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Enhancing arithmetic skills through working memory: A review of interventions and strategies

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ABSTRACT

This review article investigates the relationship between elementary school children's arithmetic skills and working memory, and it shows strategies and interventions to improve their arithmetic proficiency. This review highlights the role of working memory in information processing while solving arithmetic problems. It also proposes the specific methods used for enhancing arithmetic skills, such as instructional techniques and cognitive training programs. In the line of comprehensive examinations of empirical studies, this article presents effective approaches to educators and researchers who are exploring to foster development of school-age children in mathematics by utilizing the functionality of working memory.

Keywords: arithmetic skills, working memory, cognitive training programs, individual differences

INTRODUCTION

Proficiency in basic arithmetic operations is a fundamental cornerstone of mathematics learning; hence, four-operation problems are part of mathematics curriculum for most in primary school level (Boz & Erden, 2021). This skill provides making decisions, solving mathematical problems, and navigating various aspects of daily life. However, a considerable number of children struggle with solving arithmetic problems, resulting in difficulty in their future mathematical abilities. All processes of number concepts and counting include cognitive mechanism (Hubber et al., 2014), where children store, monitor and manipulate information in their memory and those processes are related to working memory (DeStefano & LeFevre, 2004; Raghubar et al., 2010). Therefore, understanding the cognitive processes is crucial to develop more effective tools to support children's arithmetic skills.

Working memory is a system, which is responsible for temporarily storing and manipulating information required for complex cognitive tasks, such as problem-solving and reasoning (Baddeley, 1986). It includes the ability to hold information in short-term storage while performing operations on that information (Alloway & Passolunghi, 2011). Research has shown that working memory plays an important role in arithmetic performance since children require to retain and manipulate numerical information to solve arithmetic problems accurately.

The purpose of this study is to provide a comprehensive review of the cognitive framework of arithmetic operations and propose working memory based interventions and strategies aimed at enhancing children's arithmetic skills. In this study, the author discusses first the importance of problem-solving skills in mathematics and examine the relationship between children's arithmetic skills and working memory, focusing on how interventions targeting working memory processes can enhance arithmetic proficiency.

The author begins by exploring the mechanisms underlying the role of working memory in arithmetic processing. Next, the author discusses individual differences in working memory that may influence arithmetic performance. Subsequently, the author reviews existing interventions, including cognitive training programs and instructional strategies, designed to improve arithmetic skills by targeting working memory functions. Finally, the author offers insights and recommendations for educators and researchers interested in improving children's arithmetic development through targeted interventions and methods.

This study is a part of the author's PhD dissertation.

COGNITIVE FRAMEWORK OF ARITHMETIC SKILLS

One of the most important purposes of mathematics education is enabling students to make connection between their experiences and math. The primary mathematics curriculum emphasizes on learning concepts, being quick in arithmetic operations, making connection between mathematical concepts, having the ability of communicating by using the language of math, concepts, terms, and numbers, making mathematical modelling and reasoning, choosing proper strategies to explain relationships between objects, and having the ability of problem-solving. Mathematics curricula are based on helping students reveal their experiences and different views, and then create mathematical meanings with their concrete experiences. Another important goal of a mathematics education is to enable students to become problem-solvers because it is assumed that students who are good at solving mathematical problems can overcome the problems in their daily life. Therefore, problem-solving is a main activity in teaching mathematics (Schoenfeld, 1989; Silver, 1985).

Problem-solving is a series of cognitive activities to accomplish a definite purpose (Schoenfeld, 1989). A theoretical framework is required for a given problem to understand the cognitive processes of arithmetic learning. For instance, Dagenbach and McCloskey's (1992) developed cognitive model of number processing. This model helps to differentiate between input processes and abstract cognitive representations involved in calculations. Numbers are perceived verbally (two times four) or numerically (2×4). Both are converted to an abstract representation, which is managed through calculation procedures. Then, results are converted to the proper output (numeric or verbal). This process provides to increase children's arithmetic skills and use language for mathematics problems. In addition, cognitive manipulation is conducted when numeric symbols relate to verbal numeric representations (Decker & Roberts, 2015).

