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Evaluating the effectiveness of digital math tools in enhancing problem-solving skills for students with special needs in U.S. Public Schools

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Abstract

Students with special needs, including those with learning disabilities (LD) and emotional/behavioral disorders (EB/D), face significant challenges in developing problem-solving skills in mathematics. These difficulties are often exacerbated by inadequate instructional strategies, gaps in teacher training, and limited access to tailored educational resources. Digital math tools have emerged as promising interventions to bridge these gaps, offering personalized learning experiences that address diverse student needs. This study explores the effectiveness of digital math tools in enhancing problem-solving skills for students with special needs in U.S. public schools. Drawing from a comprehensive review of existing literature, the study examines the role of teacher preparedness, the adaptability of digital interventions, and the integration of evidence-based frameworks like the concrete–representational–abstract (CRA) approach. Findings highlight the potential of digital tools, such as virtual manipulatives and adaptive learning platforms, to improve mathematical outcomes and engagement for students with special needs. The research also underscores the critical importance of ongoing professional development for educators and the design of more inclusive, technology-supported instructional environments. These insights contribute to advancing inclusive education practices and improving long-term academic and developmental outcomes for students with special needs.

Keywords: Learning Disabilities (LD); Special Needs; Digital Math Tools; Adaptive Learning

1. Introduction

Students with special needs, particularly those with learning disabilities (LD) and emotional/behavioral disorders (EB/D), often face unique challenges in developing mathematical problem-solving skills. These skills require the integration of foundational arithmetic and higher-order thinking, areas that many students with LD and EB/D struggle with due to cognitive demands [1]. Moreover, gaps in teacher preparation exacerbate these challenges, as general education teachers frequently lack specialized training to address the needs of such students effectively [2].

The challenges associated with mathematical learning difficulties extend far beyond the classroom. Developmental learning disorders, particularly those affecting numeracy, can significantly impact various aspects of a child's development and future prospects. For children, low numeracy is linked to poor academic achievement, reduced self-esteem, and heightened risks to mental health [3]. As these individuals transition into adulthood, mathematical difficulties may limit career opportunities, hinder daily independence, and contribute to a diminished quality of life [4, 5, 6. 7]. Despite efforts to classify these difficulties, significant variability exists in their severity, causes, and developmental trajectories, making it challenging to establish a universally accepted framework [8, 9, 10].

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Digital math tools, such as interactive apps, gamified platforms, and adaptive software, have emerged as promising solutions to these challenges. By offering individualized and engaging learning experiences, these tools can reinforce foundational skills, provide visual and auditory support, and foster deeper understanding. For students with LD and EB/D, such tools offer potential not only to improve problem-solving skills but also to boost engagement and academic outcomes.

This study evaluates the effectiveness of digital math tools in enhancing mathematical problem-solving skills for students with special needs. It aims to assess their immediate impact on skill acquisition and their longer-term influence on student engagement and academic performance. By exploring these dimensions, this research seeks to contribute to more inclusive and effective educational practices.

1.1. Challenges in Mathematics Education for Students with Special Needs

Between 5% and 8% of school-age children have memory or cognitive deficits that significantly interfere with their ability to learn concepts or procedures in one or more mathematical domains [11]. These deficits are associated with challenges in working memory, processing speed, and executive functioning, which hinder students' ability to grasp abstract concepts and apply learned skills to problem-solving tasks. This research identifies three subtypes of mathematics learning disabilities and emphasizes the need to link findings in mathematical cognition with learning disability interventions to better support these students.

Furthermore, traditional teaching methods often fail to address these specific needs, leaving students disengaged and underperforming. Additionally, the lack of adaptive instructional approaches further exacerbates difficulties, as these methods do not consider the unique cognitive and neural challenges faced by students with LD [2].

1.2. The Role of Teacher Preparation

Effective instruction for students with special needs hinges on specialized training. DeSimone and Parmar [12] identified notable gaps in teacher preparedness, especially among middle school mathematics educators. These gaps include limited comprehension of inclusive teaching strategies and insufficient collaboration between general and special education teachers. To address these challenges, enhanced teacher education programs that prioritize evidence-based practices and foster collaborative approaches are essential.

Moreover, middle school mathematics teachers frequently report difficulties in supporting students with learning disabilities (LD) in inclusive classrooms. Challenges include a lack of understanding of these students' unique learning needs and inadequate preparation through preservice and inservice teacher training programs. Research highlights the effectiveness of instructional strategies such as summarization techniques, peer mediation, computer-assisted instruction, graphic organizers, and alternative text forms in helping students with disabilities comprehend complex subjects like science and social studies [13]. These strategies could be adapted to mathematics instruction to foster problem-solving skills in inclusive educational settings.

1.3. Teacher Training, Self-Efficacy, and Perspectives on E-Learning Tools

The integration of technology into teaching mathematics is a critical area in special education, requiring adequately trained and confident educators. A study by Baglama et al. [14] emphasizes the importance of preparing special education teachers to effectively use technology in their instructional practices. Teachers' self-efficacy beliefs and technology-related knowledge significantly influence their ability to integrate these tools into math instruction successfully.

This study provides a comprehensive perspective on the views of special education teachers regarding the use of technology in teaching mathematics. It highlights that while teachers recognize the benefits of technology in facilitating the teaching of various mathematical concepts and skills, they also face challenges such as internet connectivity issues and lack of feedback from technological devices.

