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The Impact of Augmented Reality Technology on Visual Perception in Preschool Children at Risk of Specific Learning Disorder

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A B S T R A C T

Preschool children at risk of specific learning disorders face challenges in processing visual information due to deficits in visual perception, which can adversely impact their cognitive and academic development. This study aimed to investigate the effect of augmented reality (AR) technology on enhancing visual perception in these children. A quasi-experimental pretest–posttest control group design was employed. The population consisted of preschool children at risk of specific learning disorders in preschools in Darab during the 2024–2025 academic year. Through purposive sampling, 16 children were selected using the Steele (2004) Learning Disabilities Screening Questionnaire and Captain's Log software, and they were randomly assigned to experimental and control groups (8 children per group). The experimental group underwent eight 30-minute AR-based intervention sessions. The Frostig Visual Perception Test was administered to both groups during the pretest and posttest phases. Analysis of covariance (ANCOVA), controlling for pretest scores, indicated that the experimental group significantly outperformed the control group in visual perception ($p < .001$, partial $\eta^2 = .784$) and its subcomponents, including eye-motor coordination ($p = .007$, partial $\eta^2 = .442$), figure-ground discrimination ($p = .001$, partial $\eta^2 = .556$), constancy of shape ($p = .007$, partial $\eta^2 = .443$), position in space ($p = .018$, partial $\eta^2 = .361$), and spatial relationships ($p = .017$, partial $\eta^2 = .366$). These findings underscore the effectiveness of AR in enhancing visual perception. By providing an interactive, dynamic, and engaging learning environment, AR proves to be an effective tool for early interventions aimed at supporting children with special needs.

Keywords: *augmented reality, learning disorder, preschool children, visual perception.*

1. Introduction

In today's world, where every child follows a unique learning path, paying attention to subtle differences in their cognitive and perceptual development can have a profound impact on their academic and social future. One of the most significant challenges in this regard is the identification and treatment of specific learning disorders, which are neurodevelopmental conditions that often go undiagnosed in young children and typically become apparent only after academic failures (American Psychiatric Association, 2022; Hallahan et al., 2013). This delay in identifying these problems may lead to decreased self-esteem, a weak self-concept, and even psychosocial issues for these children (Frostig et al., 2019). Children with specific learning disorders often face significant challenges with visual perception, which directly impacts their learning process (Meng et al., 2024; Nour-Darvishali et al., 2014). A recent scoping review of 34 studies also concluded that children with specific learning disorders tend to show poorer motor skills than their peers, particularly on complex motor tasks (Blanchet & Assaiante, 2022). Visual perception refers to the ability to process and organize information from the visual sense, playing a critical role in learning basic skills like reading, writing, and arithmetic (Khatib et al., 2022; Kurtz, 2015; Yang & Meng, 2020). In fact, some children, despite having normal vision, encounter substantial learning difficulties due to issues with processing visual information, which can lead to disorders such as dyslexia (Zahed et al., 2012).

Early childhood is a particularly important window for addressing such difficulties. Visual-perceptual and visual-motor skills are still developing before school entry, yet they already predict later learning. In a longitudinal study of Chinese kindergarten children, visual processing measured before school entry explained unique variance in character reading and early mathematics 14 months later, even after controlling for prior performance, nonverbal intelligence, inhibitory control, and sustained attention (Yang & Meng, 2020). A meta-analysis of 96 studies likewise reported moderate associations between visuomotor integration and both mathematics (r = .39) and reading (r = .34) achievement, with the strength of these associations varying by educational stage and disability status (Khatib et al., 2022). Together with the case for early identification of children at risk of learning disabilities (Steele, 2004), this evidence suggests that perceptual weaknesses are better addressed during the preschool years than after academic failure has already occurred.

In this context, targeted educational interventions, particularly those aimed at enhancing visual perception in children with specific learning disorders, have received increasing attention. Aghaei Sabet et al. (2013) found that visual interventions significantly improved reading accuracy and comprehension in children (Aghaei Sabet et al., 2013). Moreover, studies have shown that strengthening visual perception can directly impact children's academic performance, especially in reading and writing (Carlson et al., 2013; Chang & Yu, 2017; Gajre & Setia, 2015). Controlled trials published in recent years point in the same direction. In a randomized controlled trial of children with specific learning disability, a game-based virtual reality program significantly improved scores on the Motor-Free Visual Perception Test-3 whether or not a therapist guided the sessions (Köse et al., 2022). In a small randomized trial of children aged 5 to 10 years with visual-perceptual defects associated with developmental disability, adding an interactive digital game to standard rehabilitation produced significantly larger gains in visual-perceptual skills than standard rehabilitation alone (Wu et al., 2022). Therefore, it is crucial to have a clear and accurate understanding of these processes and to identify effective methods for enhancing them.

Given the importance of early diagnosis and intervention in improving visual perception, the use of modern technologies can play a significant role in this area. Technology should do more than just deliver educational content; it should also be used as a tool to enhance students' self-esteem and independence (Zahed et al., 2012; Zaraii Zavaraki & Jafarkhani, 2009). Teachers play a crucial role in the success of educational and assistive technologies. By understanding both the potential and challenges of technology and integrating it effectively with teaching methods (Zaraii Zavaraki et al., 2017), teachers can create an inspiring, non-judgmental environment (Wertz et al., 2013; Wertz et al., 2011) that boosts students' confidence and self-worth (Sparrowhawk & Heald, 2019). Teachers should use technology as a complementary tool alongside direct teaching methods, not as a substitute for themselves, to maximize its impact on the learning of students with special needs (Wertz et al., 2007/2013). Fortunately, advances in technology and the development of computer-based diagnostic assessment tools in recent years have allowed for more accurate and in-depth identification of learning difficulties, enhancing effective educational

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solutions in regular classrooms (Florian & Hegarty, 2012). Zaraii Zavaraki's (2019) blended learning model, which emphasizes digital technologies for students with special educational needs, includes components such as analysis, design, production, implementation, management, support, and evaluation (Zaraii Zavaraki, 2019). In this model, augmented reality (AR) technology is positioned as one of the key tools in the production phase and plays an important role in the development of educational tools (Zaraii Zavaraki, 2024). At the same time, recent systematic reviews caution that realizing this potential in special education depends on overcoming high costs, technical complexity, and a narrow research focus (Chang et al., 2025).