A variety of cognitive processes are required to accomplish fluency in calculation and knowledge to choose proper strategies. For instance, an answer of simple sums is retrieved from memory and procedural strategies, such as counting or decomposition are used while doing complex addition (Hubber et al., 2014). All processes, such as the ability to store, monitor, and manipulate information in memory, which are necessary for arithmetic operations rely on working memory (DeStefano & LeFevre, 2004; Raghubar et al., 2010).

The effect of working memory in the strategy use while solving arithmetic problems was investigated in various studies. For example, Geary et al. (2004) studied the engagement of working memory in the strategy choice of students in 1, 3, and 5 grades when they are solving simple and complex addition problems. The findings demonstrated that the ability of solving complex arithmetic problems relied on higher working memory capacity (Adams & Hitch, 1997). On the other hand, it is supposed that the relations between working memory and complex arithmetic problems relied on strategies (Geary et al., 2004). From this view, higher working memory capacity provided more appropriate strategies (i.e., decomposition), while lower working memory resulted in less appropriate strategies (i.e., finger counting).

Working memory components have a more important role in procedural than retrieval strategies. For instance, it is found that phonological loop, which is loaded by an articulatory suppression task makes participants' responses slower when they do calculation to confirm an addition problem without using direct retrieval (Hecht, 2002). Nevertheless, they try various strategies to develop an answer to a problem (Geary et al., 2004). For instance, an order of strategies was used to solve single digit addition and subtraction problems with retaining and repeating letter strings, which they listened to understand the role of working memory in calculation (Imbo & Vandierendonck, 2007). They used counting and decomposition, but not retrieval strategies. Therefore, it can be asserted that verbal working memory plays a greater role in procedural than in retrieval strategies (Hubber et al., 2014). In addition, Wu (2010) examined the effect of working memory on mental addition and multiplication. The long-term store showed that children with greater working memory counted on direct retrieval from long-term memory and children with average working memory performed mental counting strategies more often than children with below-average working memory.

The research has shown that verbal and retrieval strategies play a significant role in learning multiplication facts by performing verbal memorization. Roussel et al. (2002) revealed that children become experienced in verbal memory strategies (i.e., direct retrieval strategy) gradually. For instance, children rehearse arithmetic facts until they store them in their memory and retrieve them directly if they need to. Multiple-digit multiplication problems are solved by using multiplication algorithms. The multiplicand is multiplied by each digit of multiplier and added to long-term store, but memorization of the multiplication facts for single digits is required to manage this process (Zhou et al., 2011). The memorization of multiplication facts (i.e., knowing that 5×4=20) is acknowledged as direct memory retrieval, which is regularly used. The procedural strategies, such as; transformation (e.g., 9×7=(10×7)-7=70-6=63), associative property (e.g., 35×15=35×3×5) and counting (e.g., 3×6=3 . . . 6 . . . 9 . . . 12 . . . 15 . . . 18) may be alternative choice to solve multiplication problems are non-retrieval and preferred to be used (LeFevre et al., 1996; Seitz & Schumann-Hengsteler, 2000). The involvement of working memory in multiplication reduces the difficulty of problems when strategies are used (Tronsky, 2005). For instance, multiplication algorithms are required for solution when the problem of complex multiplication (e.g., 32×18) is tried to be solved without any strategy. To diminish the difficulty of the problem, associative property strategy may be used to transform it to different form (e.g., 32×6×3). However, the involvement of working memory becomes reduced practically when students apply strategies to solve these multi-digit multiplication problems.

In view of strategy using, it was examined that normal-achieving students were able to make decision about more appropriate strategy, which they met their cognitive capacity to solve the problem (Siegler, 1995). According to Siegler (1988), direct retrieval strategy provides a much faster process to solve problems and it is applied when students can use their memory of multiplication facts. Procedural strategies may contribute to time-consuming and more errors, but if students do not rely on their direct retrieval skills, using them can enable them to obtain a correct answer to a problem. For example, Steel and Funnell (2001) studied with eight- to 12-year-old children who used direct retrieval and procedural strategies (e.g., calculation and counting-in-series) to solve multiplication problems. It was attained that retrieval strategy provided faster speed and less error among other strategies.

