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Exploring the effect of augmented reality in enhancing motivation and mathematics performance for children with learning disabilities

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Abstract

This research aims to explore the effect of integrating augmented reality in mathematics education, motivation, and academic achievement on children with learning disabilities, focusing on subtraction skills. A concurrent mixed-methods design was used, with the control group receiving traditional instructional approaches supported by conventional educational materials. The data were collected using the ARCS survey, mathematics test, and interview. The quantitative data were analyzed using a descriptive approach. The qualitative data were used in thematic analysis, "bottom-up". The results show an improvement in learners' motivation, and both groups showed a significant improvement in subtraction skills, although no differences were observed in the academic achievement of the two groups. A small sample size limits the generalizability of these findings.

Keywords: children with learning disabilities, augmented reality, motivation, mathematics performance, mathematics education, primary education

INTRODUCTION

Learning disabilities (LD) are among the most complex educational challenges faced by education systems worldwide, as they affect learners' ability to acquire fundamental academic skills such as reading, writing, and mathematics, despite having average or above-average intelligence (American Psychiatric Association, 2022; Fletcher et al., 2021). Among these disabilities, mathematics learning difficulties–particularly dyscalculia–pose significant barriers to students' academic progress, causing persistent problems in understanding numerical concepts, performing arithmetic operations, and solving problems (Butterworth et al., 2020; Geary, 2023).

Ouyang et al. (2024), Ziadat (2022), and Deda et al. (2024) view dyscalculia as a developmental learning disorder characterized by weakness in mathematics. It is characterized by significant and persistent difficulties in learning academic skills, particularly arithmetic, resulting from a lack of understanding of basic arithmetic operations. It represents a central nervous system disorder that causes unexplained difficulties in acquiring mathematical concepts and skills in some students (Papadaki & Karagianni, 2023). Students with dyscalculia have difficulties in domain-general abilities (i.e., impaired attention, working memory, visual memory, verbal memory, and executive functions) and domain-specific (numerical) abilities (i.e., impaired understanding of the abstract meaning of numbers and quantitative relationships, performing arithmetic operations, representing numerical magnitudes, and number perception) (Deda et al., 2024; Ouyang et al., 2024; Piazza et al., 2010; Szűcs, 2016).

In response to the growing need to improve learning outcomes for students with LD, researchers and educators have increasingly adopted innovative instructional strategies that combine effective teaching methods with advanced technologies. Augmented reality (AR) has emerged as one of the most promising tools in this field, as it offers an interactive learning environment enriched with visual, auditory, and kinesthetic stimuli, thereby enhancing students' motivation and deepening their understanding of abstract concepts (Asatryan et al., 2023; Lin et al., 2016).

Recent studies have demonstrated that integrating AR into mathematics instruction can improve conceptual understanding, reduce mathematics anxiety,

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Contribution to the literature

- Children with LD in mathematics face obstacles that hinder their learning processes, including difficulty learning and understanding mathematical concepts, an inability to perform mathematical operations, poor memory and recall, difficulty understanding mathematical language, vocabulary, symbols, and word problems, as well as anxiety and negative attitudes toward learning mathematics.
- AR is a powerful teaching tool that can enhance conceptual understanding and significantly affect academic performance.
- It also enhances the motivation for students who consistently struggle with abstract numerical concepts.

and increase engagement in learning activities (Nasir et al., 2023; Pahmi et al., 2023), increase motivation, develop cognitive skills, improve memory, and enhance the enjoyment of learning mathematics (Ahuja et al., 2022). It also impacts the general ability domain and the affective domain (motivation and engagement in learning) of students with LD in mathematics, addressing difficulties associated with dyscalculia, mastering, exploring, and understanding mathematical concepts well, and developing confidence in performance and proficiency in the use of quantities and fractions compared to traditional learning methods (Aprinastuti et al., 2020; Dhingra et al., 2024; Miundy et al., 2017; Rohizan et al., 2020; Shin et al., 2021; Thapliyal & Ahuja, 2023).

Research Problem

Many students with dyscalculia suffer from learning difficulties characterized by impaired number representation, poor counting skills, deficiencies in procedural skills, and problem-solving skills, as well as limited working memory needed to retrieve mathematical facts and concepts (Geary, 2013; Gersten et al., 2009; Kroesbergen et al., 2023; Ouyang et al., 2024; Reid et al., 2013). Studies have shown that the use of traditional learning methods does not provide sufficient support for these students to overcome these difficulties and enhance the affective aspects of learning, such as motivation and engagement (Calabuig-Moreno et al., 2020; Hughes et al., 2023; Reid et al., 2013; Vakaliuk et al., 2020).

Studies have shown that digital technology has positive effects on learning difficulties in students with dyscalculia, as it improves students' understanding and representation of abstract mathematical concepts, enhances self-confidence, self-efficacy, and interest in mathematics, and fosters a passion for mathematics (Benavides-Varela et al., 2020; Dhingra et al., 2024; Fernández-Batanero et al., 2022; Thapliyal & Ahuja, 2023). One such technology is AR, which allows learners to interact with objects in virtual space (Miundy et al., 2017). This provides interactive and engaging learning experiences and enhances motivation and enjoyment of learning mathematics (Ahuja et al., 2022; Vakaliuk et al., 2020).

