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The Effects of Digital Game-Based Learning on Arithmetic and Selective Attention in Students with Dyscalculia

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Abstract

The study aimed to investigate the effect of Digital Game-Based Learning (DGBL) on numeracy skills and selective attention among primary school students with dyscalculia in Saudi Arabia. The researchers used a mixed quasi-experimental approach. Ninety randomly selected female fifth-grade students were divided into two groups. The experimental group (n= 45) used the Lumosity cognitive training platform (Raindrops and Memory Match games). The control group (n=45) received traditional mathematics instruction. The students were assessed before and after the intervention using the arithmetic learning difficulties test and the selective attention test developed by researchers. The results showed statistically significant improvements in the skills of students in the experimental group in arithmetic and selective attention. Quantitative analysis revealed a very large effect size ($\eta^2 = 0.97$) for the DGBL intervention on both scales. The perceptions of 32 teachers, gathered through semi-structured interviews, confirmed these findings, with the majority reporting significant improvements in the math skills and auditory and visual attention of students with dyscalculia. Qualitative data demonstrated the effectiveness of the DGBL program in increasing student engagement and motivation, reducing anxiety, and providing more enjoyable and engaging learning than traditional teaching. These findings advocate for the broader integration of DGBL into special education curricula in Saudi Arabia to create more inclusive, engaging, and effective learning.

Keywords:

Attention;

Digital Game-Based Learning;

Dyscalculia;

Mathematics;

Selective Attention.

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1- Introduction

The integration of digital technologies into educational practices has spurred remarkable innovations in special education. Digital Game-Based Learning (DGBL), defined as the use of digital games as tools to facilitate learning [1], represents a promising avenue for addressing learning difficulties. Its application is important for children with dyscalculia, which can be defined as a specific learning difficulty characterized by serious and persistent challenges in understanding numerical concepts, performing arithmetic operations, and developing fluent mathematical thinking [2-4]. The cognitive foundations of dyscalculia are well documented, with research confirming deficiencies in the basic systems for number perception and quantity processing [5-7]. Furthermore, these deficits in number processing are often exacerbated by weak general cognitive skills necessary for mathematical learning, specifically working memory and selective attention, which is the ability to focus on all relevant numerical information while ignoring distractions [4, 8]. In response to these challenges, digital game-based learning has emerged as an effective intervention, supported by

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numerous studies that have acknowledged that well-designed educational games can create interactive, engaging, and less anxiety-inducing learning environments [4, 9-12]. The emergence of touchscreen devices has expanded possibilities by making sports interactions easier and more efficient [13]. Crucially, DGBL platforms can provide adaptive and personalized challenges that support basic cognitive processes in general, and numeracy skills in particular [14]. For example, for students with dyscalculia who struggle with selective attention and poor working memory, these games can provide immediate feedback and adjust the level of difficulty in real-time, both of which are crucial for this group [15-18].

However, a critical review of the literature reveals two significant gaps. First, while the theoretical benefits of digital game-based learning in cognitive training are well established, experimental studies specifically measuring its impact on selective attention in students with dyscalculia remain scarce. Most studies focus on arithmetic results without quantifying gains in cognitive skills [19, 20]. Second, the success of game-based digital learning depends not only on technology but is also significantly influenced by pedagogical integration and contextual factors. Russo et al. [21] and Badawy et al. [22] have noted, the educational value hinges on how students interact with the games, teachers' positive attitudes toward them, and their use of games as supportive, adaptive, and motivating tools. This highlights a significant implementation gap in specific regional contexts where traditional approaches remain dominant. This latter point is acutely evident in the Saudi educational context. Despite a growing body of international research and localized calls for innovative special education strategies [10, 13], the application of structured DGBL interventions for dyscalculia in Saudi schools is reportedly limited, Studies indicate that the application of digital game-based learning interventions with dyscalculia students in Saudi schools is limited [22-24].

Regrettably, there is a dearth of research in Saudi Arabia investigating the efficacy of digital game-based learning in remediating dyscalculia and related cognitive deficiencies, such as selective attention. Therefore, the current study aims to address these interconnected gaps by investigating the impact of a digital game-based learning intervention on the development of selective attention and basic arithmetic skills in dyscalculia students. The study's goal is to go beyond simply demonstrating utility and understand how DGBL can be effectively operationalized to support these learners, providing evidence-based strategies for teachers and informing policy discussions about incorporating game-based and adaptive tools into Saudi Arabian special education frameworks.

1-1-Study Problem

Students with arithmetic learning difficulties (dyscalculia) face numerous challenges that hinder their academic progress and daily life. One of the most critical issues is their limited attention span, which negatively impacts cognitive skills, academic performance, and even social interactions [2]. The study by Baccaglini-Frank et al. [25] highlighted that these learners struggle with selective attention, number processing, and basic arithmetic comprehension often becoming easily distracted when solving math problems. Integrating digital games into education doesn’t just enhance learning outcomes for students with dyscalculia, it also paves the way for innovative teaching strategies [26]. As a result, DGBL has become an urgent necessity in modern education [27]. Özkaya et al. [28] found that math-focused digital games significantly improve arithmetic skills in students with learning difficulties. Sağıroğlu et al. [29] observed 4%–19% improvement in math achievement among children with special needs, including dyscalculia, after game-based interventions.

The interactive, engaging nature of DGBL helps sustain focus, a crucial factor in mastering mathematical concepts. Yet, despite its proven benefits, Saudi schools lag in adoption, particularly for students with dyscalculia. While existing studies underscore the effectiveness of DGBL in boosting arithmetic skills and selective attention, research in Saudi Arabia’s educational context remains scarce.

Study questions:

- How effective is Digital Game-Based Learning in enhancing arithmetic skills in students with dyscalculia?
- How effective is Digital Game-Based Learning in Strengthening selective attention in students with dyscalculia?
- How effective is Digital Game-Based Learning in improving selective attention in students with dyscalculia, based on teacher perceptions?

1-2-Study Importance

This study holds substantial importance in examining the effectiveness of DGBL for enhancing arithmetic skills and selective attention among students with dyscalculia in Saudi Arabia. We urgently need innovative interventions to enhance the focus and knowledge acquisition of students with learning disabilities. Traditional teaching methods often fail to address the unique struggles of students with dyscalculia. Game-based frameworks provide learning pathways that reduce mental fatigue while maintaining engagement. Gamified elements such as scoring, levels, and rewards boost motivation and sustain attention, making learning enjoyable for students. Game-Based Learning (DGBL) (e.g., CogniFit, Lumosity) may show promise in helping kids with ADHD stay focused.

2- Theoretical Farmwork

Cognitive load theory, constructivist learning theory, and flow theory form the basis of the study's integrated theoretical framework, which explains and supports the digital game-based learning intervention for students with dyscalculia.

