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Dyscalculia and intervention tools

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Abstract

This article focuses on dyscalculia, a learning disorder affecting mathematical skills, without being related to the child's intelligence. In modern education, the diagnosis of dyscalculia is becoming more reliable with the use of technological tools. Children with this disorder often struggle with understanding mathematical concepts, performing calculations, and recognizing mathematical relationships. However, early diagnosis and appropriate intervention can significantly contribute to enhancing their learning abilities. Technology, such as digital games and educational software, has proven to be effective in enhancing the mathematical skills of students with dyscalculia.

Keywords: Dyscalculia; ICT; Constructivist Theory; Working Memory; Virtual Reality; Artificial Intelligence; Mobile Applications

1. Introduction

It is estimated that the prevalence of dyscalculia ranges from 3 to 6% of the global population. Research shows that it often appears in twins and in families with a history of similar difficulties (Tsombolis, 2017).

The term "dyscalculia" comes from the Greek word "dys" and the Latin word "calculia." There are various terms used for mathematical learning difficulties. Ladislav Kosc (1974) introduced the term "Developmental Dyscalculia," while Koontz and Berch (1996) used the term "Numerical Learning Difficulties." Hich prefers the term "Specific Numerical Difficulties," and Temple and Sherwood (2002) use the term "Mathematical Facts Disorder" (Butterworth, 2008, as cited by Drigas et al., 2016).

Kosc (1974) described developmental dyscalculia as a disorder of mathematical abilities with a genetic or congenital basis in specific parts of the brain, without being accompanied by general intellectual dysfunction (Khing, 2016).

There is a direct correlation between dyscalculia and working memory difficulties, specifically the ability to memorize numbers in a specific sequence. According to Geary (2010), there are three cognitive components in mathematical learning difficulties (Mathematics Learning Disabilities - MLD):

- Retrieval of numerical data from long-term semantic memory
- Execution of procedures for solving numerical problems
- Representation and interpretation of spatial representations of mathematical information (Geary, 2010, as cited by Drigas et al., 2016).

Learning difficulties, such as dyscalculia, persist throughout life, but with early diagnosis and appropriate intervention, students can show significant improvement (Course, 2006, as cited by Drigas et al., 2016).

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Children with learning difficulties in mathematics may exhibit the following characteristics according to Tzivinikou (2015):

- Struggle to understand and solve mathematically described word problems.
- Have trouble managing money and performing everyday transactions.
- Struggle to organize and process mathematical problems in writing.
- Cannot recognize and follow logical sequences in mathematical steps.
- Have difficulty understanding the sequence of events and steps in a problem.
- Cannot verbally describe the mathematical processes they use.
- Struggle with measurement, learning numerical data, and performing calculations.
- Cannot effectively apply mental strategies to solve mathematical problems.

2. ICT and Education

Modern technologies related directly or indirectly to computers are internationally known as Information and Communication Technology (ICT). According to Kumar (2008), ICT is a general term that encompasses any device or application for communication. This includes radio, television, mobile phones, computers, network hardware and software, satellite systems, and various related services and applications such as videoconferencing and distance learning.

According to Komi (2004), the phases of introducing Information and Communication Technologies (ICT) into education are four:

- The period of educational technology and teaching machines (before 1970): During this first period, educational technology focused on the use of teaching machines and audiovisual media. Radio and television were widely used as educational tools, aiming at direct teaching in the classroom, school broadcasts, and educational programs in general.
- The computer approach (1970-1980): The 1970s were characterized by the introduction of computers into education. This approach involved the integration of computers into school classrooms, facilitating the learning of basic computer skills.
- Computers as both a medium and a subject of education (1980-1989): In the 1980s, computing became both a tool and a subject of education. Students were taught how to use computers and software while also using computers as learning tools in various subjects.
- Information and communication technologies as teaching and learning tools (after 1990): From the 1990s onward, ICTs became an integral part of teaching and learning. The use of the internet and computers enabled the development of interactive and personalized learning methods, while simultaneously facilitating communication and collaboration between students and teachers.

3. The Use of ICT in Children with Special Learning Difficulties

The integration of Information and Communication Technologies in education has proven crucial for supporting students, especially those with special learning difficulties. Research has shown that ICT provides opportunities for increased participation in the educational process and promotes interactive experiences that encourage active student engagement (Benmarrakchi, Kafi & Elhore, 2016). Furthermore, the use of ICT can enhance students' autonomy, giving them more control over the learning process and reducing their reliance on the teacher (Vlassopoulou & Papadimitriou, 2006).

