visually, a possible plan to resolve it. Cognitive flexibility allows students to think alternatively to solve the problem, to represent differently the mathematical concepts and processes, to work simultaneously on different phases of the problem, as well as to be able to process information represented in different ways (charts, numbers, words) as well as moving flexibly between them. Finally, in order to solve the mathematical problems it is important for the student to be able to control and inhibit spontaneous thoughts and strategies (Agostino et al., 2010;Kotsopoulos& Lee, 2012; Yener et al., 2013; Cantinet al., 2013; Bock et al., 2015;Duan et al., 2010; Cragg et al., 2017; Cragg & Gilmore, 2014).

Investigating executive functioning by thinking aloud in the problem solving process and keeping recorded protocols of this procedure, allows study of students' abilities and difficulties in mathematical problem solving and to link them to weaknesses in specific executive functions (Kotsopoulos & Lee, 2012). At the same time, the above approach is a guide through which teachers can understand students' cognitive processes in mathematical- problem solving and provide important information for teaching executive control and developing interventions aiming at cultivating students' mathematical problem-solving skills.
The development of primary school pupils' executive functions through a formative assessment when dealing with mathematical problems is presented below.

2. THE INTERVENTION PROGRAM

2.1 Aims

Seventy two school–aged students participated in this intervention program (10 and 12 years). They studied at a primary school situated at an area with relatively high socioeconomical status and they were divided into two groups, the experimental group and the control group. The division of pupils into the two groups took place according to the following procedure: Each year group of the school consisted of two classes in which pupils were randomly assigned by the school. They all lived at the same area came from similar socioeconomic backgrounds and were matched by the school according to their academic ability and gender. Therefore, the experimental group consisted of the first class, while the control group included the pupils of the second class. In total, thirty-eight students constitute the intervention team and the remaining thirty-four students belong to the control group.

As regards the intervention group, 15 students attended the 4th grade of the Primary School (10 years old), while 23 students were in the 6th grade (12 years old). The intervention sessions took place during the school program and within the school environment through which students were expected to enhance their ability to solve mathematical problems and cultivate their metacognitive thinking for solving mathematical problems. In addition, this program aimed at informing teachers about the “think aloud method” and its application as a formative evaluation tool allowing the verbal feedback between teachers-students and the development of students reflection.

2.2. Materials

The intervention program’s materials included mathematical problems, a self-observation leaflet and the self-assessment brochure.During the intervention program, students were asked to solve complex mathematical problems by recording and explaining every step and every action they are thinking to get to solve the problem. Each mathematical problem wasa task which involvedthinking in several stages to be resolved. The mathematical problems were selected from textbooks that included math puzzles in a playful form, so that they were entertaining for pupils while at the same time they were in line with the content and aims of the Mathematics’Curriculum for in these classes. In addition, they matched to the students' cognitive backgroundby taking into account the knowledge and skills they had alreadyacquired at school.

The self-observation leaflet was structured on the basis of Polya's Mathematical Problem Solving Model (Polya, 2004). It included questions grouped according to the four basic phases of mathematical problem solving. It was given to students along with the mathematical problem and was used as a guide to help students to monitor their progress in solving the problem and simultaneously to recognize potential difficulties in problem-solving and ways to overcome these difficulties.

The self-assessment brochure includedquestions related to working memory, inhibition control and cognitive flexibility, as well as their role in solving the mathematical problem. Students completed itafter they had solved the mathematical problem. They evaluated themselves and recordedany difficulties they had experienced, the way by which they had overcome their difficulty, as well as what they should remember whenever they might have to solve a similar problem. The self-assessment brochure was used by students in subsequent sessions to identify their abilities and difficulties and to evaluate their progress.

2.3. Procedure

Prior to the implementation of the intervention program, students were assessed for their ability to solve complex mathematical problems, including mathematical concepts and procedures according the Mathematics Curriculum of their year group. The test of mathematical ability included five mathematical problems of increasing difficulty and the objectivewas to assess the pupils' capacity to solve mathematical problems before participating in the intervention program.After the intervention program, students were re-assessed. The measurement of mathematical competence followed the same procedure as the pre-assessment and aimedat studying the effectiveness of the intervention program and the degree to which students learnt to use their executive functions and solve mathematical problemseffectively.

For implementing the intervention, and taking into account that the researchercould not monitor individual work of every student neither could s/he provide individualized feedback whenever needed to all,students were divided into two groups based on their performance on the pre-assessment of the mathematical ability: Those whose performance was above the average (group a) and those whose performance was below the average (group b). Group (a) students worked individually and were only controlled for the solution of the problem and the correct application of the method. Students in the second group received personalized tutoring. Individualized instruction was also providedto the students of the first group when they had difficulties in solving the problems.During the problem solving phase, students worked individually and were asked to record their thinking by noting down everything they thought while working on problems, to justify their thinking and the mathematical processes they followed, not to erase their errors but to check and correct them.