Cognitive Load Theory as a Basis for Intervention Design:

The digital game-based intervention, which employs the Lumosity games Raindrops and Memory Match, is based entirely on Sweller's cognitive load theory [30]. According to this theory, working memory capacity is limited, and learning improves when instructional design manages the intrinsic load (the difficulty of the core learning content), decreases irrelevant cognitive activity, and promotes relevant processing. Traditional education can be too demanding for students with dyscalculia, who commonly struggle with working memory [2], leading to fatigue and failure. Our digital game-based intervention reduces external overload by removing extraneous written instructions and environmental distractions, allowing students to focus entirely on the required numerical or spatial task. Immediate feedback corrects learner faults without requiring excessive self-monitoring. Our intervention also contributes to optimize intrinsic load, as Lumosity's adaptive algorithms dynamically adjust task difficulty (such as the speed of falling raindrops and the length of tile sequences) based on immediate performance. This ensures that the challenge always falls within students' "Zone of Proximal Development," preventing frustration from tasks too difficult or boredom from tasks too simple. The intervention also helps to improve the ability to absorb basic information by automating the retrieval of basic facts through repeated play in interactive environments, where games assist students in developing automated mental schemas of mathematical operations and visuospatial patterns. This frees up working memory resources for higher-order thinking processes like selective attention and problem solving, addressing the underlying cognitive deficiencies in dyscalculia.

Constructivist Learning through Game-Based Interaction:

DGBL offers a digital "manipulative" environment in which children with dyscalculia can learn by doing rather than passively following rules. Students actively investigate numerical relationships (e.g., which raindrop solves the equation) and spatial sequences via trial and error. In addition, they can foster understanding in a safe setting. The game setting offers a risk-free environment for experimenting. Mistakes are framed as part of the learning cycle rather than failures, which is critical for rebuilding the students' mathematical self-concept, which has often been harmed. Finally, develop individualized cognitive schemas. Because the games are adaptive, each student's learning path is unique, allowing them to build understanding at their speed and in a way that aligns with their cognitive capabilities.

Flow Theory and the Role of Motivation & Engagement:

Csikszentmihalyi's Flow theory describes a condition of intense involvement in an activity. "Flow" is obtained by balancing challenge with expertise. DGBL effectively promotes this balance to increase participation. The adaptive game engine maintains real-time balance, keeping students fully engaged. This equilibrium is especially important for kids with dyscalculia, who may disengage due to anxiety or boredom. Furthermore, intrinsic motivation from game mechanics outperforms traditional extrinsic rewards in terms of sustained effort. Increased engagement among teachers improves cognitive practice for neurocognitive progress. Finally, it reduces anxiety and increases persistence through pleasurable flow experiences. By turning arithmetic practice into a pleasurable game, the intervention reduces math anxiety and promotes skill improvement [10].

Our central hypothesis is explained by this integrated model: dyscalculia is accompanied by negative affective problems like anxiety and low self-efficacy; however, a well-designed digital game-based learning environment can train deficient cognitive skills (arithmetic skill, selective attention) at the same time. The empirical evidence for this multi-faceted theoretical approach is provided by the quantitative advances in attention and mathematics, as well as the qualitative improvements reported by the participating teachers. This framework serves to both validate our approach and offer a perspective from which to understand the study's findings and the potential future uses of digital game-based learning for students with special needs.

3- Literature Reviews

The rapid advancement of technological innovation has given hope to the education of students with disabilities. These developments have radically transformed the education of students with disabilities, providing them with more equitable access to the same educational resources as their peers. However, ironically, students with learning disabilities who are expected to benefit most from emerging AI tools are often the ones least able to access them, or those tools are not adequately developed or adapted to their disabilities [31]. A survey conducted by Fable [32] confirms this gap, as it found that less than 7% of assistive technology users have learning disabilities, and they expressed a feeling that their community is adequately represented in the development of AI products. Studies of [19, 33, 34] have demonstrated that selective attention plays a crucial role in successful learning. Students with learning disabilities, such as dyscalculia, often struggle to direct their focus toward useful information while avoiding distractions, which hinders their academic success and complicates their daily tasks. Selective attention is a fundamental cognitive process that enables a learner to consciously concentrate on a single stimulus and maintain that focus. The more students develop this skill, the better their learning outcomes become [14, 18].

Recent developments in DGBL have provided a unique opportunity to help students with learning difficulties and dyscalculia enhance their selective attention through specialized, flexible, and adaptive support. Such success can be ensured by presenting the learning material in a way that matches each student's ability to maintain attention according to their cognitive strengths, which helps them reduce distractions and improve concentration [19, 33]. Pérez-Puelles et al. [16] found that virtual reality apps using eye-tracking technology can create engaging experiences that help students with neurodevelopmental challenges focus better visually, providing a safe space to practice skills that are useful in real life. DGBL has a broad scope, helping to diagnose and support reading, math, and writing difficulties [35]. Integrating DGBL into education is a pressing necessity, not only to improve outcomes for students with dyscalculia but also to improve educational practices [36]. Learners with dyscalculia have difficulty directing selective attention, which affects their abilities to comprehend, analyze, read, and retrieve memory, factors that negatively influence learning [18, 34].

Sweller [30] indicated that when tasks are too complex, students are more likely to become distracted and disengaged, preventing them from developing their ability to pay attention. DGBL helps dynamically reduce task difficulty based on momentary engagement metrics, ensuring that students with dyscalculia engage with challenges without becoming fatigued [37]. DGBL enhances student engagement and enthusiasm by turning learning into a fun and rewarding experience, motivating students with dyscalculia who might otherwise disengage due to boredom [4, 38]. This type of learning avoids traditional teaching methods, which often fail to meet the unique needs of these students, hindering their academic and social growth [11]. DGBL offers a crucial alternative with its adaptable strategies [39]. DGBL provides immediate and constructive feedback, which is essential for maintaining students' focus and honing their attention skills [40, 41]. The supportive and non-judgmental environment in a DGBL setting provides an answer to the anxiety and low self-esteem that often accompany dyscalculia and poor academic performance [42].

4- Research Methodology

The study employed mixed methodology, depending on a quasi-experimental design, to systematically compare the effectiveness of DGBL against traditional instructional methods. Participants were divided into two distinct groups: Experimental Group: Received instruction through a carefully designed DGBL program, and Control Group: Taught using conventional teaching methods (the standard instructional approach in Saudi schools). The control group's instruction represented the prevailing pedagogical approach in most Saudi classrooms, characterized by teacher-centered knowledge transmission, textbook-based lessons, and conventional drill-and-practice exercises. Ethical approval for the application on living organisms was obtained from the Scientific Research Ethics Committee at King Faisal University (KFU-ETHICS-2024). Written consent was obtained from all participating students to join the program voluntarily without obligation, with everyone being given the freedom to withdraw at any time, based on their personal desire. During the implementation, the Helsinki regulations for application on living beings were adhered to.

The study targeted female students with diagnosed dyscalculia; they were selected according to teachers' notes and their grades in mathematics exams. Total participants were 90 students (an experimental group of 45 students who received the DGBL intervention and a control group of 45 students who continued with the traditional method) selected randomly from a private school in Al-Ahsa to ensure diversity. Age range: 11-12 years old (fifth grade students). In addition, teachers who applied to the DGBL program (n= 32; age: m= 33.7, SD= 11.2; years of working experience: m= 7.6, SD= 9.3) were asked to evaluate their experience with DGBL programs and its effect on developing students with dyscalculia math skills and enhancing their attention ability.