Specifically, new technologies empower students' self-esteem and motivation by providing additional opportunities for practice and interaction, helping them develop a positive image of themselves and the learning process (Alexander-Passe, 2006). This approach can be particularly beneficial for students with learning difficulties, as it enables them to fully participate in the social context of the classroom and improve their social skills (Cooper, Smith & Upton, 2002).

Finally, we stress the significance of all digital technologies in the field of education and in learning difficulties training, which is highly effective and productive and facilitates and improves assessment, intervention, and educational procedures via mobile devices that bring educational activities everywhere [141-144], various ICT applications that are the main supporters of education [145-167], and AI, STEM, Games and ROBOTICS that elevate educational procedures to new performance levers [168-174]. Additionally, the development and blending of ICTs with theories and models of metacognition, mindfulness, meditation, and emotional intelligence cultivation [175-199], accelerates and improves more the educational practices and results, particularly in learning difficulties.

4. ICT and Constructivist Theory

The integration of ICT in education has brought about significant changes in the way we teach and learn. The adoption of ICT is supported by various learning theories, with constructivist theory playing a central role (Chaudhary, 2018).

Constructivist learning theory posits that knowledge is not simply transmitted from the teacher to the student, but is actively constructed by the student through interaction with the environment and peers. Piaget and Vygotsky are two of the most important theorists in constructivism. Piaget focused on the cognitive development of individuals, while Vygotsky emphasized the importance of social interaction in learning (Yang & Kwok, 2017; Wang, 2008).

ICT can support constructivist learning with tools and platforms that facilitate active participation and collaboration among students. Online learning platforms such as Moodle, and collaborative tools such as discussion forums and blogs, enable students to collaborate and exchange ideas, enhancing the process of knowledge construction (Wang, 2008).

Vygotsky's theory of social constructivist learning highlights the importance of social interaction and collaborative education. ICT can facilitate this interaction through social networks and online platforms that enable collaboration and knowledge exchange among students (Yang & Kwok, 2017).

The use of ICT in education also involves the application of scaffolding techniques that provide guidance and support to students during their learning journey. Scaffolding can be provided either by individuals (such as teachers) or systems (such as learning software and platforms). These techniques help students gradually and safely develop their skills and knowledge (Yang & Kwok, 2017; Wang, 2008).

The integration of ICT in education, supported by the theories of constructivist learning, offers significant benefits for both students and educators. Students have the opportunity to actively participate in learning, collaborate with their peers, and develop their knowledge and skills in a more efficient and interactive manner. Educators, on the other hand, can use ICT to provide more personalized and flexible support to their students, enhancing the overall educational experience (Wang, 2008).

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5. Intervention Tools

5.1. Computer-Based Tools

Brunda and J. Bhavithra developed "**Computer-Assisted Instruction (CAI)**", which includes E-Learning and Adaptive E-Learning. These tools aim to teach mathematical concepts such as number names, counting, and number comparison through interactive software. The system adapts to the level of each student, offering different difficulty levels and providing auditory feedback. The project targets children up to 8 years old with dyscalculia, enhancing their cognitive and numerical skills (Drigas et al., 2016).

Lontrup et al. (2012) developed and tested a product that examines the potential for improving the understanding of mathematical equations by students in grades 7–10 through the use of physical objects. Students face difficulties with the complexity of equations and their rules. The product consists of six **Sifteo cubes** and **a computer application**. The cubes detect when they are placed side by side, when tilted, and when their screen is pressed. The student selects the first equation in the app, which is displayed on the cubes. Students move the cubes to solve the equation, with various support tools such as color indicators, automatic point changes, and automatic calculations, which gradually decrease as they progress. The results show that physical interaction helps students better understand equations, boosting their confidence and reducing frustration. Colors and elements from gamification were used to support this process (Lontrup et al., 2012).

The research of Ginsburg et al. (2015) proposes six cognitive principles for designing and evaluating mathematical software, using the software **MathemAntics** as an example. These principles target preschool and early school-aged children and include (Drigas et al., 2016):

- Engage children in cognitively and mathematically appropriate activities.
- Develop effective models for representing abstract ideas.
- Encourage accurate and effective strategies.
- Identify and eliminate errors and misconceptions.
- Design appropriate physical interaction.
- Integrate narratives and stories with mathematical concepts.

To apply these principles, the MathemAntics software uses various media and technologies such as interactive graphics, animations, immediate feedback, adaptive activities, and gamification (Ginsburg et al., 2015).

The educational software Round with Value is designed for teachers, offering materials and lesson plans to organize their teaching according to the needs of students. The program lasts 23 hours and is suitable for teaching euro coins to children with severe learning difficulties (Institute of Educational Policy, 2022).