2.4 Individualized Intervention

During the personalized intervention, the researcher monitored the executive functions that students triggered while dealing with problems, identified weaknesses in executive functioning that lead students to wrong solutionsand discussed with the learners strategies to self-access and manage theirexecutive functioningeffectively when solving cognitive problems.Strategy instruction allows children with executive functions deficits to enhance these cognitive skills and improve their learning performance(Lynn Meltzer, 2010; L Meltzer et al., 2007). Whenever the student seemed to be unable to resolve the problem, even after having received verbal feedback,the researcher proceeded to the teaching of cognitive strategies related to specific executive functions, as shown in the figure1.

''Fig. 1'': Examples of instructions for cognitive strategies development

Working Memory	-Take notes of the basic information of the problem. -Identify the known and the unknown data of the problem. -Draw a possible resolution plan by marking the individual steps to follow.
Inhibition	-Recognize problem-solving situations that have already been solved. -Verify actions to check your correct solution. -Look back at the plan to remember and control the right path to the solution.
Cognitive flexibility	-Decode mathematical concepts behind the written wording of the problem. -Consider more ways to resolve the problem. -Illustrate the problem in different ways (drawing or painting). -Replace large numbers with smaller numbers when it is difficult to perform mathematical operations.

As seen in figure 1 the feedback provided to students is typical for each executive function. It was further elaborated by asking specific questions that correspond to students' weaknesses and, according to the literature, are associated with a specific executive function (Kotsopoulos & Lee, 2012).

As stressed in the introduction, the purpose of this article is to present the educational intervention and not the results of the study. Nevertheless, it is worth mentioning here that the intervention appeared to have resulted in a significant improvement in mathematical ability, while no improvement was found in executive functioning. It seemed that by improving their ability to solve mathematical problems by provision of feedback related to executive functioning, students did not cultivate their executive functions per se, but they enhanced their ability to use their executive functions effectively in order to solve mathematical problems.

3.DISCUSSION – CONCLUSIONS

In the literature, the limited number of educational interventions developed for primary education has focused on training of individual executive functionssometimes through the use of specific software. Such interventions however are difficult to implement within the school by teachers since they are not in line with the content of school curricula (Otero et al., 2014; Serpell & Esposito, 2016). The first conclusion of the program presented in this paper is related to the feasibility of designing and implementing educational interventions aiming at enhancing students' cognitive abilities and their learning achievementsintegrated in the learning process and in harmony with the aims of the school curricula. The present study showed the workability of educational activities incorporated in the school curriculum and their application within the school environment (Clements et al., 2016; Diamond, 2012; Dias & Seabra, 2017; Otero et al., 2014)..

The present intervention also demonstrated the effective use of the "think aloud method" as a form of formative assessment and self-assessment that for the development students' executive functions and mathematical ability(Fox et al., 2011; García Fernández et al., 2016; Gidalevich & Kramarski, 2017; Jacobse & Harskamp, 2012; Vandevelde et al., 2015; M. V. Veenman, 2011; Young & Worrell, 2018).Through this method,teachers are given the opportunity to evaluate their students' knowledge and skills, to intervene in order to strengthen them and to monitor their progress. By guiding the executive functions, teachers can develop activities with specific cognitive goals and provide targeted verbal feedback to enhance the metacognitive consciousness of students. Hence, executive functions are transformed into a clear educational tool that links the development of metacognitive skills and self-adjusting learning to educational practice. Furthermore, executive functions, metacognitive skills and self-regulation ability incorporate to the learner's ability to become aware of its cognitive strategies, to control their effectiveness and to modify them for optimalachievements(Bryce et al., 2015; Effeney, Carroll, & Bahr, 2013; Garner, 2009; Hofmann, Schmeichel, & Baddeley, 2012; Roebers & Feurer, 2016; Zimmerman, 2008). Through the "think aloud method", students realize their potential and weaknesses, evaluate them and exercise control over them. As stressed in the literature (Bannert & Mengelkamp, 2008; Ostad & Sorensen, 2007), by reflective thinking, pupils not only verbalize their thoughts and strategies while engaging in cognitive work but, at the same time, they become self-motivated and they develop self-evaluation and self-reflection.

Summing up, through the present intervention program, teachers and students were introduced to solvingmathematical problems based on students' executive functions. In this context, students were encouraged to use their executive functions to solve mathematical problems, to realize weaknesses, and to learn ways to overcome them and to solve mathematical problems. Also, teachers were trained on new tools and methodsfor the effective teaching of specific mathematical skills.

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