Given the issues discussed, the use of modern technologies, particularly augmented reality, has increasingly been recognized in recent years as a tool to enhance visual perception and improve cognitive skills in children with specific learning disorders. Augmented reality technology, by adding digital layers to the real world, creates an engaging and interactive learning environment (Garzón, 2021), which can help children strengthen their perceptual skills and address learning difficulties (Sandeep et al., 2024). A meta-analysis of 134 (quasi-)experimental studies published between 2012 and 2021 found that AR benefited all three categories of learning outcomes examined (learning responses, knowledge and skills, and performance), with treatment duration emerging as a significant moderator of its impact (Chang et al., 2022). While most research has focused on the effects of this technology at the elementary school level, fewer studies have been conducted on preschool children at risk for specific learning disorders (Abd El-Monem, 2024; Özel et al., 2025). A bibliometric mapping of 85 publications on AR in preschool education showed that this literature has concentrated on motivation, knowledge acquisition, and English language learning (Kayaduman & Sağlam, 2023), which leaves the effects of AR on young children's perceptual skills comparatively underexamined. This study seeks to investigate the impact of augmented reality technology on the visual perception of preschool children at risk for specific learning disorders.

Studies from the past two decades indicate that technology-based interventions, particularly cognitive rehabilitation software, digital games, and multimedia tools, play a significant role in improving visual perception and related functions in children with learning disorders. Many of these studies have focused on the use of computer programs and digital games to enhance perceptual and cognitive skills, and their results generally demonstrate the effectiveness of these approaches.

In the field of computer-assisted interventions and cognitive rehabilitation, several studies have shown that computer programs and rehabilitation software can significantly improve visual perception and related skills in children with learning difficulties. For example, Kakavandi et al. (2020) reported the effectiveness of computer-assisted cognitive rehabilitation based on the Captain's Log software in improving visual perception in students with specific learning disabilities, demonstrating that this program significantly enhances visual perception (Kakavandi et al., 2020). Similarly, Roitvond Giahsavand and Amiri Majd (2019) showed that Captain's Log cognitive software positively affects visual-spatial perception, verbal visual-spatial perception, and non-verbal visual-spatial memory in students with learning disabilities (Roitvond Giahsavand & Amiri Majd, 2019). In the same vein, Esmailzadeh Rouzbahani et al. (2022) reported that computer-based cognitive rehabilitation using Captain's Log software improves visual-spatial ability and problem-solving skills in students with mathematical learning disabilities (Esmailzadeh Rouzbahani et al., 2022). These findings, along with those of Afshari and Rezaei (2019) regarding the impact of the Sound Smart software on certain executive functions and memory (Afshari & Rezaei, 2019), and the findings of Shokoohi Yekta et al. (2014) and Arjmandnia et al. (2014) on the effectiveness of computer-based cognitive exercises on visual-spatial working memory (Arjmandnia et al., 2014; Shokoohi Yekta et al., 2014), demonstrate that computer-assisted cognitive interventions are effective tools for enhancing visual and spatial functions in children with learning disabilities. However, these interventions have generally relied on traditional computer software rather than specifically on augmented reality platforms.

Alongside rehabilitation software, digital and computer games have been used as an engaging and motivating tool to improve visual and cognitive skills in domestic research. Abbaszadeh Rogoshoi (2023) showed that digital educational games can improve the visual perception of first-grade students with dysgraphia, enabling them to recognize and independently write Persian letters (Abbaszadeh Rogoshoi, 2023). Yahiyozadeh (2021) also demonstrated that digital games enhance various components of visual perception (including letter discrimination, matching, and recognizing reversed letters) and short-term, medium-term, and long-term memory in students with dyslexia (Yahiyozadeh, 2021). The results of Pourfarahmand and

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Taher (2020) show that computer games based on visual skills significantly increase visual perception, auditory perception, spatial perception, and reading tracking speed in students with specific learning disabilities (Pourfarahmand & Taher, 2020). Similarly, Pakat Chi et al. (2013), Tamnai Far and Alizadeh (2015), Panahi (2018), Zarif et al. (2021), Dalvand et al. (2023), and Nobakht et al. (2023) all showed that computer or visual games positively affect visual memory, visual working memory, visual-spatial perception, eye-motor skills, and even social adjustment in students with learning disabilities (Dalvand et al., 2023; Nobakht et al., 2023; Pakat Chi et al., 2013; Panahi, 2018; Tamnai Far & Alizadeh, 2015; Zarif et al., 2021). Overall, this body of research demonstrates that digital and computer games have high potential for improving visual perception and related skills in children with special needs; however, in most of these studies, conventional digital technologies have been used, and augmented reality has rarely been directly employed as the intervention platform.

Similar results have been reported in the field of multimedia and digital educational packages. Farhang Ranjbar et al. (2019) showed that a computer-based mathematics concept teaching program improves students' visual-spatial perception and, in particular, eye-hand coordination more effectively than traditional teaching methods (Farhang Ranjbar et al., 2019). Other studies have also confirmed the role of educational multimedia in enhancing perceptual and academic skills. For example, the educational multimedia program "Dictation Helper" in the studies of Azimi and Mousavipour (2014) and Faraji and Karimi Sani (2016) led to improvements in visual and auditory memory as well as academic self-efficacy in students with spelling disabilities (Azimi & Mousavipour, 2014; Faraji & Karimi Sani, 2016). Additionally, Abdollahi et al. (2014) revealed that a multimedia educational package, focusing on fundamental learning skills, helps alleviate the symptoms of spelling disorders through enhanced visual perception skills, sequencing, and visual memory (Abdollahi et al., 2014). The role of multimedia design based on enhancing visual perception in mathematics lessons was also confirmed in the study by Naqshbandi and Mousavi (2016) (Naqshbandi & Mousavi, 2016). Mashhadi et al. (2022) found that a computer-based multimedia educational package improves eye-hand coordination skills, figure-ground perception, spatial perception, spatial relationships, visual perception, and visual memory in students with learning disabilities (Mashhadi et al., 2022). At the preschool level, Taghinejad (2012) demonstrated that teaching a computer-based drawing program significantly enhances the visual-motor coordination skills of kindergarten children (Taghinejad, 2012). These findings all emphasize that multimedia technologies and computer-based education provide an effective infrastructure for enhancing visual perception and related skills in children with special needs.