AR offers unique benefits for students with diverse learning needs by integrating digital information into the real world, building adaptable virtual personalized learning environments, creating interactive and therapeutic learning environments for children with special needs, providing soothing virtual sensory rooms to enhance sensory experiences, cognitive skills, and social interaction, creating interactive experiences that enhance learning and engagement, improve communication and social skills, and help with emotional regulation, reducing distractions, improving focus and attention, and increasing comfort and confidence (Alqassimi & Alghamdi, 2019; Asatryan et al., 2023; Chițu et al., 2023; Lee et al., 2016; Syafiq & Hakim, 2024; Yenioglu et al., 2021). This technique is particularly valuable for students with special educational needs to prepare them for real-life experiences, as it provides personalized support for these students and overcomes traditional learning barriers (Alqassimi & Alghamdi, 2019; Chițu et al., 2023; Syafiq & Hakim, 2024).

Therefore, the current study seeks to explore the effect of AR in enhancing the motivation and mathematics performance of children with LD. This study aims to answer the following two questions:

1. What is the effect of AR in enhancing the motivation of children with LD?
2. What is the effect of AR in enhancing the mathematics performance of children with LD?

Aims of Study

Building on this context, the present study aims to investigate the impact of integrating AR technology into mathematics instruction on both learning motivation and academic achievement among children with LD. Specifically, it compares the outcomes of two groups–one using traditional instructional approaches supported by conventional educational materials, and the other employing an AR-based application to practice subtraction skills. This study also seeks to provide deeper insights into how students with LD interact with technology-enhanced learning environments, contributing to the development of more effective and inclusive educational practices tailored to their needs.

LITERATURE REVIEW

Children With Learning Disabilities

Education faces many challenges, particularly in supporting students with specific learning difficulties. According to the World Health Organization (2015), 15% of the world's population suffers from some form of disability, and special education aims to meet the needs of these individuals and overcome their difficulties (Doğan & Delialioğlu, 2020)

Children with LD face significant challenges that profoundly affect their academic performance and social interactions. LD refer to a variety of disorders that affect an individual's ability to acquire, understand, and use specific academic skills, such as reading, writing, mathematical reasoning, and understanding spoken or written language (Apostolidou & Karagianni, 2025). LD are defined as neurodevelopmental disorders, LD impacts the ability to acquire and apply essential skills in areas such as reading, writing, and mathematics (American Psychiatric Association, 2022). These difficulties are not attributable to intellectual deficits, sensory impairments, or environmental factors, but rather reflect specific processing deficits that interfere with learning.

As emphasized by Fletcher et al. (2021), LD encompasses a spectrum of disorders, including dyslexia (reading), dyscalculia (mathematics), and dysgraphia (writing), each presenting unique barriers to academic success. Dyscalculia, in particular, is characterized by persistent difficulties in understanding numerical concepts, performing calculations, and solving mathematical problems (Geary, 2023). These challenges often extend beyond academics to daily activities requiring numerical reasoning, such as budgeting and time management.

Recent studies underscore the importance of early and accurate diagnosis in addressing LD effectively. Comprehensive evaluations that consider cognitive and behavioral factors are essential for identifying specific areas of need (Waters & Lucas, 2023). Innovative tools, such as the KeyMath diagnostic assessment, have been developed to pinpoint difficulties in mathematics and guide targeted interventions. Additionally, advancements in inclusive education emphasize collaborative strategies to support students with LD, as discussed by Papadakaki et al. (2022), who highlight the necessity of tailoring interventions to individual needs.

Challenges in Mathematics for Children With Learning Disabilities

Children with LD in mathematics face distinct obstacles that significantly impede their academic progress. These challenges can be categorized into several key areas:

Weak number sense

Students with LD often struggle to grasp basic numerical concepts, such as quantity, magnitude, and the relationships between numbers (Butterworth et al., 2020). These foundational gaps hinder their ability to perform arithmetic operations like addition and subtraction, which are essential for more advanced mathematical tasks.

Memory and retrieval deficits

Working memory deficits are common among children with LD, making it difficult for them to retain and manipulate numerical information during problem-solving (Geary, 2023). This limitation also affects their ability to retrieve basic math facts, leading to slower processing speeds and heightened frustration (Ashcraft & Krause, 2021). Apostolidou & Karagianni (2025); Szűcs (2016) explained that one subtype of mathematics learning difficulties is associated with reading difficulties and impaired verbal short-term memory and working memory. Another subtype of mathematics learning difficulties is associated with impaired visuospatial short-term memory and working memory. Understanding mathematics learning difficulties requires a precise definition of the memory processes associated with supporting executive functions, relevant to mathematical learning.

Difficulty understanding mathematical language, mathematical vocabulary, symbols, and word problems

They present significant challenges for children with LD. They often struggle to interpret abstract concepts and apply them in practical situations, understand basic arithmetic operations, and grasp the meaning of numbers, sequences, and quantitative relationships. leading to confusion and difficulty solving complex problems (Aprenastouti et al., 2020; Dida et al., 2024; Fletcher et al., 2021; Kuhn et al., 2020).

Anxiety and negative attitudes

Math anxiety is prevalent among children with LD and can lead to a cycle of avoidance and poor performance (Ashcraft & Krause, 2021). This anxiety exacerbates their struggles, creating barriers to academic success. However, targeted interventions, such as fostering a growth mindset and using relaxation techniques, have been shown to build confidence and improve mathematical outcomes (Geary, 2023).