5.2. Multimedia Tools and the Web

Hasselbring et al. (2005) conducted a study on the use of technology for learning mathematics in children with dyscalculia. They developed the software ***FASTT***. FASTT Math uses unique features to help users connect facts with their answers through interactive software. The findings showed that when the software is used daily for about 10 minutes, most students with math difficulties can develop fluency in a single operation after approximately 100 sessions. Therefore, the key to success seems to lie in consistent use of the program. As expected, students who used the program regularly performed much better than those who were irregular users (Hasselbring et al., 2005).

The game ***The Number Race*** is an adaptive educational software designed to address dyscalculia. Its goal is to improve children's numeracy skills through interactive exercises that adapt to each player's skill level. It provides a fun and effective means of developing basic numerical skills and overcoming difficulties related to dyscalculia. Results showed that this software application could be effective in addressing dyscalculia, at least for children aged 7-8 years and younger (Wilson, 2006).

Another study was conducted by Räsänen et al. (2009), examining the effectiveness of digital intervention for children with dyscalculia or low numeracy skills. Thirty children from preschool and early school age were randomly divided into two groups. The first group used ***The Number Race***, while the second group played ***Graphogame-Math***. *The Number Race* focuses on teaching number sense and addition through an interactive game, while *Graphogame-Math* uses auditory stimuli to reinforce learning of quantitative distinctions. Both groups were trained with the games for three weeks, 10-15 minutes daily (Drigas et al., 2016). The results showed that children achieved significant improvement in number comparison, but the result did not generalize to counting or arithmetic. However, the feedback provided by the tools allows the child to adjust their actions in relation to the goal (Räsänen et al., 2009).

Calcularis is a computer-based educational program created by Käser et al. to help children with dyscalculia. The study involved thirty-two German-speaking students (2nd-5th grade) in Switzerland who had difficulties learning mathematics. The children used the program for 20 minutes a day, five days a week, for 6-12 weeks. *Calcularis* consists of 10 different types of games that leverage number representations, visualization of numbers using colored blocks, arithmetic operations, and word problems (Drigas et al., 2016). With variations of the numbers used in the games, 81 different exercise types (difficulty levels) are created. Users start the program from the lowest level and progress according to their abilities (Käser et al., 2011).

The project by Laurillard et al. (2009) involved the development of digital interventions for children with dyscalculia. They designed and tested the programs ***Dots2-Digits*** and ***Dots2Track***, which aimed to help students connect dots with digits. They studied the software and created an online environment for the creation of an interactive website, offering teachers access to information and discussion forums. According to the educators, the use of digital games allows students to practice more compared to traditional teaching (Drigas et al., 2016).

5.3. Virtual Reality

A study by Marcus Vansconcelos and his collaborators examined how a **virtual environment** affects children with dyscalculia. The ***Tom's Rescue*** virtual environment was used, which includes 18 educational games designed to incorporate fun elements and educational goals. These games cover skills such as number recognition, number sequences, number comparison, and the four basic arithmetic operations (addition, subtraction, multiplication, division). The study was conducted in São Paulo, Brazil, and involved 26 children with dyscalculia, with an average age of 8 years, attending 2nd grade. The children were randomly assigned to two groups: the experimental group, which interacted with the virtual environment and the specially designed games, and the control group, which participated in remedial teaching using traditional methods. The experimental group attended one-hour sessions, twice a week, for 5 weeks. The results showed that the use of the virtual environment significantly improved the children's math skills and increased their motivation. The computer was found to be a more engaging and fun tool compared to traditional teaching methods, providing a more encouraging and effective learning environment (Drigas et al., 2016).

Plerou and Vlamos explored how an **interactive virtual environment** influences students' ability to solve algorithmic problems. The study involved 46 students aged 15-16 from the first year of a Vocational Education School in Corfu. The students were divided into two equal groups: the control group, where students worked on traditional algorithmic thinking problems in class with 25 minutes of available time, and the interactive assessment group, where students worked on the same problems in an interactive virtual environment in a computer lab, with 15 minutes of available time plus additional time for reading instructions. The results showed that students who worked in the interactive virtual environment performed better on less complex algorithmic thinking tasks compared to the traditional group. The use of the virtual environment helped students better understand the basic concepts of algorithms and improve their performance on less complex problems, offering a more engaging and creative approach to mathematical thinking (Plerou et al., 2013).