Beyond Iran, recent controlled studies of game-based and immersive technologies in children with learning and neurodevelopmental difficulties report broadly similar benefits. In a controlled study of children with dyslexia, a virtual reality rehabilitation program produced greater improvements in non-word reading and reading speed than conventional neuropsychological treatment, and these gains were still evident one year after training ended (Maresca et al., 2024). In a pilot study of children with specific learning disorders, a six-week virtual reality program was followed by improvements in visual attention, inhibition, flexibility, and planning, most of which were maintained after six months (Di Giusto et al., 2023). Dalvand et al. (2023) reported that online visual games improved oculomotor and visual perception skills (Dalvand et al., 2023), but not balance, in children with developmental dyslexia, and a single-blind randomized controlled trial found that children with ADHD who received virtual reality in addition to occupational therapy improved significantly in fine-motor precision, balance, figure-ground perception, and visual memory (Şahin et al., 2026). A recent mini-review of virtual reality in ADHD, autism spectrum disorder, and specific learning disorders concluded that such tools can support both the assessment and the rehabilitation of specific functional domains (Capobianco et al., 2025). Most of these studies, however, used virtual reality or conventional digital games rather than augmented reality, and most involved school-age children rather than preschoolers.

Despite the substantial evidence regarding software, computer games, and multimedia, studies specifically focusing on augmented reality technology are still emerging and remain limited both nationally and internationally. In Iran, Khateri et al. (2019, 2021) conducted two studies demonstrating that augmented reality technology positively impacts both learning and academic motivation in second-grade students with dyslexia (Khateri et al., 2019, 2021). These studies show that adding interactive digital layers to educational content makes the learning experience more engaging for students with special needs and increases their participation. However, these studies have primarily focused on academic learning and motivational variables in

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elementary school students with dyslexia, while visual perception, particularly in preschool children, has not been the primary focus.

Internationally, syntheses of augmented reality in special education agree that the approach is promising but that the evidence base is still thin. A meta-analysis of single-subject studies found that AR was most effective for promoting learning skills, followed by social, physical, and living skills (Baragash et al., 2020), and systematic reviews of AR for students with special educational needs report generally encouraging outcomes (Fernández-Batanero et al., 2022; Kapetanaki et al., 2022; Yenioglu et al., 2023). The most recent review identified only 16 eligible studies in K–12 special education; none used true randomization, and the authors noted limited evidence that gains generalize beyond the AR context (Chang et al., 2025). Studies focusing on children with learning disabilities remain few. In one multiple-baseline study, an AR-based video-modeling intervention helped seven middle school students with specific learning disabilities solve multistep mathematics problems, with gains maintained across at least three of four problem types (Kellems et al., 2020).

At the international level, multiple empirical studies indicate that augmented reality can directly influence visual perception, spatial skills, and visual-motor integration in children. Wuang et al. (2021) reported that an augmented reality-based kinesthetic game training system (Wuang et al., 2021), delivered over eight weeks (two 30-minute sessions per week), produced significantly greater gains than conventional visual-perceptual training in visual-motor integration, visual-perceptual skills, and school functioning in children with developmental delay. Özel et al. (2025) also reported that teaching geometric shapes using augmented reality-supported educational materials significantly enhances visual perception in preschool children (26 children aged 5–6 years) (Özel et al., 2025), as measured by the Frostig Visual Perception Test. The findings of Düzyol et al. (2022), Gecu-Parmaksiz and Delialioğlu (2020), and Intarapreecha and Sangsawang (2023) reinforce that augmented reality-based activities in teaching spatial concepts, spatial orientation, and spatial skills in preschool children and students with learning disabilities are effective, showing greater improvement in spatial knowledge, orientation, and learning motivation compared to traditional methods (Düzyol et al., 2022; Gecu-Parmaksiz & Delialioğlu, 2020; Intarapreecha & Sangsawang, 2023). Evidence on feasibility is also encouraging: in a mixed-methods study with 12 teachers and 65 preschoolers aged 4–5 years, children could operate an AR application independently, and both teachers and children enjoyed using it, although some concerns about the technology were raised (Law et al., 2025).

Other studies have explored the use of augmented reality to improve writing skills and visual-auditory perception in children with learning disabilities. Abd El-Monem (2024), in a quasi-experimental study of 24 kindergarten children (12 per group), showed that an augmented reality-based e-book significantly enhances visual and auditory perception skills in preschool children at risk of learning difficulties (Abd El-Monem, 2024). Prasomsri (2024) reported that an augmented reality-based writing program improves visual perception, visual-motor integration, and writing abilities in children with learning disabilities (Prasomsri, 2024). Selvam and Gnana Piragasam (2025), based on interviews with special education teachers, emphasized the potential of augmented reality in reducing writing challenges and enhancing the active participation of students with learning disabilities (Selvam & Gnana Piragasam, 2025). Furthermore, multicomponent preschool programs such as those of Lewis Presser et al. (2025) and Del-Moral-Pérez et al. (2025), which combine augmented reality with digital games, educational robotics, and storytelling activities, have been associated with gains in spatial navigation skills, eye-hand coordination, computational thinking, and logical reasoning in preschool children (Del-Moral-Pérez et al., 2025; Lewis Presser et al., 2025).

A systematic review by Sandeep et al. (2024) offers a comprehensive overview of the role of technology-based interventions in enhancing visual perception in children (Sandeep et al., 2024). They examined interventions based on iPads and various software across groups, including children with developmental delays, dyslexia, cerebral palsy, Down syndrome, and other disabilities. The study found that technology-based visual perception interventions are valuable and effective tools for rehabilitating children, and as technology progresses, more innovative approaches should be developed in this field. Although this review covered various types of technologies, with augmented reality being only a part of the overall landscape, the final conclusion clearly highlights the importance of interactive and digital technologies in improving visual perception skills.