Augmented reality in Mathematics Education for Children With Learning Disabilities

Assistive technology plays a pivotal role in supporting students with LD in mathematics, enhancing their educational/learning experiences and outcomes

(Drljić & Doz, 2025). One of these technologies is AR, which helps the learner to work on his weak areas in mathematics, develop cognitive skills, and improve memory (Ahuja et al., 2022; Cevikbas et al., 2023; Dhingra et al., 2024). It represents a promising direction in improving the learning of students with LD by providing an interactive and engaging learning environment and works to bridge the gap between abstract mathematical concepts and concrete understanding (Dhaas, 2024; Ruiz Muñoz, 2024). It is defined as an enhanced visualization of real images by adding virtual objects such as text, images, sound, animation, video clips, and 3D models (Sirakaya & Cakma, 2018). It is also defined as an enhanced representation of the real environment by adding computer-generated virtual elements (Koumpouros, 2024).

Recent studies highlight the growing interest in AR for mathematics education. AR has been found to positively impact academic performance, motivation, and three-dimensional thinking skills (Erşen & Alp, 2024). It enhances student engagement, comprehension, and problem-solving abilities through immersive, interactive experiences (Nasir et al., 2023). AR supports learning, motivation, and spatial abilities (Palanci & Turan, 2021). AR's effectiveness in addressing learning barriers, mathematical anxiety, and cognitive problems has been noted (Pahmi et al., 2023).

AR has shown promising potential in improving mathematics education for children with LD. It provides immediate feedback and adaptive learning paths that allow students with LD to be repeatedly exposed to abstract mathematical concepts (Chang et al., 2025; Vashisht, 2024). AR systems also track student progress, identify areas of difficulty, and adjust task complexity, accordingly, providing targeted support and guidance, and creating a realistic environment rich in stimuli and visual cues (Lytvynova & Soroko, 2023; Herpich et al., 2019).

The growing interest in AR in teaching mathematics to students with LD is due to its reliance on several theoretical and conceptual frameworks that highlight its potential for learning, skill enhancement, and affective aspects. These include cognitive load theory, which is linked to learning and teaching design. This theory suggests that learning improves when the learning material reduces the external cognitive load (processing unnecessary information and unnecessary details) and increases the relevant cognitive load (engagement in deep cognitive processing). AR achieves this by presenting abstract mathematical concepts and ideas in a sensory manner rich with visual stimuli, breaking down the mathematical problem into simpler sub-problems to make it more realistic, and building mental and visual representations of mathematical concepts and ideas, which reduces the effort placed on the working memory of students with mathematics LD who suffer from weaknesses in processing mathematical information (Sweller, 1988, 2005).

Also, AR is based on constructivist theory, which assumes that the learner builds understanding and knowledge of the world through experience, learning by doing, experiencing things, and reflecting on them. This occurs through AR environments that enable students to participate actively, actively receive information, actively interact with virtual objects, experience mathematical concepts to build a tangible understanding of them, see the relationships between mathematical concepts tangibly, and interact with virtual three-dimensional mathematical objects and manipulate them sensorily and visually, such as rotating geometric shapes virtually (Mohamad et al., 2024; Piaget, 1970).

Studies have demonstrated that AR can improve students' ability to complete geometric tasks independently, enhance learning motivation, and increase frustration tolerance (Lin et al., 2016). AR-based interventions, often combined with video modeling and explicit instruction, have been effective in teaching various mathematical concepts, including geometry, integer operations, and unit conversions (Kellems et al., 2020; Morris et al., 2021; Ryan, 2020). These interventions have significantly improved problem-solving skills and the ability to apply learned concepts to new situations, reducing cognitive load and increasing self-efficacy, promoting a more positive attitude towards mathematics (Alahmari et al., 2023). For example, the study by Morris et al. (2021) examined the effects of combining video modeling, explicit instruction, and AR to teach mathematics to two 8th grade students with disabilities. They found that the intervention had a strong positive effect on their performance across four math skills, with high levels of maintenance and generalization. Other example is in Ryan's (2020) study examined the effectiveness of using an AR-based video intervention to teach four types of multistep math problems to seven middle school students with specific LD, found that the intervention led to significant improvements in the students' problem-solving skills.

AR technology has also been successfully integrated with physical and digital modeling to develop process skills and mathematical concepts in geometry for students with mathematical LD (Haas et al., 2021; Schutera et al., 2021). Schutera et al. (2021) found that AR applications can provide interactive, visual representations of abstract concepts, making them more accessible and engaging. Studies have demonstrated positive outcomes when using AR in mathematics education, including improved understanding and reduced stress for students with learning difficulties (Bulut & Ferri, 2023; Lazo-Amado et al., 2022).

AR provides a new and different approach to educating students with LD, which is needed to better support their learning compared to the traditional educational approaches which can be challenging and frustrating for students with LD, leading to a loss of interest in education. It can enhance the learning ability of students with LD by making the learning process more interactive and enjoyable (Asatryan et al., 2023). Asatryan et al. (2023) used AR technology with children aged 7-10 years old. The aim is to improve learners' attention and engagement. They found that the use of AR applications increases learners' motivation and enjoyment, and this increase their understanding of mathematics concepts.