We applied a pretest to confirm that there was no significant difference in math skills or attention levels between the two groups before the study began. The selection of fifth-grade students for the current study was important and strategic. This age group exposes students to more advanced math concepts, making them ideal for game-based mastery. Furthermore, children aged 11 and 12 often have sufficient digital literacy to effectively interact with game interfaces and have the concentration needed to engage in training successfully. The selection of a specific group of fifth-grade students in the Al-Ahsa region was initially strategic to ensure control and feasibility, which allowed for an in-depth study of the basic mechanisms of the digital learning-based curriculum in a homogeneous group. We agree that this represents an important dividing line for the study's conclusions and the generalization of results to different samples. Therefore, the researchers in the Futures Research Department called for the involvement of larger and more diverse population groups in subsequent iterative studies to confirm the validity of the results on a wider scale

The study also included 32 teachers who supervised the intervention. Their perspectives were explored, and their qualitative feedback was collected, providing valuable real-world insights into the impact of the intervention on student engagement and behavior. Using this methodological approach, the study ensured that its results would provide a valid and reliable test of the effectiveness of DGBL for students with dyscalculia in the Saudi educational context. All participants gave their written permission to join the program of their own free will, and they could leave at any time without having to do anything. Figure 1 shows a flowchart of the process of the methodology.

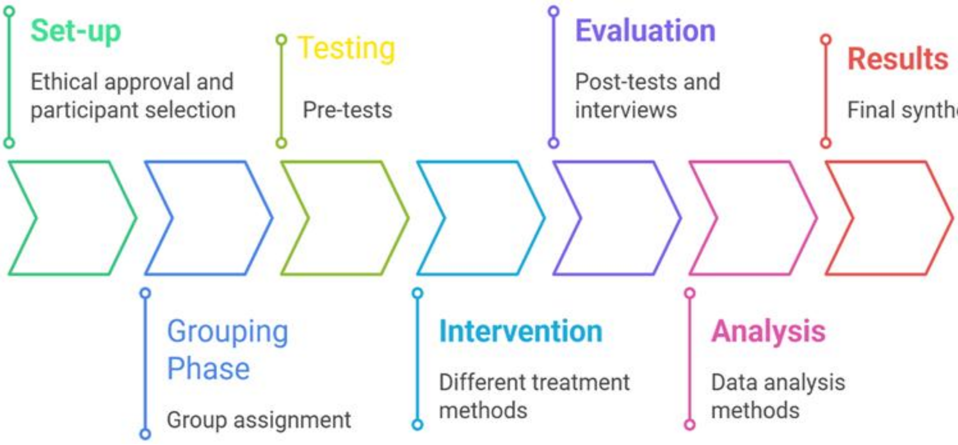

Figure 1. Flowchart of the process of the methodology

4-1-Study Tools

Game-Based Learning Program

The intervention was specifically designed to address the research questions related to numeracy skills that can be improved through frequent and interactive practice of basic fifth-grade arithmetic concepts in diverse contexts, and selective attention that can be enhanced by requiring students to focus on relevant numerical information and exclude increasingly challenging auditory and visual distractions in the game environment. Pérez-Puelles et al. [16] show that visual discrimination tasks for measuring selective attention gains from video games that rely on selective reaction time under distraction are ideal because they are interactive for children and provide rich, quantifiable data, such as mean reaction time, accuracy, and error rate. The intervention used Lumosity gaming software to implement digital learning through the Raindrops and Memory Match games, aiming to create an interactive, adaptive, and mastery-oriented environment for students with dyscalculia and stimulate their spontaneous attention. The basic design philosophy was based on providing immediate responses, offering a safe space for error correction to build computational fluency, and enhancing selective attention by reducing external cognitive load. Both games, Lumosity Raindrops and Lumosity Memory Match, were browser-based applications accessed on desktop computers and tablets used in the school. The rationale for choosing the games "Raindrops" and "Memory Match" from the Lumosity platform is that both games are dually suitable for both cognitive and academic aspects, as well as being experimentally verified. Unlike many recreational games, Lumosity tasks were developed based on cognitive science research, and were designed to target specific executive functions such as numerical processing, working memory, and selective attention, which are directly related to dyscalculia. Furthermore, Lumosity has been used in previous studies on cognitive training [37, 38] providing a validated standard for measuring intervention effects—a standard lacking in many customized or commercial educational games. This choice ensures theoretical relevance and methodological comparability with published studies.

Lumosity Raindrops Game: The Lumosity Raindrops game aims to primarily measure mental arithmetic and processing speed as well as basic mathematical and cognitive skills. The Raindrops game measures the speed and accuracy of a child's mental arithmetic under pressure. It tests how quickly they can absorb basic arithmetic knowledge, apply it to a problem stored in working memory, and visually identify the solution among several moving targets (see Figure 2).

The game targets some cognitive abilities: (1) Mental Arithmetic: The basic skill of the game is based on the ability to perform arithmetic operations (such as addition and subtraction) "with the child's mind," without using a calculator, pen, or paper. The game relies on the rapid retrieval of mathematical facts from long-term memory. The game features falling raindrops containing numbers. To solve the equation at the top of the screen, the child must identify the raindrop containing the number that correctly completes the equation (for example, for "? - 5 = 3," you must find the raindrop "8" before it reaches the bottom), as shown in Figure 2. (2) Processing Speed: the speed at which a child's mind comprehends equations and numbers, processes them, and selects the correct answer. Raindrops fall continuously and at an increasing speed. Children must solve the equations and quickly click on the correct answer before the drop reaches the bottom. This time pressure is a direct measure of their cognitive speed. (3) Working Memory: Working memory is used extensively to support mental arithmetic, temporarily storing and processing information. A child must hold an equation (e.g., "4 + ? = 11") in their mind while scanning the falling drops, performing the calculation (11 - 4 = 7), and then searching for the result. They simultaneously hold the target, perform the calculation, and compare the result to visual stimuli. (4) Selective Attention: the game requires efficient visual processing under distractions. This requires the ability to focus on important stimuli, such as the numbers in the raindrops, ignoring unimportant stimuli, such as the background or other falling drops, and quickly scanning the field of vision for the target. The challenge increases as the number and speed of the falling drops increase. Stevens & Bavelier [36] linked selective attention to learning outcomes, arguing that effective assessment should enhance the brain's ability to suppress competing distractors. Identifying a central goal amidst lateral distractions is a standard model for accurately measuring this inhibitory control mechanism.

(5) Cognitive Flexibility: the game presents processes that require flexible switching strategies. The game tests the child's mental ability to switch between different concepts or rules. Although equations focus primarily on addition and subtraction, they can be represented in different ways (e.g., "? = 10 - 7," "3 + 4 = ?," "? - 2 = 9"), requiring the child to be flexible enough to understand that the "?" sign can be in different positions and apply the correct process to solve it.