INDIVIDUAL DIFFERENCES IN WORKING MEMORY

Individuals vary in working memory capacity, which can impact their arithmetic performance. Individual differences are associated with differences in total capacity and processing efficiency. For example, when an individual is exposed to flow of information in working memory, his/her capacity can be exceeded, leading to increasing memory load. The excess of information in memory then results in reduced capacity in storage and processing. The performance in cognitive tasks depends on controlling irrelevant information while performing those tasks. For instance, information must be suppressed when it is not relevant for the task anymore. Relevant and irrelevant information may compete for limited access in working memory, and individuals either resist these irrelevant items to have access in memory or remove them if they get access (Hasher & Zacks, 2007). Thus, individuals who can control processes perform better in high-order cognitive tasks like arithmetic problems (Friedman & Miyake, 2004).

INTERVENTIONS TARGETING WORKING MEMORY

The evidence shows that individual's working memory capacity is a significant element to be able to perform various cognitive tasks, including arithmetic operations. Even though this capacity is limited, the effectiveness of working memory processes can be enhanced by specific interventions, such as working memory training programs and instructional strategies.

Working memory training involves activities, which are designed to improve working memory capacity. This kind of training program is required to be built in a way to be adaptive for participants. Therefore, the difficulty of tasks can adjust based on their performance to yield optimal learning outcomes. For instance, cogmed working memory training program is a series of computerized tasks in which participants must remember and manipulate visual and auditorial items in working memory (Holmes et al., 2009). The implementation of this training showed the transfer effect in reading and mathematics (Wass et al., 2012). Furthermore, Kuhn and Holling (2014) conducted a study involving updating training for children, with a specific focus on enhancing the mathematical abilities of elementary school students through computer-based exercises. Among various computerized training programs used sequentially, n-back training predominantly targeted spatial working memory through updating tasks. In this training, participants were required to determine whether a stimulus presented on the screen matched its location n steps earlier. The assumption was that such training would enhance spatial updating skills, which are known to be crucial for mathematical performance (van der Ven et al., 2012). The results indicated that while the training led to a statistically significant improvement in mathematics scores among participants, the effect size was relatively small, likely due to the brief duration of the intervention.

One factor that requires to be into consideration must be a variability in intervention outcomes, which is the specificity of training tasks and transfer effects. Cognitive training programs closely resemble arithmetic tasks and require participants to engage in arithmetic processing while maintaining and manipulating information in working memory. This may be more effective in improving arithmetic skills. Moreover, interventions that incorporate individualized instruction and provide opportunities for practice and feedback may enhance learning outcomes. Furthermore, the duration and intensity of interventions, as well as the age and cognitive abilities of participants, may influence intervention effectiveness. Long-term interventions that provide sustained practice and support over extended periods may yield greater benefits than short-term interventions. Additionally, instructional strategies for enhancing arithmetic skills through working memory often incorporate explicit teaching methods and scaffolding techniques to support children's working memory demands during arithmetic tasks. For instance, teachers may use visual aids, such as number lines and manipulatives, to help children visualize numerical concepts and reduce cognitive load. Additionally, providing step-by-step instructions and opportunities for practice can help children develop strategies for managing working memory resources effectively.

CONCLUSIONS & RECOMMENDATIONS

This study shows evidence to educators and researchers to understand the relationship between children's arithmetic skills and working memory to support arithmetic learning and development. The role of working memory in arithmetic processing was described with previous research and examples in math. Educators who desire to enhance children's arithmetic skills can implement targeted interventions and instructional strategies.

Future research should explore the mechanisms, which underly working memory's role in arithmetic processing and investigate different interventions and strategies for improving arithmetic skills within cognitive settings. For instance, longitudinal studies, which examine the effects of early intervention programs on arithmetic outcomes and academic achievement are required to assess the long-term impact of working memory training.

In conclusion, working memory plays a crucial role in children's arithmetic skills, and working memory training programs can be utilized as an efficient tool to enhance their performance in math. By conducting evidence-based interventions and instructional strategies into educational practices, educators can support children's arithmetic learning and foster academic achievement not only in math, but also in different subject areas.

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