MATERIALS AND METHODS

This study used a mixed-methods sequential explanatory design. This design combines quantitative research design and qualitative research design. Mixed methods research involves collecting quantitative and qualitative data, and analysis of the data integrates both forms of data. The initial phase, quantitative data was gathered through motivation and academic achievement to explore learners' motivation and academic achievement. After analysis the data, a follow-up interview was conducted with the teacher (Creswell, 2014). The interview aimed gain insights into the teacher's views on integrating AR into mathematics practices in mathematics practices activities and to understand the reason for their motivation or demotivation.

Sample and Research Context

This study's participants were children aged 8-9 years old in second grade. They are from one of integration schools in the eastern Saudi Arabia. The participants were four learners with LD, two girls and two boys. The children were diagnosing as learners with learning difficulties under the admission requirements for the learning disabilities program by Saudi Ministry of Education (MoE).

The children were categorized as: G1 the girl in the CG, B1 is the boy in the CG, G2 is the girl in GG and B2 is the boy in the CG.

One female teacher was involved in this study. The teacher has bachelor's degree in special needs and master's degree in guidance and psychological counselling. She has eleven years' experience in teaching learners with LD.

One of the integrating schools was chosen to conduct the research. Integration schools are the school that approved by MoE (2025) to accept students with disabilities in normal schools. MoE (2025) integrates students with disabilities into normal schools. The aim is to develop their academic, social, and personal skills, raise their academic achievement, improve their learning outcomes, and ensure they receive appropriate education, training, and rehabilitation. According to MoE (2025), students with disabilities are taught in general education classes with their peers, while a resource room is provided with the necessary spatial and resources based on the students' needs. General education plans and curricula are also provided to them, with the curriculum adapted to the student's individual educational plan. Spatial integration is implemented in general education schools through classes attached to schools, with a specialized curriculum tailored to the needs of students with disabilities, with the goal of integrating them with their peers within the school community. The service is provided by a special education teacher, with the aim of educating and professionally qualifying them.

Research Tools

The survey that was used in this study was developed by Keller (1987). The model is designed to enhance and maintain motivation in educational settings. It works to increase learner attention to the learning topic, increase learner confidence in the learning material, connect the material to its benefits in daily life, and achieve learner satisfaction with the learning process and the learning material (Keller, 1987). The model is based on expectancy-value theory, which contains two components: the value of the desired goal and the expectation of successfully achieving that goal (Keller, 1984).

The model consists of four components: attention section has five items that capture learners' interest; it refers to the focus of attention learners give to an idea or topic. Relevance section has four items that learners need to see the value in what they are learning and refers to the meaning or importance attributed to an idea or concept. Confidence section has three items that test students' confidence, which show clear objectives, feedback, and a sense of achievement, indicating students' belief in their ability to succeed. The last section is satisfaction. This section has six items that test learners' feelings of success and see the results of their efforts, their motivation, and motivation, and refers to the feeling of satisfaction when a need or desire is met. The answering method includes a 5 Likert scale ranging from 1 = strongly disagree to 5 = strongly agree.

The app was used in this study is titled "math skills subtraction". It was designed for children aged 4 and older, focusing on early math skills, particularly subtraction. The goal is to enhancing learning through interactive methods. The app is designed with large buttons, simple text, and intuitive navigation to cater to children. It randomly presents subtraction questions (e.g., "4 - 2 = ?", "8 - 2 = ?", etc.) that require children to think and respond. The main interface shows various subtraction problems, with colorful circles highlighting the numbers involved in each question. Children can likely see problems displayed in their surroundings and interact with virtual objects superimposed on their real environment by using device's camera.

The selection of AR technology for this study was based on its proven potential to enhance student engagement, motivation, and conceptual understanding, particularly among learners with mathematics learning difficulties (Asatryan et al., 2023; Lin et al., 2016). AR provides an interactive and multisensory learning environment that bridges the gap between abstract concepts and real-world applications, which is especially beneficial for children with LD who require concrete, visual, and hands-on experiences. The "math skills subtraction" application was specifically chosen due to its alignment with the study's learning objectives, its age-appropriate design for young learners, and its features that combine gamification with immediate feedback. These characteristics make it a suitable tool for reinforcing subtraction skills while maintaining high levels of learner motivation.

The app has some of gamification elements for example there is a counter showing "questions left" and the number of correct answer where users can see their progress. The app also provides immediate feedback.

The mathematics performance test was developed by the teacher and reviewed by the educational supervisory body.. The test has 10 questions that measure the level of recall and comprehension. The children should answer 8-10 questions correctly. The tests were given to the children two times before and after the intervention.

The study tools, the test and survey, were applied to 5 students classified as having learning difficulties, who are different from the students participating in the research.

To strengthen the description of the mathematics performance test, it is recommended to include details regarding its validity and reliability. For example, the process of establishing content validity could involve having the test reviewed by subject matter experts to ensure alignment with the learning objectives and curriculum standards. Reliability could be assessed using statistical measures such as Cronbach's alpha to determine internal consistency, or through a test-retest method to confirm score stability over time. Including these details would enhance the credibility and replicability of the study.