The existing literature underscores several key findings: First, domestic studies widely demonstrate the effectiveness of computer software, digital games, and multimedia in improving visual perception, visual-spatial perception,

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visual memory, and related skills in students with learning disabilities. However, the direct application of augmented reality in enhancing visual perception, particularly in the preschool stage and in children at risk of specific learning disorders, is very limited. Second, international studies, especially in recent years, provide growing evidence on the effectiveness of augmented reality in visual perception, spatial skills, auditory-visual perception, and writing in preschool children and students with special needs, but these studies are often conducted in non-Iranian cultural and educational contexts. Third, a significant portion of these studies—both domestic and international—has focused on elementary school children diagnosed with learning disabilities, with less emphasis on preschool children at risk of specific learning disorders and the use of standard tools like the Frostig Visual Perception Test alongside augmented reality-based interventions. Fourth, the AR evidence base remains methodologically limited: a recent review of K–12 special education found no study using true randomization (Chang et al., 2025), long-term studies are still needed to establish the value of AR beyond its initial novelty (Mohammadhossein et al., 2024), and AR research is dominated by media-comparison designs that cannot show how or when AR works (Buchner & Kerres, 2023). Therefore, the present study aims to fill this gap by examining the impact of augmented reality technology on the visual perception of preschool children at risk of specific learning disabilities.

2. Methods and Materials

2.1. Study Design and Participants

In the present study, a quasi-experimental quantitative design with a pretest–posttest structure and a control group was employed. The statistical population consisted of all preschool children at risk of specific learning disorders who attended preschool centers in Darab during the 2024–2025 academic year (1403–1404). The participants were selected through purposive sampling. Initially, the Preschool Children's Learning Disabilities Symptoms Questionnaire (Steele, 2004) was completed by teachers for 80 students in one of the preschool centers in Darab. Based on the results of this assessment, 19 students were identified as being at risk of specific learning disorders. Subsequently, the researcher assessed the visual perception skills of these students using the Captain's Log software. To be included in the final sample, children were required to (a) obtain a score of 30 or higher on the Steele checklist, the threshold indicating risk for a specific learning disorder (Abedini & Yarmohammadian, 2016), and (b) fail to obtain a passing score on all six visual-perception subtests of the Captain's Log software, confirming the presence of visual-perception deficits. Three of the 19 children who met the Steele-checklist criterion were excluded because they were unable to complete the individually administered Captain's Log assessment (e.g., due to inattention or refusal to continue the tasks); none of the remaining children passed any of the six visual-perception subtests. The final sample therefore comprised 16 children, with ages ranging from 5.0 to 5.9 years ($M = 5.39$, $SD = 0.26$). Participants were then allocated to the experimental and control groups in a 1:1 ratio ($n = 8$ per group); each group comprised four girls and four boys. For the allocation procedure, a sex-stratified computer-generated sequence was created in Microsoft Excel using the RAND() function, sorted within the two sex strata, and implemented by the first author after eligibility screening. Sex was therefore used as a stratification variable, yielding four girls and four boys in each group. Initially, a pretest was administered to both groups. Then, the experimental group received an instructional intervention based on augmented reality technology, while the control group received no intervention and continued with the center's regular curriculum. After the intervention period, a posttest was administered to both groups. The pretest and posttest data were then analyzed to examine the effectiveness of augmented reality technology on improving visual perception in preschool children at risk of specific learning disorders.

2.2. Measures

In this study, the Steele (2004) Preschool Learning Disabilities Screening Checklist was used to identify students at risk of specific learning disorders (Steele, 2004). Following a review of early diagnosis and intervention research for children at risk, Steele (2004) developed a 22-item checklist to identify preschool children with neuropsychological or developmental learning disorders, which is filled out by educators (Steele, 2004). The maximum score on this checklist is 44, indicating the presence of pre-academic symptoms of specific learning disorders. To assess concurrent validity, Abedi et al. (2008) reported a correlation coefficient of 0.79 between this instrument and the NEPSY test, and its reliability coefficient was calculated as 0.93 (Abedi et al., 2008). According to this questionnaire, a score of 30 or higher indicates risk for

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specific learning disorders (Abedini & Yarmohammadian, 2016). In the present study, preschool teachers in Darab filled out the Steele checklist for 80 students, and based on the results, 19 children were identified as being at risk for specific learning disorders.

To assess children's visual perception skills for sample selection, the 2020 version of Captain's Log: MindPower Builder software was used. This software includes several cognitive and perceptual assessment subtests, including the Visual Scanning Identification Test, Selective Comparison Reasoning Test, Numeric Perceptual Recall Test, Visual Memory Identification Test, Sequential Memory Patterns Test, Conceptual Sequential Patterns Test, Working Memory Capacity Test, Auditory Pattern Recognition Test, and Auditory Sequential Memory Test. According to the software documentation (Captain's Log MindPower Builder, 2020), the first six tests in this section specifically target visual perception skills and were used for screening in the present study. For this study, a passing score was defined as meeting or exceeding the following raw-score criterion on each visual-perception subtest: Visual Scanning Identification Test ≥ 8/10; Selective Comparison Reasoning Test ≥ 8/10; Numeric Perceptual Recall Test ≥ 7/10; Visual Memory Identification Test ≥ 8/10; Sequential Memory Patterns Test ≥ 7/10; and Conceptual Sequential Patterns Test ≥ 8/10. A child was eligible only if the child failed to reach the passing criterion on all six subtests. None of the 16 retained children met a passing criterion on any of the six visual-perception tests.

The Frostig Advanced Visual Perception Test (Frostig et al., 2019) was used as the pretest and posttest measure. The Persian-language version assesses five visual-perception components: eye-motor coordination, figure-ground discrimination, constancy of shape, position in space, and spatial relationships. An Iranian standardization study reported internal consistency of Cronbach's α = .67, with subtest–total correlations ranging from r = .28 to .60. Criterion-related validity was examined against mathematics, reading, dictation, and the mean of these academic indicators; for the total score, the reported correlations were r = .031, .024, .054, and .007, respectively, whereas statistically significant criterion correlations were observed for subtests 4 and 5 with some academic indicators (Brand, 1989; Kord Noghabi & Dertaj, 2007). The test also provides remedial-training strategies, which informed the design of the augmented reality content in this study, and it was administered at both pretest and posttest.