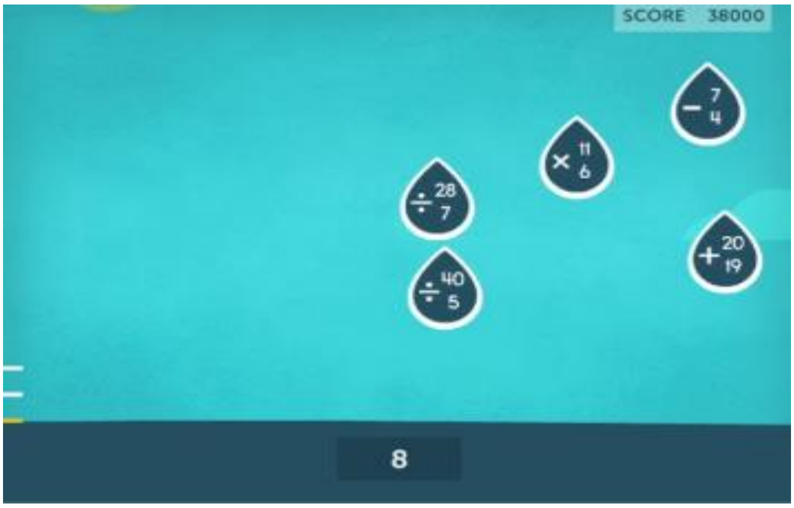

Figure 2. Examples of Lumosity Raindrops Game

The Lumosity Memory Match game helps improve selective attention by training and measuring a key part of working memory known as visual short-term memory (VSTM), especially focusing on remembering where things are. The game involves presenting a pattern of tiles that light up and then disappear. The child must retain that visual image in their mind long enough to repeat the pattern after the delay.

The game targets some cognitive abilities: (1) Visual Short-Term Memory (VSTM): VSTM is the primary ability measured by the game, which focuses on stimulating selective attention. It serves as a child's temporary "notebook" for visual information. It is the ability to hold a small amount of visual information (such as shapes, colors, and locations) in the child's mind for a short period to complete a task. The game involves the child retaining a visual image of a pattern of tiles that light up and then disappear. They must retain the image in their mind long enough to repeat the pattern after the delay (see Figure 3). (2) Spatial Memory: Spatial memory stimulation is a key component of the memory tested by the game. The memory-matching test is not about remembering abstract symbols but rather locations on a grid. The task involves not only remembering the "blue square" but also remembering the location of the piece on the grid. The challenge increases as the grid grows and the sequences become longer, increasing the need for spatial recall. (3) Sequencing and Chunking: As the game progresses, the sequences become longer and more complex, forcing the child to utilize higher-level executive functions to succeed. This activity stimulates the child's ability to remember the exact order in which the pieces were lit up. Their brain uses chunking strategies to improve memory capacity. The game encourages and tests a child's brain's natural ability to group information into larger, more manageable chunks. Instead of remembering nine individual squares, for example, they may begin to remember them as a shape or pattern (e.g., an L followed by a diagonal line).

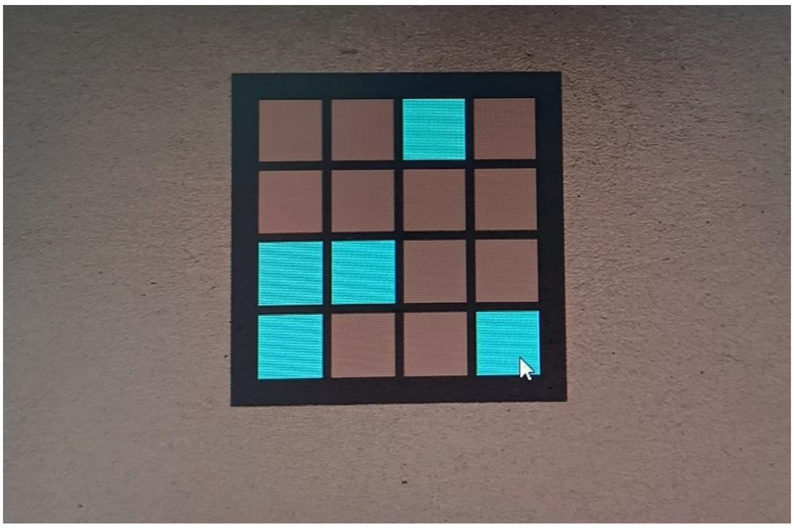

Figure 3. Examples of the Lumosity Memory Match game

Test for Arithmetic Learning Difficulties (Dyscalculia): The arithmetic learning difficulties (dyscalculia) test was developed by researchers with the cooperation of the General Administration of Special Education and the General Administration of Assessment and Education Quality in Saudi Arabia and consists of a) a comprehensive test booklet (teacher and student versions); b) carefully designed diagnostic items aligned with learning standards for students with difficulties, specific mathematics competencies, and support materials that include sample questions with answers, scoring rubrics, administration guidelines, and an error analysis framework. The researcher chose grade-level adaptation; the fifth-grade version was selected for the current study. The test consists of 15 main items (each with multiple sub-questions) and covers 7 core arithmetic skills: four basic operations (addition, subtraction, multiplication, and division), number rounding (to the nearest thousand), fractions and fractional operations, number comparison (<, >, and place value identification), and number representation (standard, expanded, and word forms).

Psychometric Properties: (A) Reliability Analysis: The difficulty indices of the test items ranged from 0.44 to 0.67, while the discrimination indices for high-performing and low-performing subjects ranged from 0.46 to 0.77. The internal consistency of the test was calculated at α = 0.86, indicating high reliability. The test-retest reliability was 0.86, indicating strong reliability. (B) Validity Verification (Construct validity): The researchers conducted confirmatory factor analysis (CFA) on AMOS using version 25.0. The aim was to identify associations between latent variables, discover data patterns, verify the structure, and confirm factor loadings. The final version of the test was administered to the study sample, and a covariance analysis (CFA) was used to verify the validity of the factor structure. CFA is crucial because it establishes the main and full interdimensional of the target test and the factor loadings. Figure 4 shows the consistency of test items with their dimensions.

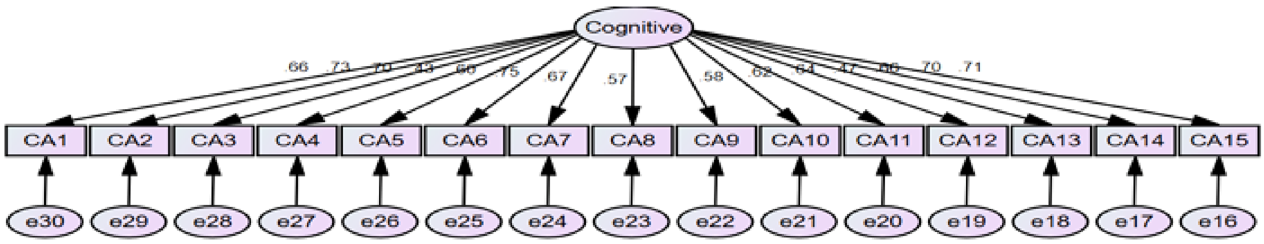

Figure 4. Results of confirmatory factor analysis to determine the correlation between items in the Arithmetic Learning Difficulties (Dyscalculia) Test

This rigorously developed instrument represents a gold-standard assessment tool for identifying arithmetic learning difficulties in Saudi elementary students, with relevance for fifth-grade females with dyscalculia. Its strong psychometric properties ensure reliable and valid measurement of both baseline abilities and intervention outcomes.