Semi-structured interview was then conducted with the teacher. The interview was conducted after the analysis of the data to gain better understating of the results. The interview was audio-recorded, and hand notes were also taken. The teacher was typically asked about her opinion on the implementation of AR technology with learners with LD. The interview was 20 minutes.

Research Processes and Implementation of Experimental Treatment

The children undertook mathematic classes with their normal peers and then they must revise and practice the mathematics concept in learning resource room (LRR). The available materials in LRR including whiteboard, the Internet connection, digital and physical gams and hand-on activities.

To this research, the children were divided into two groups. Each group has two learners one boy and one girl. The first group is the control group (CG) and the second group is the game group (GG). The children completed mathematics classes with their normal peers, the teacher then took them to LRR. Each group has its own time in LRR. The teacher in the LRR revised lessons- the subtraction lesson in this research- using the whiteboard, YouTube and other games and then she gave them time to practice by themselves. The children should complete at least three worksheets.

Both groups did the mathematics test and surveyed tow times (before and after the intervention). Both groups can revise the mathematics concept using the material in the LRR. CG then used paper worksheets to practice the mathematics concept as is mentioned in the learning objectives and they must complete at least three worksheets each has 10 questions to make sure that they understand the concept. For GG "bolt on" model was applied. The model allows teachers to explain mathematical concepts and processes using different learning approaches, further engaging within advanced technologies to practice the mathematics concepts (Alghamdi, 2019). In this case GG used the AR "math skills subtraction" App to practice the lesson.

Before the use of the AR App, we make sure that the children can use the app correctly and understand the aim of the game is to practice not for play.

This research focuses on topic of subtracting. The short-term objective of this lesson is: A learner will subtract two numbers within the number 12 by solving 8 out of 10 problems given to them on a sheet of paper. The expected number of weeks to achieve this objective is one to two weeks.

Data Analysis

Descriptive statistics were used to analyze the test. The survey result was analysis manually and the results were presented case by case. In terms of analysis qualitative data, the interviews audio transcript was transcribed into word documents in the original interview language (Arabic). The documents were analyzed and then translated into English. This study followed thematic analysis "bottom-up" developed by Braun and Clarke (2006) for identifying, analyzing, and reporting patterns.

Table 1. Cronbach's alpha values

Items	Number of questions	Cronbach's alpha values
Attention	5	0.9
Relevance	4	0.9
Confidence	3	0.8
Satisfaction	6	0.9

Validity and Reliability

The survey was conducted, and Cronbach's alpha values were checked. The survey was developed using paper, was gives to the learners.

Cronbach's alpha values were calculated to test the reliability of the survey questions. Values for Cronbach's alpha indicated high internal consistency bigger than 0.7 (**Table 1**).

To establish validity for qualitative data, a researcher must check for accuracy by employing strategies such as rich and thick descriptive data (Creswell, 2014). This study therefore used a rich and thick descriptive dataset and maintained an audit trail of all analysis processes. Interview was recorded and transcribed into text documents that were retained for recordkeeping.

RESULTS

The Effect of Augmented Reality on Enhancing Motivation for Children With Learning Disabilities (Comparison of Arcs Survey)

This section presents the results for ARCS at the beginning (pre-survey) and end of the sessions (post-survey) for each case in CG and GG.

The results for the cases in CG are presented in **Table 2** and **Table 3**.

Case 1 is G1 is a girl in the CG. **Table 2** present the results for ARCS survey for pre- and post-survey.

The final findings from this case show that there are no differences between G1's motivation before and after doing the sessions using paper worksheets. G1 shows strong motivation in nearly all categories. Confidence and satisfaction scored perfect agreement. However, there are slight concerns with attention and relevance.

At attention category at pre- and post-survey (**Table 2**) show that G1 feels neutral about the statement "mathematics material fascinates me". Further, G1 has no answer in the statement "this material makes me want to continue learning". At relevance category at pre- and post-survey in **Table 2**, G1 has no responses on the statement "this material allows me to fully understand the concepts that are being expressed".

Table 2. The result of ARCS pre- and post-survey for G1

Category		TI	SA2	Neutral	SD2	No answer
Attention	Pre-survey	5	3	1 (this material fascinates me)	0	1 (this material makes me want to continue learning)
	Post-survey	5	3	1 (this material fascinates me)	0	1 (this material makes me want to continue learning)
Relevance	Pre-survey	4	3	1 (this material allows me to fully understand the concepts that are being expressed)	0	
	Post-survey	4	3	1 (this material allows me to fully understand the concepts that are being expressed)	0	
Confidence	Pre-survey	3	3	0	0	
	Post-survey	3	3	0	0	
Satisfaction	Pre-survey	6	6	0	0	
	Post-survey	6	6	0	0	

Note. TI: Total items; SA2: Strongly agree/agree; & SD2: Strongly disagree/disagree

Table 3. The result of ARCS pre- and post-survey for B1

Category		TI	SA2	N	Strongly disagree/disagree	NA
Attention	Pre-survey	5	4	0	1 (this material boots my learning motivation)	
	Post-survey	5	4	0	1 (this material boots my learning motivation)	
Relevance	Pre-survey	4	3	0	1 (this material teaches me how to apply knowledge that I have learnt from class)	
	Post-survey	4	3	0	1 (this material teaches me how to apply knowledge that I have learnt from class)	
Confidence	Pre-survey	3	3	0	0	
	Post-survey	3	3	0	0	
Satisfaction	Pre-survey	6	6	0	0	
	Post-survey	6	6	0	0	