2.3. *Intervention*

The ARCHIN augmented reality application was developed using the Unity engine for Android devices running version 8 or higher. The program features interactive AR components aimed at strengthening the visual perception skills of preschool children at risk of specific learning disorders. The augmented reality–based instructional program was conducted across eight 30-minute sessions, during which children interacted with virtual shapes and objects to enhance their visual perception skills. The structure of the instructional program is outlined below:

Table 1

Augmented Reality–Based Instructional Program

Session	Objective	Instructional Content
1	Introduction to the ARCHIN program	Introduction to and familiarization with augmented reality technology (ARCHIN)
2	Eye-Motor Coordination	Strengthening visual tracking skills through hand–eye interaction
3	Figure Ground	Review of previous session; identifying a target shape within a complex 3D environment
4	Constancy of Shape	Review of previous session; recognizing a shape regardless of changes in color, size, or orientation
5-6	Position in space	Review of previous session; identifying shapes in rotated positions
7-8	Spatial Relationships	Review of previous session; determining the relative positions of objects within a 3D space

The augmented reality–based instructional sessions were designed to enhance children's visual perception skills based on the model of Frostig et al. (1964/2019) (Frostig et al., 2019). The first session introduces the ARCHIN program, during which children initiate the AR environment by selecting the start option, choose shapes, and place them in designated locations, remove them, and become familiar with moving and resizing virtual objects. The second session

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focuses on eye-motor coordination; children create paths using shapes (such as grass or flowers) and guide virtual objects, like rabbits or chickens, along straight and curved pathways. The third session reviews previous content and focuses on figure ground, with children identifying objects such as stars, balls, or cucumbers within a visually complex 3D environment. The fourth session reinforces constancy of shape; children learn to recognize shapes regardless of variations in color, size, or orientation. The fifth and sixth sessions address position in space, helping children identify objects in various orientations. The seventh and eighth sessions strengthen spatial relationships, during which children reconstruct spatial patterns based on provided models. Throughout all sessions, children use the star icon to record successful task completion. Sample images from the ARCHIN educational program are presented below.

Figure 1

Sample images of the instructional content in the ARCHIN augmented reality program



2.4. Data Analysis

For data analysis, descriptive statistics—including measures of central tendency and variability such as mean and standard deviation—were calculated. In the inferential statistics section, analysis of covariance (ANCOVA) was conducted using SPSS software (version 27).

3. Findings and Results

The mean and standard deviation of the pretest and posttest scores for visual perception and its components for the experimental and control groups are presented in Table 2.

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Table 2

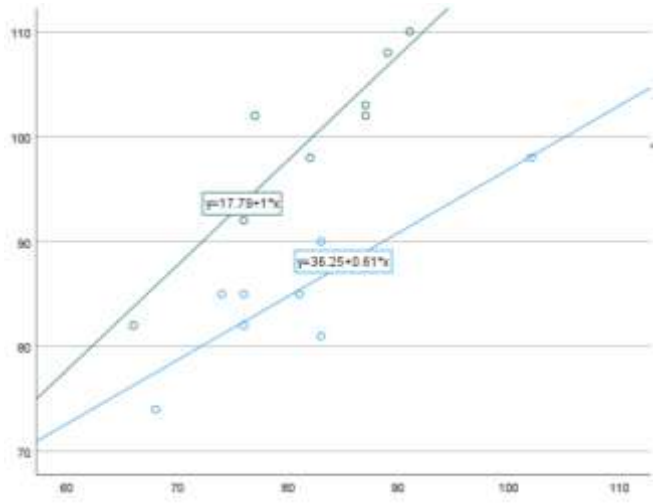
Means and Standard Deviations of Visual Perception and Its Components in the Pretest–Posttest Phases for the Experimental and Control Groups

Variable	Group	Pretest		Posttest		
		Mean	SD	Mean	SD	Adjusted Mean
Visual Perception	Experimental	81.88	8.425	99.63	9.039	99.049
	Control	80.38	10.099	85.00	6.969	85.576
Eye-Motor Coordination	Experimental	9.25	1.832	11.50	1.414	11.531
	Control	9.38	1.685	9.75	1.389	9.719
Figure Ground	Experimental	7.00	0.756	8.00	0.926	7.894
	Control	6.75	1.035	6.88	0.835	6.981
Constancy of Shape	Experimental	8.00	0.756	9.75	1.035	9.815
	Control	8.13	1.727	8.13	2.232	8.060
Position in Space	Experimental	8.38	1.188	10.38	1.408	10.217
	Control	7.75	1.669	8.50	1.195	8.658
Spatial Relationships	Experimental	8.38	0.744	10.38	0.744	10.279
	Control	8.13	0.835	9.13	1.126	9.221

This section evaluates the assumptions necessary for conducting the analysis of covariance (ANCOVA), including the homogeneity of regression slopes and the linear relationship between the covariate and the dependent variable. In the between-subjects effects test, used to examine the homogeneity of regression slopes assumption, the primary focus is on the group × pretest interaction for visual perception, which resulted in an F value of 3.551 and a significance level of p = .084. Since the p value exceeds the .05 threshold, the interaction is not statistically significant, and the assumption of homogeneity of regression slopes holds. Subsequently, the linear relationship between the covariate (pretest visual perception score) and the dependent variable (posttest visual perception score) was examined using scatterplots and simple linear regression analysis.

Figure 2

Linear relationship between the pretest and posttest visual perception scores in the experimental and control groups



As illustrated in Figure 2, the regression lines have nearly parallel slopes, indicating a linear relationship between the pretest and posttest visual perception scores in both the experimental and control groups. The results of the analysis of covariance for testing the research hypotheses are presented below. To examine the assumption of homogeneity of variances in ANCOVA, Levene's test was conducted. The Levene's statistics for visual perception,

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eye-motor coordination, figure ground, constancy of shape, position in space, and spatial relationships were 0.844, 0.904, 0.400, 0.142, 0.664, and 0.377, respectively. None of these values were significant ($p > .05$). Therefore, the results of Levene's test indicate that the assumption of homogeneity of error variances was not violated. Normality of the ANCOVA residuals was assessed using the Shapiro–Wilk test. The model-specific results were: visual perception, $W = .962$, $p = .682$; eye-motor coordination, $W = .951$, $p = .505$; figure ground, $W = .944$, $p = .407$; constancy of shape, $W = .957$, $p = .601$; position in space, $W = .949$, $p = .486$; and spatial relationships, $W = .972$, $p = .873$. All six tests were nonsignificant ($p > .05$), providing no evidence of a violation of residual normality.