Selective Attention Improvement Assessment Test: The purpose of the test is to measure changes in selective attention before and after using electronic game-based learning. The test measures the ability of students with arithmetic learning difficulties to strengthen their selective attention skills. Selective attention encompasses a wide range of competencies, including auditory and visual attention. The idea of the test is that there is a target stimulus located in the middle of a number of non-target stimuli known as distractors, and the students are asked to judge as quickly as possible the nature of that stimulus by pressing a certain key on the keyboard if the stimulus has a certain characteristic that distinguishes it, or by pressing another key if the stimulus appears in another form, and by avoiding the visual distractions that surround the target stimulus. This procedure is the focus of the selective attention process, which is focusing on the target stimuli and ignoring distractions.

The researchers reviewed a wide range of foreign literature specifically focused on selective attention. She then designed the test according to the following steps: a) The examinee is presented with three squares of equal size, arranged horizontally but possibly of different colours. b) The examinee is asked to focus on the colour of the square in the center and ignore the coloured squares on either side. c) If the colour of the square in the middle is red or green, the subject presses the right arrow on the keyboard, and if the color of the square in the middle is blue or green, the subject presses the left arrow on the keyboard.

To ensure the test's accuracy and consistency, two key methods were employed: Expert Validation: The test was reviewed by a panel of six evaluators to assess its validity. For an item to be approved, a minimum agreement threshold of 80% among judges was required. Discriminatory Power Analysis: A sample group of 20 students was used to evaluate the test's ability to distinguish between different performance levels. Statistical significance was measured using critical F-values (ranging from 5.2 to 5.3) to confirm discriminatory validity. Additionally, internal consistency was assessed using the Kuder-Richardson 20 (KR-20) formula, yielding a reliability coefficient of 0.852, indicating a high level of consistency for the test.

4-2- Study Procedures

The intervention was implemented over 10 weeks, with students in the experimental group participating in four 30-minute sessions per week (total intervention time: 20 hours). Game-based training sessions replaced traditional in-class mathematics lessons. Teachers were trained to supervise the sessions, facilitate student login, and provide technical assistance as needed; however, they did not provide math instruction. The experimental group teachers were enrolled in a 20-hour training course over three weeks to teach them how to use the gamified learning strategy in the classroom. The teachers' training focused on raising awareness about the pedagogical basis behind game design, how to manage computer lab sessions, interpreting progress information that shows students' proficiency levels and task completion times, and strategies for linking game achievements to classroom encouragement, without providing answers. After the training course, the experimental group was taught using this teaching method, while the control group was taught using traditional methods. Both groups underwent a pre-test and final test to measure the impact of the two different teaching methods on their achievement and attention. Table 1 summarizes the study design.

To ensure a basis for comparison, the traditional teaching method for the control group was designed to mimic standard educational practices in mathematics classrooms. This included teacher-centered group teaching, for a duration similar to the experimental intervention (20 hours over 10 weeks, divided into four weekly sessions of 30 minutes each). The teaching focused on the same fifth-grade math content covered by the DGBL games, using the ministry's prescribed textbook. Teaching methods relied primarily on direct explanation and traditional worksheet exercises, without the adaptive feedback or interactive game elements found in the DGBL games. No additional exercises were included to develop cognitive skills or attention.

Table 1. Study Design

Pre-intervention	Measure attention and skills	Measure attention and skills
Intervention	Use of digital games	Traditional teaching
Post-intervention	Re- test	Re- test

5- Data Analysis

The researchers began collecting data after developing and validating the study tools. To ensure sample equivalence, a pretest was administered to the experimental and control groups to ensure equal initial performance levels between the two groups, a requirement for obtaining valid results for the experimental procedure. This pretest was conducted prior to implementing the game-based e-learning approach. The experimental group used the DGBL method, which involved students learning through interactive online games. The control group, on the other hand, used more traditional classroom methods. This type of test enabled us to evaluate the impact of game-based learning, compared to traditional teaching, on student performance. Means, standard deviations, and t-tests were used to assess the differences between the performance of the control and experimental groups before the intervention.

Table 2 shows that the scores of the experimental and control groups were equivalent, as there was no significant difference in their performance on both the arithmetic skills and attention tests (T-value = 0.565, Sig. = 0.645 for the first test; T-value = 0.562, Sig. = 0.714 for the second test), indicating that both groups began with equal performance levels.

Table 2. Pre-test Results of Math Skills and Attention Skills

Tests	Group	No.	Mean	St. dev.	T-value	df.	Sig.
Arithmetic Learning Difficulties (Dyscalculia) Test	Experimental	45	6.56	1.14	0.565	88	0.645
Arithmetic Learning Difficulties (Dyscalculia) Test	Control	45	5.65	1.32	0.565	88	0.645
Attention skills	Experimental	45	4.33	1.33	0.562	88	0.714
Attention skills	Control	45	4.21	1.58	0.562	88	0.714

To examine the post-intervention semi-structured teacher interview, open coding and thematic analysis procedures [43] were used. The researchers transcribed all interviews. Thematic analysis incorporates themes and their reporting within the data. The authors initially spent time identifying the data, reading and rereading the transcripts, and writing down initial ideas, then systematically coding intriguing features in the transcripts and grouping these codes into potential themes. The authors also carefully analyzed the details of each theme to define and name it in a way that provides a clear picture of what the participants said. Finally, they selected vivid and engaging examples from the texts and linked them to the themes and the overarching research question of understanding teachers' experiences with this intervention.

6- Results and Discussion

6-1- Analysis of Mathematical Skills Results

We aim to investigate the effectiveness of an educational program based on digital games in enhancing math skills in students with dyscalculia. We calculate the effect size of digital games in enhancing arithmetic skills for students with dyscalculia; the following formula was applied: $\eta^2 = (t^2/df) + t^2$ Where t^2 is the square of the t-value, df is the degrees of freedom, and η^2 is the variance ratio (see Table 3).

Table 3. Effect size of digital games in enhancing arithmetic skills and Gain ratio

	Experimental Group	N	$\eta 2$	Effect size		
Digital games	Pretest	45	0.14	Large		
	Posttest	45				
		Gain Ratio Calculation				
Test Type	M2	M1	P	M2-M1	P-M1	Gain Ratio
	32.46	10.33	38	24.33	27.67	1.3

Table 3 shows a large effect size ($\eta^2 = 0.14$), which is classified as a substantial effect and signifies a statistically significant impact of the intervention that uses digital games (P = 0.8) on developing mathematical skills in students with dyscalculia. The variance observed in mathematical skills (as the dependent variable) is strongly attributed to DGBL (as the independent variable). Previous findings demonstrate the potential of DGBL to effectively enhance mathematical skills and support modern and innovative practices in teaching students with dyscalculia who have not been successfully taught by traditional methods of mathematics. A gain ratio greater than 1.0 implies that the students' growth from pre-test to post-test exceeded the growth that would have been expected based on their starting point alone.