Note. TI: Total items; SA2: Strongly agree/agree; N: neutral; & NA: No answer

Table 4. The result of ARCS pre- and post-survey for G2

Category		TI	SA2	Neutral	Strongly disagree/disagree	NA
Attention	Pre-survey	5	2	1 (this material fascinates me)	2 (this material boots my learning motivation & makes me want to continue answering)	
	Post-survey	5	5	0	0	
Relevance	Pre-survey	4	0	0	0	
	Post-survey	4	4	0	0	
Confidence	Pre-survey	3	3	0	0	
	Post-survey	3	3	0	0	
Satisfaction	Pre-survey	6	4	0	2 (I feel satisfied when I answer a question correctly & the number of questions that I answer correctly increase)	
	Post-survey	6	6	0	0	

Note. TI: Total items; SA2: Strongly agree/agree; & NA: No answer

Table 5. The result of ARCS pre- and post-survey for B2

Category		TI	SA2	Neutral	SD2	NA
Attention	Pre-survey	5	2	3 (this material fascinates me, boots my learning motivation, & helps me to focus on my studying)	0	
	Post-survey	5	5	0	0	
Relevance	Pre-survey	4	4	0	0	
	Post-survey	4	4	0	0	
Confidence	Pre-survey	3	3	0	0	
	Post-survey	3	3	0	0	
Satisfaction	Pre-survey	6	6	0	0	
	Post-survey	6	6	0	0	

Note. TI: Total items; SA2: Strongly agree/agree; SD2: Strongly disagree/disagree; & NA: No answer

Case 2 is B1 is a boy in the CG, the results for ARCS pre- and post-survey present in **Table 3**.

The final findings from this case show that there are no differences between B1's motivation before and after mathematics sessions. B1 displays strong motivation in nearly all categories. Confidence and satisfaction scored perfect agreement. There are slight concerns with attention and relevance.

At attention category at pre- and post-surveys (**Table 3**) show that B1 strongly disagrees with the statement "math material boosts my learning motivation".

At relevance category the results present in **Table 3**, B1 at both surveys strongly disagrees with the statement "this material teaches me how to apply knowledge that I have learned from class".

The results for ARCS at the beginning (pre-survey) and end of AR sessions (post-survey) for each case in GG.

Case 2 is B1 is a boy in the CG, the results for ARCS pre- and post-survey present in **Table 3**.

Case 3 is G2 is a girl in the GG. **Table 4** presents the results for ARCS pre- and post-survey.

The final findings from this case show that there are slight differences between G2's motivation before and after the AR sessions. G2 expresses strong motivation in nearly all categories. Relevance and confidence scored perfect agreement. On the other hand, there are slight concerns with attention and satisfaction at pre- survey. While her attention and satisfaction increase after the sessions of AR as shown in **Table 4**.

In attention category at pre-survey (**Table 4**), G2 feels neutral about the statement "this material fascinates me". Furthermore, she strongly disagrees with the statements "this material boosts my learning motivation" and "this material makes me want to continue answering".

In satisfaction category at pre-survey (**Table 4**), G2 responses strongly disagrees with the statements "I feel satisfied when I answer a question correctly" and disagrees with "I feel satisfied when the number of questions that I answer correctly increase".

Case 4 is B2 is a boy in the GG, **Table 5** presents the results for ARCS survey for ARCS pre-survey and we also presents the results for ARCS post-survey.

Case 3 is G2 is a girl in the GG, **Table 5** presents the results for ARCS pre- and post-survey.

The final findings are presented in **Table 5**. The results show that there are slight differences between B2's motivation before and after AR sessions. B2 expresses strong motivation in nearly all categories. Relevance, confidence and satisfaction scored perfect agreement. Only attention has slight concerns at pre-survey (**Table 5**). On the other hand, B2's attention increased after AR sessions as shown in **Table 5**. The attention category at pre-survey (**Table 5**) shows that B2 feels neutral about these statements "this material fascinates me", "this material boosts my learning

Table 6. The results for the mathematics performance tests

Student number	Group	Mathematics performance test	
		Pre-test 1	Post-test 1
G1	CG	1	8
B1		0	9
G2	GG	1	10
B2		0	10

motivation", and "this material helps me to focus on my studying".

The teacher in the interview was asked about the reason for the children in both groups at pre- and post-survey express strong motivation across most of the categories especially in the category of confidence and satisfaction. She said that "I taught them by using a variety of methods. I used applications, such as YouTube channel and "iEN Ethraia" website. I created PowerPoint practices slides and presented on the board".

The teacher was asked about the reason for them to have shorter attention and relevance spans when they engage in mathematics activities as was observed in the pre- and post-survey for CG and pre-survey in GG. She said that "mathematics classroom requires a lot of focus, the children with LD are processing difficulties that can make it harder for them to keep up. Also, they may become easily frustrated if they struggle to understand the content".

The teacher responded to concerns about the G2 student being the only one dissatisfied with the mathematics materials in the pre-survey. She explained, "The children are required to complete all activities, even if they get the answers correct initially. I provided additional activities to ensure they fully achieve the learning objectives. I believe this is why she became unhappy, despite having the correct answers.".