Table 3

Test of Between-Subjects Effects (ANCOVA)

Dependent Variable	Source	SS	df	MS	F	Sig.	Partial η^2
Visual Perception	Pretest (Covariate)	713.775	1	713.775	46.840	0.000	0.783
	Group	720.760	1	720.760	47.299	0.000	0.784
Eye-Motor Coordination	Pretest (Covariate)	10.906	1	10.906	8.544	0.012	0.397
	Group	13.124	1	13.124	10.282	0.007	0.442
Figure Ground	Pretest (Covariate)	8.266	1	8.266	41.192	0.000	0.760
	Group	3.264	1	3.264	16.264	0.001	0.556
Constancy of Shape	Pretest (Covariate)	26.915	1	26.915	22.633	0.000	0.635
	Group	12.290	1	12.290	10.334	0.007	0.443
Position in Space	Pretest (Covariate)	7.532	1	7.532	5.992	0.029	0.315
	Group	9.225	1	9.225	7.338	0.018	0.361
Spatial Relationships	Pretest (Covariate)	5.207	1	5.207	8.974	0.010	0.408
	Group	4.346	1	4.346	7.490	0.017	0.366

The results presented in Table 3 indicate that both the group effect (independent variable) and the covariate (pretest score) were statistically significant for all dependent variables—visual perception, eye-motor coordination, figure ground, constancy of shape, position in space, and spatial relationships. For visual perception, the covariate yielded an F value of 46.840 ($p < .001$) with a partial η^2 of .783. For eye-motor coordination, the group effect was significant, $F = 10.282$, $p = .007$, partial $\eta^2 = .442$. In the case of figure ground, the group effect was also significant, $F = 16.264$, $p = .001$, partial $\eta^2 = .556$. For constancy of shape, the group effect was significant, $F = 10.334$, $p = .007$, partial $\eta^2 = .443$. For position in space, the group effect reached significance, $F = 7.338$, $p = .018$, partial $\eta^2 = .361$. Finally, for spatial relationships, the group effect was significant, $F = 7.490$, $p = .017$, partial $\eta^2 = .366$. These findings indicate significant improvements from the augmented reality intervention across all visual perception components in preschool children at risk of specific learning disorders. In all cases, the adjusted means for the experimental group were significantly higher than the control group. Therefore, all research hypotheses were supported.

It is important to distinguish between two effect-size statistics reported in this study. Partial η^2, reported for each source in Table 3, quantifies the unique proportion of variance in the dependent variable accounted for by that specific term (e.g., the group, or AR-intervention, effect) after removing variance attributable to the other term in the model; it is the appropriate index for evaluating the specific effect of the AR intervention. By contrast, the full ANCOVA model (covariate + group) accounted for a substantially larger share of total variance in each outcome—ADJUSTED $R^2 = .871$ for visual perception, .518 for eye-motor coordination, .811 for figure ground, .663 for constancy of shape, .503 for position in space, and .542 for spatial relationships—because these ADJUSTED R^2 values combine the variance explained by the pretest covariate with that explained by group membership. Because pretest scores are, by design, strongly related to posttest scores, model ADJUSTED R^2 is not an appropriate index of the AR

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intervention's specific effect and should not be interpreted as such.

4. Discussion

The present study investigated the effect of augmented reality technology on the visual perception of preschool children at risk of specific learning disorders. A quasi-experimental design with pretest, posttest, and a control group was employed to examine one main hypothesis and five sub-hypotheses, each corresponding to a specific component of visual perception: eye-motor coordination, figure ground, constancy of shape, position in space, and spatial relationships. The results of the analysis of covariance indicated that all hypotheses were supported, demonstrating that augmented reality technology significantly improved visual perception and its components among preschool children. The main hypothesis proposed that the visual perception level of preschool students at risk of specific learning disorders who used augmented reality technology would be higher than that of students who did not use it. The findings supported this hypothesis: the adjusted mean posttest score for the experimental group (99.049) was significantly higher than that for the control group (85.576), $F = 47.299$, $p < .001$, partial $\eta^2 = .784$, indicating large effect of the AR intervention on visual perception after controlling for pretest scores. These results are consistent with the studies of Abd El-Monem (2024), Özel et al. (2025), Prasomsri (2024), and Wuang et al. (2021) (Abd El-Monem, 2024; Özel et al., 2025; Prasomsri, 2024; Wuang et al., 2021), all of which reported improvements in visual perception or related visual-motor outcomes following augmented reality–based interventions, and with the broader evidence on technology-based visual perception interventions summarized by Sandeep et al. (2024) (Sandeep et al., 2024). They also parallel recent randomized trials of game-based and virtual reality training, in which children with specific learning disability (Köse et al., 2022), children with visual-perceptual defects associated with developmental disability (Wu et al., 2022), and children with ADHD (Şahin et al., 2026) showed gains in visual-perceptual skills. This effectiveness may be explained by multisensory learning theory, which posits that the visual and interactive stimuli provided by augmented reality enhance the brain's processing of visual information and increase children's focus and engagement by creating dynamic and motivating learning environments. Two cautions apply, however. First, the effect observed here (partial $\eta^2 = .784$) is considerably larger than the mean effects reported in large syntheses of AR in education (Chang et al., 2022); with only 16 children, such a large estimate is likely to be imprecise and may shrink in larger samples. Second, because the control group received no intervention, the design cannot show which features of AR produced the gains. Reviews note that AR research is dominated by media-comparison designs (Buchner & Kerres, 2023) and that design features such as attention-guiding visual cues and activities that prompt active learning strategies appear to be particularly beneficial (Buchner et al., 2022). After an introductory session, each ARCHIN session targeted a single perceptual skill, later sessions began with a review of earlier content, and children recorded successful task completion with a star icon; these features may have supported attention and reduced extraneous cognitive load, but their individual contributions were not tested here.