Further supporting these findings, qualitative research conducted in North Cyprus involving 15 special education teachers revealed that educators perceive themselves as competent in using technology to teach mathematics to students with special needs. Using a semi-structured interview form and content analysis, the study found that teachers value technology for its potential to enhance student achievement and facilitate individualized learning in mathematics. However, it also highlighted the need for ongoing training and resources to ensure teachers can fully leverage these tools to meet diverse student needs [14.

Building on these insights, Wen et al. [15] explored the challenges and effectiveness of e-learning tools for students with specific learning disabilities (SLD) through semi-structured interviews with middle school math teachers. The study revealed that while teachers utilized various math e-learning tools, these tools were often not tailored to the unique needs of students with SLDs, limiting their effectiveness. Teachers emphasized the importance of developing adaptable tools and incorporating their insights into the design process to ensure greater efficacy in addressing individual learning challenges.

Together, these studies underscore the critical role of teacher preparation, self-efficacy, and collaboration in optimizing technology integration. They highlight the necessity for innovative, adaptable e-learning tools and ongoing professional development to enhance instructional practices in special education mathematics.

1.4. Effectiveness of Digital-Based Interventions and Benefits of Digital Math Tools

Recent research highlights the potential benefits of digital-based interventions for students with mathematical learning difficulties. A meta-analysis by Benavides-Varela et al. [16] examined the effectiveness of these digital interventions, revealing a mean effect size of 0.55, which indicates a moderate positive impact on students' mathematical performance. However, the effectiveness of digital tools is not uniform across all contexts. A study by Wen et al. [15] found that existing e-learning tools are often insufficiently effective or inclusive for students with specific learning disabilities (SLD), underscoring the need for more tailored and adaptable digital resources to meet diverse learner needs.

In addition to these findings, teacher adaptability plays a key role in optimizing the effectiveness of digital-based interventions. Research on adaptive teaching practices in mathematics (spanning 1975–2014) emphasizes the importance of three key elements: (a) a stimulus, or something to which the teacher must attend; (b) teacher metacognition and reflection, or interpretation and analysis; and (c) teacher action, or response. These elements are crucial when integrating digital tools into the classroom. For example, teachers must use digital tools not only to enhance learning but also as stimuli that guide their metacognitive reflections on students' progress. This can involve modifying curricula, selecting appropriate digital tools, or adapting classroom discourse to better suit the technological interventions in place [17].

Technology-supported math instruction, particularly through digital tools like virtual manipulatives, has been identified as an effective strategy to assist students with disabilities in achieving parity with their peers. Bouck et al. [18] discuss how virtual manipulatives and other digital tools offer accessible and effective methods for teaching mathematical concepts, providing students with opportunities to interact with and visualize math in new ways, which facilitates deeper understanding. However, these tools' successful integration requires adequate teacher training and a supportive infrastructure.

In addition to virtual manipulatives, adaptive learning platforms such as Istation Math provide personalized learning paths that adjust to individual student progress. These platforms support problem-solving by breaking down complex tasks into manageable steps, providing immediate feedback, and offering multiple representations of mathematical concepts, which are particularly beneficial for students with special needs [19].

Further supporting the effectiveness of digital tools, Basham et al. [20] demonstrated that technology-enhanced learning environments can increase engagement and academic performance for students with disabilities. Similarly, Bouck et al. [20] the concrete–representational–abstract (CRA) instructional framework has been identified as an evidence-based practice for students with learning disabilities who struggle in mathematics. By applying quality indicators and evidence-based practice standards [22], research has determined that the CRA framework effectively supports students in tackling computational problems, such as addition, subtraction, and multiplication, particularly those involving regrouping. This hands-on, structured approach enhances conceptual understanding and problem-solving skills, making it a valuable tool for educators working with students with learning disabilities.

The Institute of Education Sciences (IES) highlights the advantages of using virtual manipulatives as tools to support students in learning mathematical concepts, particularly fractions. According to IES, virtual manipulatives allow students to interact with digital shapes and representations on a screen, helping them to better visualize and understand complex ideas such as fractions [23]. Furthermore, IES-funded initiatives, like the HALF (Helping At-risk and Low-achieving students in Fractions) system, emphasize the integration of intelligent tutoring systems with virtual manipulatives. This approach anchors new learning within familiar contexts, enhancing students' conceptual understanding and problem-solving skills [24].

Together, these studies underscore the potential of digital tools in enhancing mathematical problem-solving skills for students with LD. However, they also highlight the importance of developing tools specifically designed to meet the unique needs of these students and the critical role of teacher training in effectively integrating technology into mathematics instruction.

2. Conclusion

The findings of this research underscore the transformative potential of digital math tools in enhancing problem-solving skills for students with special needs. These tools provide opportunities for personalized, engaging, and adaptive learning, addressing the unique cognitive and emotional challenges faced by students with LD and EB/D. Technologies such as virtual manipulatives and adaptive learning platforms, when integrated effectively, have demonstrated significant improvements in student outcomes.

However, the success of these interventions' hinges on several factors, including the quality of teacher training and the development of tools that align with the specific needs of diverse learners. The research highlights the importance of teacher preparedness, self-efficacy, and collaboration in leveraging digital tools to foster inclusive mathematics instruction. Furthermore, incorporating evidence-based practices like the CRA instructional framework into digital learning environments can significantly enhance the conceptual understanding and problem-solving abilities of students with special needs.

To maximize the benefits of these tools, stakeholders must invest in professional development programs, robust infrastructure, and ongoing collaboration between educators, researchers, and technology developers. By addressing these factors, digital math tools can play a pivotal role in creating equitable and effective learning opportunities, empowering students with special needs to achieve academic success and greater independence in their future endeavors.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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