The Effect of Augmented Reality on Enhancing Mathematics Performance for Children With Learning Disabilities (Comparison of Mathematics Performance Test)

Summary results of pre- and post- mathematics for each learner is presented in **Table 6**. **Table 6** shows that all learners gained better results in post-test. The overall findings indicated that the children have lack of a correct understanding of subtract.

By looking to the pre-test papers, when analysis the way of thinking, the overall findings indicated that the children have lack of a correct understanding of subtract.

Sometimes they are confused with subtraction. For example, G1 treated all questions as additional and answered every question by combining the numbers instead of subtracting them (e.g., 1 - 1 = 2), showing a misunderstanding of the subtraction concept."

They sometimes might misunderstand the subtraction operator (-) as an instruction to combine rather than subtract "misunderstanding of mathematical symbols". G2 for example answered the questions by combining the numbers (e.g., 1 - 1 = 11, 8 - 8 = 88).

They sometimes provide random answers to some questions. Some answers do not reflect any clear mathematical logic, such as 10 - 1 = 4, 8 - 8 = 10 "manipulating digits" or guessing without clear understanding. This pattern was particularly common among the boys' answers.

In contrast, at the post test, the result shows there is no differences between CG and GG. The overall results show that the children in both groups achieved the learning objectives by answering at least 8 questions. This indicates there is significant improvement in understanding subtraction and the relationship between numbers for both groups. The children in the CG answered at least 8 questions in the post test. While children in GG answered all 10 questions correctly. The children developed better number sense and subtraction skills. They have a shift from symbolic/misunderstood thinking to conceptual understanding.

In the interview with the teacher, she was asked about the high scores in the final test for both groups, she stated "I incorporate technology for preparation, explanation, and evaluation. With hands-on activities and digital games displayed on the board, I try to engage the children effectively. I must make sure the children achieve the learning objectives before leaving LRR.

The teacher was asked about her opinion about the integration of AR in mathematics practices activities. She remarked, "it was amazing experience. With 11 years teaching children with LD, I have used various types of technology, but AR was new for me. The children were delighted playing together. Children in general have a natural need to move around, this technology makes them move around, play, and enjoy. The best part of the game is that it provides regular, positive feedback. This feature really helps me as I usually need to sit beside each child to offer feedback. Also, the children must complete at least 30 activities in each session, when they are using worksheets, they easily get bored but with the AR they do not want to stop".

These results set the stage for a deeper interpretation of how AR influenced students' motivation and mathematics performance, as discussed later.

DISCUSSION

The findings of this study indicate that integrating AR into mathematics instruction had a positive influence on students' motivation, particularly for the GG, while the CG maintained stable motivation levels. This result aligns with Lin et al. (2016), who reported that AR enhances engagement and allows students to work more independently, and with Asatryan et al. (2023), who found that AR applications increased attention and enjoyment among children with special needs. The improvement in the attention and satisfaction dimensions among GG students suggests that the interactive and game-like features of AR contribute to sustaining learners' interest and fostering a sense of accomplishment. The result is consistent with previous studies that confirmed that AR provides interactive and engaging learning experiences and enhances the emotional aspects of learning, such as motivation and engagement, and enjoyment in learning mathematics, compared to traditional learning methods that do not provide sufficient support for students with mathematics learning difficulties (Ahuja et al., 2022; Calabuig-Moreno et al., 2020; Hughes et al., 2023; Reid et al., 2013; Vakaliuk et al., 2020). This finding is also consistent with previous studies indicating that AR provides comfortable virtual sensory environments to enhance sensory experiences, engagement, and immersion in the learning process, promote emotional regulation, reduce distractions, improve focus and attention, and increase comfort and confidence (Alqassimi & Alghamdi, 2019; Asatryan et al., 2023; Chițu et al., 2023; Lee et al., 2016; Syafiq & Hakim, 2024; Yenioglu et al., 2021), enhancing self-confidence, self-efficacy, interest, and passion for mathematics among students with learning difficulties (Benavides-Varela et al., 2020; Dhingra et al., 2024; Fernández-Batanero et al., 2022; Thapliyal & Ahuja, 2023).

Despite these motivational gains, some students in both groups demonstrated relatively low scores in attention and relevance. This outcome can be understood in light of Geary (2023) and Ashcraft and Krause (2021), who noted that mathematics LD often involve working memory and attentional difficulties, making it challenging for students to maintain focus and connect learning activities to prior knowledge. The teacher's interview responses also confirmed that students with LD may become easily frustrated when encountering difficulties in understanding mathematical content, which can reduce their perceived relevance of the material.

In terms of academic performance, the results showed that both groups achieved significant improvements in subtraction skills after the intervention. This is consistent with Rahman et al. (2020) and Pahmi et al. (2023), who found that AR-based learning, when integrated with other instructional approaches, can produce comparable achievement outcomes to traditional methods while offering higher engagement. It also agrees with Drljić and Doz (2025) that assistive technologies such as AR play a pivotal role in supporting students with learning difficulties in mathematics and enhancing their teaching/learning experiences and outcomes. Furthermore, it aligns with the studies of Dhingra et al. (2024), Cevikbas et al. (2023), and Ahuja et al. (2022), which found that AR helps learners address their weaknesses in mathematics, develop cognitive skills, and improve memory. Finally, it aligns with the studies of Dhaas (2024) and Ruiz Muñoz (2024) argue that AR provides an interactive and engaging learning environment rich in stimuli, prompts, and visual cues, bridging the gap between abstract mathematical concepts and concrete understanding, thus improving the learning of students with LD. This aligns with studies by Chang et al. (2025), Vashisht (2024), Lytvynova and Soroko (2023), and Herpich et al. (2019), which demonstrate that AR adjusts task complexity, provides support and guidance for students with LD, and offers immediate feedback and adaptive learning pathways that allow for repeated exposure to abstract mathematical concepts.