To determine whether the experimental group achieved significantly better math skills than the control group due to the DGBL approach, means and standard deviations were calculated for students' performance on the math skills test for both groups. A t-test was also conducted. Table 4 shows the results.

Table 4. Results of t-test

Group	N	Mean	SD	T	df	Sig
Experimental	45	32.46	0.581	16.821	88	0.01
Control	45	10.67	4.632	16.821	88	0.01

Table 4 shows a statistically significant difference in favor of the performance of the experimental group (M = 32.46, SD = .581) compared to the control group (M = 10.67, SD = 4.632). This demonstrates the positive impact of applying DGBL strategies on the numeracy skills of female students with arithmetic learning difficulties in the experimental group. The experimental group's variance of 0.581 indicates that participants' scores were relatively close to the mean, meaning that the intervention had a consistent effect on all participants. In contrast, the control group's variance of 4.632 indicates that their scores were more variable and that participants in this group performed less consistently. The significant difference in results, the average score of the DGBL group (32.46), was nearly three times higher than that of the control group (10.67) indicating that the intervention not only improved abilities but also fundamentally altered students' interactions with mathematics. The roughly quadrupled scores indicate a move away from basic procedural memory and toward more fluent, applied problem-solving, which is a significant area of difficulty in dyscalculia. The experimental group's very low standard deviation (0.581) is particularly noteworthy; it shows that the DGBL platform (Lumosity) served as a reliable equalizer. Unlike traditional instruction, which frequently yields uneven results (SD = 4.632), the game-based setting provided a consistently effective support system.

The t-test yielded a statistic of 16.821, with 88 degrees of freedom and a p-value below 0.05, indicating a statistically significant difference and affirming the reliability of the intervention findings. This result supports the hypothesis that there is a strong positive relationship between the level of DGBL implemented by the teacher and the level of achievement on the mathematics skills test among fifth-grade female students. Proving that essential components of engagement or interaction are built into the structure of DGBL and enhance the performance of learners with dyscalculia. This result went along with many studies; for example, Kohn et al. [15] conducted a pilot study evaluating an adaptive computer program designed to improve math skills in children with dyscalculia. Räsänen et al. [44] showed the effect of computer-assisted intervention for children with low numeracy skills. In addition, these findings were reinforced by studies conducted by Al-Barakat et al. [23], Al-Hassan et al. [24], which demonstrated the role of digital game applications in enhancing mathematical thinking skills in primary school mathematics students.

6-2- Analysis of Selective Attention Results

To analyze the extent to which the educational program based on digital games stimulates selective attention among students with dyscalculia. We calculate the effect size of digital games in enhancing selective attention for students with dyscalculia (see Table 5).

Table 5. Effect of digital games in stimulating selective attention and the Gain ratio

	Experimental Group	N	$\eta 2$	Effect size		
Digital games	Pretest	45	0.97	Very Large		
	Posttest	45				
Test Type	M2	M1	P	M2-M1	P-M1	Gain Ratio
Selective attention	14.59	7.33	22	7.26	14.67	1.5

Table 5 shows that digital game-based instruction had a relatively significant effect of 0.97 on stimulating selective attention in students with dyscalculia, confirming the vital role of digital game-based instruction in enhancing selective attention. Although the effect size (0.97) is considered large, it is reasonable given the close match between training and assessment, and the low performance at the beginning of training can be interpreted as an indicator of a strong effect of near transition. The observed variance in selective attention (as the dependent variable) was largely attributable to teaching using digital games (as the independent variable). This observation demonstrates the potential of digital games as a modern and revolutionary educational tool that supports innovative teaching practices and enhances selective attention. The increase ratio of 1.5 for selective attention, which is larger than the 1.3 for arithmetic skills (see Table 3), provides an important interpretation: the cognitive skill (attention) responded proportionally more to the intervention than the academic skill (arithmetic). This lends support to a putative causative paradigm in which DGBL first improves the core attentional deficit, which then promotes the acquisition and implementation of mathematical processes. This sequencing is critical in developing successful therapies for learning difficulties.

To determine whether the experimental group achieved better selective attention skills than the control group due to the impact of DGBL, means and standard deviations were calculated for the students' performance on the selective attention test for both groups. A t-test was also conducted.

Table 6. Results of the T-test

Group	N	Mean	STD	T	df	Sig
Experimental	45	14.59	1.421	10.732	88	0.000
Control	45	9.73	2.751	10.732	88	0.000

Table 6 shows a significant difference in selective attention between the experimental and control groups, with the experimental group outperforming the control group, indicating that DGBL can help students improve their spontaneous attention. A t-value of 10.732 and a p-value of 0.000 indicate that the data are highly statistically significant.

This significant improvement in selective attention (Experimental M=14.59 vs. Control M=9.73) is perhaps the study's most important result, as it addresses a fundamental cognitive bottleneck in dyscalculia. The games 'Raindrops' and 'Memory Match' are intended to teach the brain's executive function networks. The need to recognize correct numbers among falling distractors ('Raindrops') and recall spatial sequences ('Memory Match') places direct demands on attentional control and inhibition. As a result, the improvement is not a consequence but rather a desired outcome of the cognitive training inherent in the games. This analysis shows that DGBL's strength stems from its dual function: it functions as both an arithmetic content delivery mechanism and a cognitive rehabilitation tool for underlying attentional impairments. The application of this trained attention to a different standardized test (the Selective Attention Improvement Assessment Test) demonstrates that the improvements were not task-specific but rather indicated a generalizable improvement in cognitive control, which is required for all academic learning.

The findings indicated that game-based digital learning significantly enhanced students' spontaneous attention levels in comparison to conventional educational methods. The average performance score for the experimental group was 14.59, while the average performance score for the control group was 9.73. A p-value of less than 0.05 supported this hypothesis, confirming the accuracy and reliability of the results. Results revealed that DGBL improves students' selective attention compared to other teaching methods. Digital games have been proven not only to engage students but also to enable teachers to customize a unique learning experience to maximize the interest of students who struggle to stay alert and attentive throughout the lesson due to their dyscalculia. Numerous studies corroborate the present findings on selective attention, including the research by Samson et al. [35], which associated video game exposure with children's attentional capabilities. In addition, Ren et al. [26] conducted a systematic review (meta-analysis) that combined the results of digital game interventions on improving numeracy skills and attention.

Figure 5 summarizes the post-test analysis of mathematics and attention skills between the experimental and control groups. Bars show the mean scores, while error bars represent the standard deviations.