In 2022, Lu, Cho, and Zou published a study examining how virtual reality can improve working memory. The results were positive, showing that participants found this learning method effective and innovative. Virtual reality games can benefit children with learning difficulties, including those facing problems with geometry. Studies have shown that games like ***Minecraft*** and ***Geometry Explorer*** can help develop spatial skills and improve understanding of geometric concepts (Drigas & Galitskaya, 2023).

Geometry Explorer uses a virtual environment to enhance students' understanding of three-dimensional (3D) geometric concepts through interaction with 3D shapes. Designed as a game, it aims to make learning geometry more engaging and interactive for students. In this game, users must adjust the dimensions of the 3D shapes to achieve specific volume goals. Users earn points for achieving the goals quickly, and a leaderboard motivates them to improve their performance. Through this approach, the system strives to make the process of learning volume calculation formulas and spatial perception more enjoyable and appealing (Lai et al., 2016).

A study conducted in 2022 by Su et al. in Taiwan utilized the ***Virtual Reality Immersive Learning Mathematics Geometry System*** **(VRMLGS)**, a virtual reality system specifically designed for teaching geometric concepts. The study involved 40 second-year high school students who were divided into two equal groups: a control group and an experimental group. The study lasted five weeks and began with a pre-test to assess the students' prior knowledge of geometric concepts. During the study, the experimental group used the virtual reality system to learn geometric concepts, while the control group was taught using traditional methods. At the end of the study, a post-test was conducted to evaluate the knowledge the students gained. The results showed that after using the virtual reality technology, students were able to perform learning tasks and acquire all the essential knowledge of basic mathematical geometry through course activities. It significantly improved the learning experience, interest, and self-confidence of the students (Su et al., 2022).

In 2021, a study was conducted to examine the effect of virtual reality on the teaching and learning of geometry. The system used was ***NeoTrie VR***, a dynamic 3D virtual reality geometry software that allows for the creation, visualization, manipulation, and dynamic interaction with three-dimensional geometric objects and models. The research was conducted in four classrooms in Spain and Poland, with students aged 10-15 years. The students were divided into groups and followed a learning model combining traditional teaching methods and the use of NeoTrie VR. The results showed that the use of NeoTrie VR allowed students to improve their spatial sense, reasoning skills, argumentation, interest, and motivation (Rodríguez, 2021).

The study by Syafril et al. (2021) aimed to design and evaluate the effectiveness of the **VirGO (Virtual Geometry)** mobile application, which is based on augmented reality, for learning mathematics. The development of the VirGO application was carried out in three stages:

- User Needs Analysis and Design of Digital Tools
- Creation of the augmented reality software using Unity3D, Blender for modeling, and Vuforia for the development of augmented reality and indicators
- Evaluation and testing of the application with 120 students from three middle schools in Padang

The results of the study showed that the VirGO application, based on augmented reality, has three main advantages:

- It provides realistic visualization of the details of objects and educational materials.
- It offers interactivity through advanced video, image, and animation features.
- It increases students' interest in learning mathematics and reduces the sense of boredom (Syafril et al., 2021).

5.4. Artificial Intelligence

The research conducted by Erica Melis and her collaborators focuses on the development and evaluation of ***ActiveMath***, an intelligent mathematical educational system that uses artificial intelligence and semantic technologies to offer personalized learning support. The first study, published in 2004, presents *ActiveMath* as an innovative teaching system. *ActiveMath* adapts exercises and explanations based on the needs and abilities of the students, offering interactive exercises and automated feedback. The study showed that *ActiveMath* can improve students' learning experience and enhance their mathematical skills compared to traditional teaching methods. The second study, published in 2001, expands on the description of *ActiveMath* as a general and adaptive online learning environment. The system offers a wide range of mathematical content and uses artificial intelligence to adapt the material to students' needs. Students can interact with the environment online and receive personalized exercises and feedback. The results of the study showed that *ActiveMath* is a flexible and effective tool for improving students' mathematical skills. The third study, published in 2006, focuses on the semantically aware components and services of *ActiveMath*. This study describes how the use of semantic technology improves the system's adaptability and accuracy. The semantically aware components allow the system to better understand mathematical content and adapt the teaching more precisely to the student's needs. The results showed that using semantic technologies enhances the learning experience and mathematical performance of students, making *ActiveMath* an advanced and effective learning tool. *ActiveMath* uses XML for mathematical documents and OMDoc, an extension of the OpenMath standard for mathematical symbols and expressions, for encoding its content. This teaching system could be used for distance learning, homework, or teacher-supported instruction. Overall, these three studies highlight the innovation and effectiveness of *ActiveMath* as an intelligent mathematical teaching system that uses artificial intelligence and semantic technologies to provide personalized learning support. The studies show that *ActiveMath* can significantly improve students' mathematical skills and enhance the learning experience through the use of advanced technologies (Erica et al., 2004; Erica et al., 2001; Erica et al., 2006).