In evaluating the sub-hypotheses, the results showed that augmented reality technology significantly improved each component of visual perception. The first sub-hypothesis posited that preschool students at risk of specific learning disorders who used augmented reality would demonstrate higher levels of eye–hand (visual–motor) coordination than their peers who did not. The adjusted mean for the experimental group (11.531) exceeded that of the control group (9.719), $F = 10.282$, $p = .007$, partial $\eta^2 = .442$. These results are consistent with those of Del-Moral-Pérez et al. (2025), Prasomsri (2024), and Wuang et al. (2021) (Del-Moral-Pérez et al., 2025; Prasomsri, 2024), who reported gains in eye–hand coordination or visual-motor integration after AR-based activities, and with the improvement in fine-motor precision reported after virtual reality training in children with ADHD (Şahin et al., 2026). They are also relevant to the poorer motor skills that children with specific learning disorders tend to show, particularly on complex tasks (Blanchet & Assaiante, 2022). The findings can be interpreted through information-processing theory, according to which repeated, feedback-rich coupling of visual input with hand movements may refine visual-motor mappings; because no neurophysiological measures were collected, this explanation remains tentative. The second sub-hypothesis asserted that augmented reality would enhance figure ground. The experimental group showed a higher adjusted mean (7.894) compared with the control group (6.981), $F = 16.264$, $p = .001$, partial $\eta^2 = .556$. This result is consistent with Özel et al. (2025) (Özel et al., 2025) and with the gains in figure-ground perception reported after a virtual reality program in children with ADHD (Şahin et

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al., 2026), and it can be interpreted within Gestalt theory, which emphasizes the organization of visual stimuli. The third sub-hypothesis concerned constancy of shape. The experimental group again outperformed the control group, with adjusted means of 9.815 and 8.060, respectively ($F = 10.334$, $p = .007$, partial $\eta^2 = .443$). This finding aligns with Özel et al. (2025) and further supports Gestalt principles regarding visual stability (Özel et al., 2025). The fourth sub-hypothesis addressed position in space. The experimental group achieved a higher adjusted mean (10.217) than the control group (8.658), $F = 7.338$, $p = .018$, partial $\eta^2 = .361$. These results are consistent with the studies of Yang et al. (2024), Intarapreecha and Sangsawang (2023), Gecu-Parmaksiz and Delialioğlu (2020), and Düzyol et al. (2022), and are supported by spatial thinking theory (Düzyol et al., 2022; Gecu-Parmaksiz & Delialioğlu, 2020; Intarapreecha & Sangsawang, 2023; Yang et al., 2024). Finally, the fifth sub-hypothesis proposed that augmented reality would improve spatial relationships. The adjusted mean for the experimental group (10.279) exceeded that of the control group (9.221), $F = 7.490$, $p = .017$, partial $\eta^2 = .366$. This finding aligns with Lewis Presser et al. (2025), Yang et al. (2024), Düzyol et al. (2022), Intarapreecha and Sangsawang (2023), and Gecu-Parmaksiz and Delialioğlu (2020), and is also explained by spatial thinking theory (Düzyol et al., 2022; Gecu-Parmaksiz & Delialioğlu, 2020; Intarapreecha & Sangsawang, 2023; Lewis Presser et al., 2025; Yang et al., 2024).

The present study examined the effectiveness of augmented reality technology in enhancing visual perception among preschool children at risk of specific learning disorders. These preliminary findings, from a small, single-site sample, suggest that this AR-based intervention improved overall visual perception and all its constituent components, including eye-motor coordination, figure-ground discrimination, constancy of shape, position in space, and spatial relationships. The experimental group showed substantially greater gains than the control group, with group membership (i.e., receiving the AR intervention) accounting for a large share of the variance in visual perception after controlling for pretest scores (partial $\eta^2 = .784$).

These results contribute to the growing body of literature supporting technology-based interventions for children with special educational needs. By creating an interactive, multisensory, and engaging learning environment, augmented reality appears to facilitate the development of fundamental perceptual skills that are critical precursors to academic success. The AR-based program's effectiveness may be attributable to its capacity to provide immediate feedback, maintain children's attention through dynamic visual stimuli, and offer repeated practice opportunities in a motivating context—elements that align with key principles of cognitive and perceptual learning theories. Because these mechanisms were not directly measured, they should be treated as hypotheses, and reviews stress that long-term studies are needed to establish the value of AR beyond its initial novelty (Mohammadhossein et al., 2024).

The findings carry significant practical implications for early childhood education and special education. First, they suggest that AR technology can serve as a valuable tool for early intervention, potentially mitigating the adverse academic and psychosocial consequences associated with undiagnosed learning disorders. Second, the demonstrated effectiveness across all five Frostig subscales indicates that AR interventions can address multiple facets of visual perception simultaneously, offering a comprehensive approach to perceptual skill development. Third, the positive outcomes underscore the importance of integrating innovative technologies into preschool curricula, particularly for children identified as at-risk for learning difficulties. Cost and technical complexity remain barriers to the adoption of AR in special education (Chang et al., 2025), which favors lightweight applications that run on standard Android devices, as ARCHIN does.

From a theoretical perspective, these findings extend our understanding of how technology-mediated learning environments can support perceptual development. The results align with multisensory learning theory, Gestalt principles of perceptual organization, and spatial thinking frameworks, suggesting that AR may provide a suitable platform for supporting visual-perceptual development. Furthermore, the study validates the application of Zaraii Zavaraki's (2019) blended learning model, which positions augmented reality as a key tool in the production phase of educational technology design (Zaraii Zavaraki, 2019).

The study also addresses a notable gap in the literature by focusing specifically on preschool children at risk for specific learning disorders—a population that has received limited attention in AR research compared to elementary school children with diagnosed learning disabilities (see also (Kayaduman & Sağlam, 2023)). By demonstrating effectiveness at this critical developmental stage, the findings highlight the potential of AR to serve as a preventive intervention, addressing perceptual difficulties before they manifest as academic failure. That children aged

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4–5 years can operate AR applications independently (Law et al., 2025) supports the practicality of such preventive use, and the associations of early visual processing and visual-motor integration with later reading and mathematics (Khatib et al., 2022; Yang & Meng, 2020) give the targeted skills clear educational relevance.