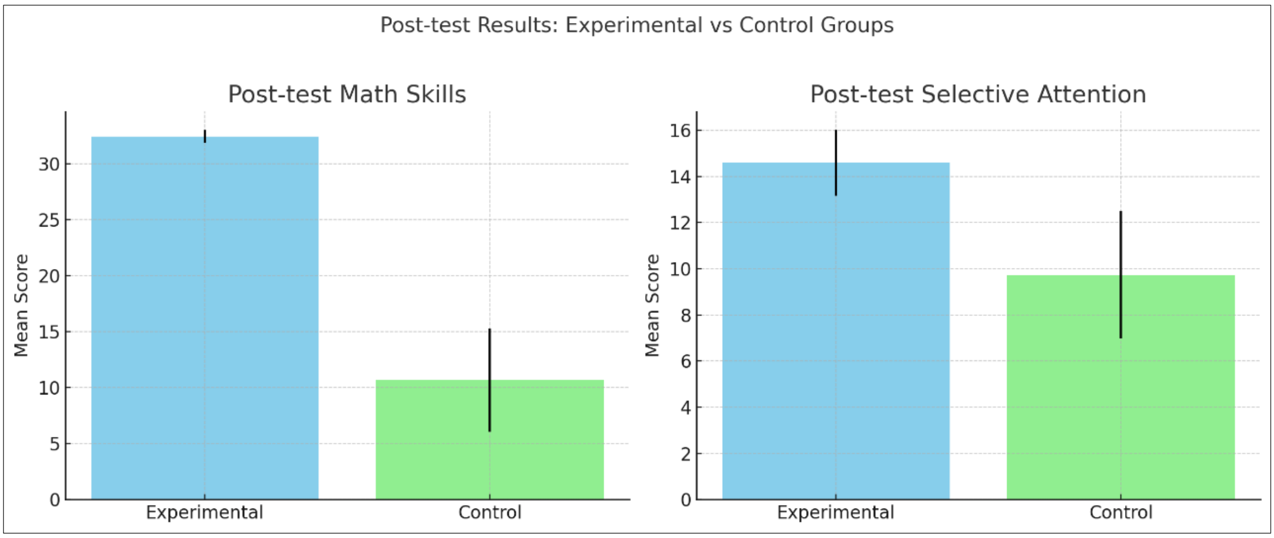

Figure 5. Post-test analysis of mathematics and attention skills between the experimental and control groups

The main results demonstrated the effectiveness of game-based learning in improving mathematical skills and selective attention in children with dyscalculia. Digital games enhanced cognitive development in mathematics, problem-solving, and memory in the experimental group compared to the control group, which received traditional instruction.

6-3- The Effectiveness of Game-Based Learning in Improving Selective Attention and Math Skills in Students with Dyscalculia, based on Teacher Perceptions

To assess teachers' perceptions of the improved performance of students with dyscalculia, semi-structured interviews were conducted after the intervention (number of participants: 32). Teachers reported whether they had observed improvements in each student's auditory and visual attention and arithmetic skills. A chi-square goodness-of-fit test was used to determine whether the distribution of their responses (improvement vs. no improvement) differed significantly from what would be expected by chance.

Table 7 shows that the results of the chi-square analysis are statistically significant for both auditory attention, χ^2 (1, N=32) = 5.78, $p < 0.05$, and visual attention, χ^2 (1, N=32) = 11.56, $p < 0.001$, as well as arithmetic skills (N=32) = 13.23, $p < 0.000$. This indicates that most teachers observed a statistically significant improvement in the selective attention and arithmetic skills of students in the experimental group after the game-based learning intervention. This finding is consistent with a study by Kokandy [45], which showed that teachers have positive attitudes toward digital games, seeing them as improving student engagement and skills such as critical thinking and self-motivation. The results also aligned with the results of Matic et al. [27], which indicates that mathematics teachers consider digital games a useful educational tool, as well as with Alsuhaymi & Alzebidi [46] findings that teachers in Saudi schools have a positive attitude towards adopting video games in education.

Table 7. Teacher Perceptions of Student Improvement in Selective Attention and Math Skills

Factor	Observed Improvement	Expected Count	χ^2	df	p-value
Auditory Attention	20 / 32 (62.5%)	16	5.78	1	< 0.05
Visual Attention	24 / 32 (75.0%)	16	11.56	1	< 0.001
Math skills	28 / 32 (87.5%)	18	13.23	1	< 0.000

6-4- Semi-Structured Teachers' Interview Outcomes

What are the benefits of digital games in enhancing selective attention and mathematical skills in students with dyscalculia teachers' perceptions?

Based on Christou [43] open coding and thematic analysis procedures, major themes emerged from the teachers' interviews. Each theme is further categorized into subthemes that reflect strengths and weaknesses.

6-5- Improved Engagement and Motivation

Table 8 showed that most teachers (86%) believe that teaching their students with dyscalculia through digital games has increased student engagement. In this context, some studies have supported this claim that digital games enhance attention and significantly improve students' math skills. For example, the views of teachers involved in teaching students with dyscalculia were consistent with Chen et al. [38], which demonstrated that students with learning disabilities reported feeling more motivated to interact with tools such as Lumosity and CogniFit. The results of the study by Wadsworth et al. [40] also showed that students with learning difficulties expressed their benefit from electronic games in learning arithmetic and found them more attractive compared to traditional learning methods. During an interview with teachers who facilitated and monitored students' engagement with the digital games, a mathematics teacher remarked*, "The Lumosity game allowed my students to progress at their own pace and offered them challenging tasks without causing overwhelm."* Another math teacher reported, "*My students can work at their pace, and the system provides them tasks that challenge them without overwhelming them"*.

Table 8. Display the benefits of applications in enhancing selective attention and mathematical skills among students with learning disabilities from teachers' perceptions

Benefit	Theme	Subtheme
Improved Engagement and Motivation	Digital based-game learning increase students' engagement. (86%)	Teachers report that students with dyscalculia feel more motivated to engage with Lumosity game
Focus Increasing	Students' ability to focus on tasks when using digital games has increased that provide feedback. (80%)	Students with dyscalculia report greater focus during reading tasks when using text-to-speech technology.
Personalized Learning	Digital games adapt to each student's learning pace, reducing frustration and cognitive overload. (92%)	Students using digital games learning platforms like Dream Box felt less overwhelmed and were able to focus better.
Reduced Anxiety and Increased Confidence	The supportive, non-judgmental nature of digital games reduces anxiety and builds self-confidence. (87%)	Students with Dyscalculia felt more confident when using tools like speech-to-text software.
Improve task performance and reduce distraction	Maintaining students' focus by tracking attention during digital games and intervening in a timely manner. (90%)	Students with dyscalculia are less distracted and manage their time better.
Advantages of Social-Emotional Development	Digital games that are supportive and specifically designed for students with dyscalculia give them a lesser sense of stigma and enhance their engagement in classroom activities. (88%)	Teachers expressed satisfaction with the improved social interactions of students with dyscalculia who used digital games.

Bioulac et al. [37] demonstrated that interactive digital games provide immediate feedback, encouraging students to actively participate in their learning process. This heightened engagement can subsequently aid in sustaining focus and enhancing selective attention over time. Chen et al. [38] elucidated those studies utilizing digital games like CogniFit or Lumosity showed that individuals with learning difficulties exhibited heightened incentives to engage through reward systems, thereby enhancing their focus during arithmetic problems.