The remarkable shift from conceptual misunderstandings–such as confusing addition and subtraction or misinterpreting mathematical symbols–to accurate problem-solving reflects the ability of AR and other multisensory strategies to deepen conceptual understanding (Haas et al., 2021; Ritchey & Goeke, 2021), as it builds an enhanced perception of images and the real environment by adding virtual objects such as text, images, sound, animation, video, and 3D models (Koumpouros, 2024; Sirakaya & Cakma, 2018).

Overall, the results indicate that while AR is not the sole factor influencing mathematics achievement, it plays a key role in enhancing learning experiences, maintaining student motivation, and supporting conceptual clarity, improving conceptual understanding, mastering, exploring, and comprehending mathematical concepts, reducing mathematics anxiety, promoting engagement in learning activities, and developing motivation, confidence in performance, and proficiency in using quantities and fractions (Bahmi et al., 2023; Nasser et al., 2023).

These findings can generally be interpreted in light of cognitive load theory. AR, by presenting abstract mathematical concepts and ideas in a sensory manner rich with visual stimuli, breaking down mathematical problems into simpler sub-problems to make them more realistic, and constructing mental and visual representations of mathematical concepts and ideas–engaging in deep knowledge processing–increases the relevant cognitive load and reduces the strain on working memory for students with mathematical learning difficulties who struggle with processing mathematical information. Furthermore, it avoids focusing on unnecessary information and details, thus reducing the external cognitive load (Sweller, 1988, 2005). AR significantly improved problem-solving skills and the ability to apply mathematical concepts in new situations, reducing cognitive load, increasing self-confidence, and fostering positive attitudes towards mathematics (Al-Ahmari et al., 2023). It can also be explained in light of constructivist theory, where the learner builds understanding and knowledge of the world through Learning by doing, experimentation, and reflection. This occurs through AR environments that enhance motivation and enable students to actively participate, experience information, and interact effectively with virtual objects and mathematical concepts to build a tangible understanding of them and see the relationships between mathematical concepts in a concrete way (Mohamad et al., 2024; Piaget, 1970). The integration of AR into inclusive classrooms can therefore serve as a complementary strategy to existing teaching methods, particularly for students who benefit from interactive, feedback-rich environments.

CONCLUSIONS

This study examined the impact of integrating AR into mathematics instruction on motivation and academic achievement among children with LD.

This study aimed to investigate the impact of integrating AR technology into mathematics education on both the learning motivation and academic achievement of children with LD. It also sought to provide deeper insights into how students with LD interact with technology-enhanced learning environments. The study concluded that integrating AR into mathematics education positively affects both the motivation and academic achievement of children with LD. The findings revealed that the AR-based approach significantly enhanced students' motivation–particularly in the attention and satisfaction dimensions–while both the AR group and the CG demonstrated improved mathematics performance in the post-test. These results suggest that AR can serve as an effective tool for maintaining engagement and promoting conceptual understanding in mathematics, especially for learners who face persistent difficulties with abstract numerical concepts.

Recommendations

For teachers

Incorporate AR applications alongside traditional instructional methods to maintain students' interest, provide immediate feedback, and create opportunities for active, hands-on learning.

For curriculum designers

Develop AR-based resources aligned with curriculum standards, ensuring they target specific learning difficulties such as dyscalculia and address gaps in attention and memory.

For policymakers and school leaders

Provide professional development opportunities for educators to gain skills in integrating AR and other emerging technologies into their instructional practices.

For future research

Investigate the combined use of AR with multisensory and game-based learning strategies, and assess its impact on reducing mathematics anxiety among students with LD.

Research Proposals

The study suggests further research into the impact of AR and assistive technologies on working memory and improving mathematical word problem solving in children with dyscalculia; the cognitive-emotional indicators of students at risk of dyscalculia; the effectiveness of an intelligent educational system based on cognitive load theory for teaching mathematics and enhancing self-efficacy and engagement in learning among students with LD; the effectiveness of digital interventions for children with LD in mathematics to develop mathematical and cognitive skills, motivation, and reduce cognitive load; and finally, the impact of AR on improving attention and learning in children with LD and those with attention deficit hyperactivity disorder.

Limitations

The study was limited by its small sample size, which restricts the generalizability of the results. While the outcomes are promising, the small sample size limits the generalizability of the findings. Future studies should replicate this research with larger and more diverse participant groups and explore the long-term effects of AR integration on learning retention and transfer of mathematical skills to real-life contexts.

Additionally, the intervention was conducted over a short duration, making it difficult to assess the long-term effects of AR on motivation and academic achievement. Future research should involve larger participant groups, extended intervention periods, and the inclusion of diverse learning environments to validate and expand upon these findings.

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