Anthony and his collaborators (2008) proposed a prototype system based on intelligent teaching systems for solving algebraic equations by students. The system designers were inspired by the idea that handwritten data input could lead to better results than typing. The recognizer used was the ***Freehand Formula Entry System (FFES)***. To train the recognizer, the researchers collected data from over 40 high school and middle school students in algebra, to ensure that the recognizer could adapt to various forms of handwriting. The study conducted to evaluate this project showed that students who entered mathematical equations via handwriting were faster and less prone to errors than those who typed. Of the 46 students who participated, over 80% stated that they preferred handwriting (Drigas et al., 2016).

5.5. Mobile Applications

According to a study by Kubier (2019), iPad applications such as ***Garden of Numbers***, ***Learn Numbers***, and ***Learn Math*** can be used for primary school students with learning difficulties, especially those with dyscalculia. The study was conducted in schools in the Rafha district of Saudi Arabia, with 38 students participating. The students attended 28 sessions, lasting 40 minutes, four times a week, focusing on memorizing number sequences, understanding mathematical operations, and distinguishing mathematical symbols. The students were divided into two groups: one group used the iPad applications, and the other followed the regular classroom curriculum. The results showed that students who used the iPad applications experienced significant reductions in dyscalculia compared to the control group that followed the regular curriculum (Kubier, 2019).

The study by O'Malley et al. used the ***Math Racer*** app by i4software on iPads to improve numeracy skills in students with moderate to severe cognitive disabilities, including those on the autism spectrum and with multiple disabilities. The study was conducted at a special school in Maryland with ten 7th and 8th-grade students. The students completed timed math exercises for addition and subtraction, with results automatically recorded. The study lasted for four weeks and showed that students solved more math problems correctly per minute while using the app compared to using paper and pencil. They also showed increased interest and engagement when using the iPads (O'Malley et al., 2013).

Dr. Nagavalli and her collaborators mention two popular iPad apps that help children with dyscalculia. The ***MathBoard*** app is suitable for preschool children with simple addition and subtraction problems and for elementary school students with multiplication, division, squares, cubes, and square root problems.

The ***Long Division*** app allows students to study and practice the method of long division, solving problems step by step (Drigas et al., 2016).

Kiger, Dani Herro, and Deb Prunty conducted a study to assess the impact of a mobile intervention on third-grade students' math performance. The study involved 87 students from an elementary school in the Midwest United States, divided into an intervention group and a comparison group. The intervention group used iPod Touch devices with math apps **(*Multiplication Genius Lite*, *Mad Math Lite*, *Flash To Pass*, *Math Drills Lite*, *Math Tappers: Multiples*, *Multiplication Flashcards To Go*, *Brain Thaw*, *Math Magic*, *FlowMath*)**, while the comparison group followed traditional learning methods. Students in the intervention group showed significant improvement in solving multiplication problems, outperforming the comparison group. The study concluded that the use of mobile devices can enhance numeracy fluency and student engagement, providing an effective and cost-efficient solution for education. The study emphasized the need for further research on the long-term effects of mobile learning in different educational settings (Kiger et al., 2012).

The two mobile applications, ***Go Play Ball*** and ***Go Road Trip***, are part of the ***GoMath! Mobile*** project aimed at school-age children and their families. They provide mathematical activities that can be performed during everyday activities. *Go Play Ball* allows users to record their performance in softball or baseball and view graphs or charts with their stats and the stats of their favorite professional players. Six families from Boston used the app for 3-4 weeks during the baseball season. *Go Road Trip* includes nine math games designed to encourage mathematical discussion during family road trips. Seven families with middle school students tested the app while traveling by car. The project was successful, as participants were able to use the mobile platform anytime and anywhere during fun activities, while simultaneously enhancing their social interactions (Drigas et al., 2016).

6. Conclusion

Addressing dyscalculia requires a combined approach that includes early diagnosis, personalized intervention, and the use of technologies such as software and digital games to enhance students' mathematical skills. The integration of ICT in education offers dynamic and effective solutions for students with learning difficulties, boosting their self-esteem and motivation to learn. Specifically, the use of digital tools and interactive environments such as virtual reality games, educational software, and mobile applications can significantly improve the mathematical skills of children with dyscalculia.

Compliance with ethical standards

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Disclosure of conflict of interest

The Authors proclaim no conflict of interest.

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