6-6- Increased Selective Attention

As shown in Table 8, 80% of teachers believed that students taught math using digital gaming tools, which simultaneously train attention, demonstrated greater concentration. These teachers asserted that the tasks presented in digital games helped them concentrate better in the classroom than traditional instruction. The teachers' interview confirms this claim. A teacher stated, "*Kids don't have to struggle with reading the instructions of math tasks; the app reads for them, and they can focus on understanding*". This finding is consistent with the study by Conn [47], which observed that repeated attention control training within play-based learning improves students' ability to filter out distractions. In studies using attention-enhancing tools such as Lumosity, students with dyscalculia reported feeling able to concentrate longer and filter out irrelevant stimuli when engaging in learning activities. They reported that their attention span improved after using digital games, which contributed to improved performance on school tasks [37].

6-7- Personalized Learning

As shown in Table 8, most teachers (92%) perceived that one of the most significant qualitative benefits of digital games in math education was their ability to personalize learning experiences for individual students with dyscalculia. Digital games adapt to students' abilities, adjusting the level of difficulty and pacing according to their progress. This personal approach reduces cognitive overload, helping students focus on the task without feeling overwhelmed, which is especially beneficial for those with learning disabilities [11]. VanLehn [39] has proved that involving adaptive learning systems, such as Dream Box and Smart Sparrow, students with dyscalculia reported feeling more in control of their learning process. Many students stated they appreciated the personalized feedback, which allowed them to work at their own pace without pressure or frustration. This customization helps maintain their attention longer than traditional one-size-fits-all teaching methods [39].

6-8- Building Confidence and Reducing Anxiety

Table 8 shows that most teachers (87%) believe that students with dyscalculia often provide immediate feedback, which is effective in building their self-confidence. The supportive nature of these tools helps address the frustration and anxiety common among students who have difficulty concentrating and are overwhelmed by learning tasks. The positive reinforcement provided by digital games creates a safe environment for students to strengthen their skills without fear of failure. This benefits students with dyscalculia, who feel less anxious about completing tasks quickly. This positive experience fosters an increased desire to focus and experiment with new learning strategies [48, 49].

6-9- Reduced Distractions and Better Task Management

Table 8 shows that most teachers (90%) believe that digital games designed to track student behavior, including engagement levels and attention patterns, open the way for immediate interventions, thus reducing distraction. Alotaibi [13] supports this claim in her study, which indicated that digital games were designed to motivate students when they are distracted by providing reminders or adjusting the complexity of tasks to regain their attention. Teachers observe that real-time feedback and task management help students focus and stay engaged [44]. One teacher reported, "*Students with dyscalculia experienced less fatigue and increased ability to focus on each part of the task while learning through games*". This result is consistent with the study by Wadsworth [40], *which indicated* that students' ability to concentrate during digital gaming learning sessions increased. In the teacher interviews, one teacher stated, "*I now can track the progress of students with dyscalculia and adjust teaching strategies during game-based learning*". Conn [47] demonstrated in their study that teachers of children with dyscalculia noticed that their children seemed to enjoy using digital games more than traditional worksheets and had longer periods of sustained attention.

6-10- Social-Emotional Benefits

The qualitative results in Table 8 showed that 86% of teachers reported that students with dyscalculia showed social and emotional improvements. They gained confidence in their ability to focus and learn through games, and their social interactions in the classroom improved. A teacher commented, "T*hey feel less stigmatized by their problem with math because digital games allow them to succeed at their pace without drawing attention to their difficulties*". Another added, "*Students who have used digital games for attention training often report feeling less isolated or frustrated in class*". This finding is confirmed by Holmes et al. [42], which discovered that a sense of inclusion could boost participants' motivation to participate in-group activities and interact with peers, hence improving their learning and attentiveness.

7- Conclusion

The study presented substantial empirical evidence that Digital Game-Based Learning (DGBL) is an effective and impactful educational intervention for Saudi primary school students with dyscalculia. Students in the experimental group who used the Lumosity platform's Raindrops and Memory Match games to practice basic arithmetic and selective attention outperformed students in the control group who received more conventional education, according to the quantitative results. The large effect sizes ($\eta^2 = 0.14$ for arithmetic and $\eta^2 = 0.97$ for selective attention) demonstrate the effectiveness of digital game-based learning interventions. They confirm that well-designed digital games not only supplement the learning process but also effectively and efficiently address the key cognitive deficits associated with dyscalculia, namely deficiencies in number processing and the ability to ignore distractions.

Qualitative insights gained from teacher interviews influenced these results, highlighting the numerous benefits of game-based digital learning that go beyond cognitive aspects. Teachers regularly reported enhanced student engagement, motivation, less math anxiety, and greater self-confidence. The adaptive and interactive nature of the games created a personalized, mastery-oriented learning environment that kept students focused while reducing cognitive overload - a critical advantage for students who are easily overwhelmed by rigid, conventional methods. Furthermore, the supportive and unbiased framework for game-based learning contributed to a favorable shift in students' attitudes toward mathematics (as perceived by their teachers), converting their experience from fear and avoidance to curiosity and tenacity.

The study demonstrated that game-based learning is an important educational method for making learning environments more inclusive, engaging, and effective for students with dyscalculia. It effectively bridges the gap between cognitive training and curricular content while also developing crucial arithmetic fluency and selective attention skills required for academic achievement. As a result, the inclusion of structured DGBL programs in Saudi Arabia's special education curricula is actively encouraged.

7-1- Limitations and Future Research

There are some limitations that will guide future progress in this field. There are concerns regarding the sustained development of numeracy skills and selective attention after completing game-based training. The study was conducted on a specific group of fifth-grade female students in the Al-Ahsa region; it needs to include larger, more diverse populations to confidently generalize these positive findings to all students with dyscalculia. The study underscores a secondary issue concerning the chosen games, Lumosity Raindrops and Lumosity. Memory Match: future research should focus on developing more flexible DGBL systems whose difficulty and speed can be precisely adjusted to suit each student's cognitive strengths and weaknesses

The study highlights several avenues for future research. Longitudinal studies are particularly well-suited to track the ongoing impact of DGBL on students' academic progress, selective attention, motivation, and self-confidence over time. Future research should investigate how digital games can be effectively and seamlessly integrated with traditional classroom teaching methods, ensuring that technology enhances the learning experience. Research into the social and emotional effects of games on reducing anxiety and improving peer interactions in the classroom is also essential to integrating games into schools and enhancing academic skills.

8- Declarations

8-1- Author Contributions

Conceptualization, Y.A., R.A., and A.M.; methodology, Y.A., R.A., and A.M.; validation, Y.A.; formal analysis, M.H.; investigation, Y.A.; resources, M.H.; data curation, Y.A.; writing—original draft preparation, M.H.; writing—review and editing, R.A. and M.A.; visualization, Y.A.; project administration, M.A. All authors have read and agreed to the published version of the manuscript.

8-2- Data Availability Statement

The data presented in this study are available on request from the corresponding author.

8-3- Funding

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8-4- Acknowledgements

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8-5- Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the King Faisal University (protocol code KFU-ETHICS-2024, March 2024)." for studies involving humans**.**

8-6- Informed Consent Statement

Informed consent was obtained from all subjects involved in the study. All teachers in the study sample signed written consent during their responses in the questionnaire without obligations, with the assurance that they could withdraw at any time without liability. The scope of the consent was participation, data use, and consent to publish.

8-7- Conflicts of Interest

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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