5. Conclusion

In conclusion, augmented reality technology appears to be a promising intervention for enhancing visual perception in preschool children at risk for specific learning disorders, although these pilot-scale, single-site findings will need to be replicated in larger, more diverse samples before firm conclusions can be drawn. The interactive, engaging, and adaptable nature of AR makes it particularly well-suited for early childhood education, where maintaining children's interest and providing developmentally appropriate learning experiences are paramount. As technology continues to evolve, AR-based interventions may become increasingly accessible and integrated into mainstream educational practices, offering new opportunities to support children's cognitive and academic development during the crucial preschool years.

While this study provides valuable insights into the effectiveness of augmented reality for enhancing visual perception in preschool children at risk for specific learning disorders, several limitations should be acknowledged when interpreting the findings.

The most significant limitation is the small sample size, comprising only 16 participants (8 per group). Although the study employed rigorous randomization procedures and the sample size was adequate for detecting the large effect sizes observed, the limited number of participants restricts the generalizability of the findings. The sample was drawn from a single preschool center in Darab, which may not be representative of the broader population of preschool children across different regions, socioeconomic backgrounds, or cultural contexts. The findings may not extend to children with varying degrees of risk for learning disorders or those from different geographic locations. The study was conducted exclusively in Darab, Iran, which limits the applicability of the results to other educational and cultural settings. Preschool curricula, teacher training, parental involvement, and access to technology may vary considerably across regions, potentially influencing the effectiveness of AR-based interventions. Future research should examine the intervention's effectiveness in diverse contexts to establish cross-cultural validity.

The study assessed immediate post-intervention effects but did not include a follow-up assessment to evaluate the durability of the observed improvements. Without longitudinal data, it remains unclear whether the gains in visual perception persist over time, transfer to academic skills, or require ongoing intervention to maintain. This limitation is particularly relevant given that the ultimate goal of early intervention is to produce lasting improvements that prevent later academic difficulties. This gap is notable because recent studies of immersive interventions in children with learning difficulties have reported gains that largely persisted for six months to one year after training (Di Giusto et al., 2023; Maresca et al., 2024), so follow-up testing would show whether comparable durability can be achieved with AR.

The study compared the AR intervention group to a no-intervention control group that continued with the regular preschool curriculum. This design does not allow for comparisons between AR and other active interventions, such as traditional perceptual training, paper-based exercises, or other technology-based approaches. Consequently, it is difficult to determine whether AR is uniquely effective or simply superior to no intervention. Future research should incorporate comparison groups receiving alternative interventions.

The researchers who administered the pretest and posttest assessments were not blind to group assignment, which introduces the possibility of experimenter bias. Although standardized testing procedures were followed and the Frostig Visual Perception Test provides objective scoring criteria, the absence of blinding may have influenced test administration or scoring in subtle ways. Similarly, participants in the experimental group may have experienced expectancy effects due to the novelty of the AR intervention.

The ARCHIN augmented reality application was developed specifically for this study and tested on Android devices running version 8 or higher. The effectiveness of the intervention may be contingent on the specific features of this application, the quality of the AR implementation, and the type of devices used. It remains unclear whether similar effects would be obtained with different AR platforms, applications, or hardware configurations.

The study did not systematically examine how individual characteristics such as age, gender, baseline cognitive abilities, prior technology experience, or socioeconomic status might moderate the effectiveness of the AR

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intervention. Understanding these moderators is essential for identifying which children are most likely to benefit from AR-based interventions and for personalizing intervention approaches.

The study relied exclusively on the Frostig Visual Perception Test as the outcome measure, which, although a well-validated and comprehensive instrument, provides only one perspective on visual perceptual abilities. The findings do not address whether improvements on the Frostig test translate to functional outcomes such as classroom performance, academic skills, or daily living activities. Including additional outcome measures, such as academic achievement tests, behavioral observations, or teacher ratings, would provide a more comprehensive picture of the intervention's impact. Systematic reviews of AR in special education likewise report limited evidence that gains generalize beyond the AR context (Chang et al., 2025).

The experimental group's superior performance may have been influenced, in part, by the novelty and engagement value of the AR technology rather than its specific perceptual training properties. Children in the experimental group may have been more motivated and attentive simply because they were using new technology, which could have inflated the observed effects. Long-term studies with extended intervention periods could help disentangle novelty effects from genuine learning gains. Reviews of AR in education similarly point out that long-term studies are needed to determine its value beyond the initial novelty (Mohammadhossein et al., 2024), and a large meta-analysis identified treatment duration as a significant moderator of the impact of AR (Chang et al., 2022); the present program lasted only eight 30-minute sessions.

The AR intervention required specialized software development, appropriate hardware, and researcher facilitation. These resource requirements may limit the feasibility of implementing such interventions in under-resourced educational settings without significant investment in technology infrastructure and teacher training. This concern is echoed in systematic reviews that identify high costs and technical complexity as persistent barriers to AR in special education (Chang et al., 2025).

Based on the findings and limitations of the present study, the following suggestions are offered for future research, educational practice, and policy development.

Future research should replicate this study with larger and more diverse samples across multiple geographic regions and educational settings. Larger sample sizes would enhance statistical power, allow for more robust subgroup analyses, and increase the generalizability of findings. Researchers should consider multi-site studies that include preschools from urban, suburban, and rural areas, as well as different socioeconomic and cultural contexts. To assess the durability and long-term impact of AR-based visual perception training, researchers should conduct longitudinal studies with extended follow-up periods (e.g., 6 months, 1 year, and 2 years post-intervention; cf. (Di Giusto et al., 2023; Maresca et al., 2024)). Such studies would determine whether the observed gains persist over time, whether they translate to improved academic performance in primary school, and whether booster sessions are needed to maintain effects.

Future research should compare AR-based interventions with other active intervention approaches, including traditional perceptual training, occupational therapy, paper-based exercises, and other technology-based interventions (e.g., computer games, tablet applications, virtual reality). Comparative studies would help identify the most effective and efficient approaches for enhancing visual perception in at-risk children. Rather than simple media comparisons, which dominate the AR literature and have limited explanatory value, such studies should test which design features of AR support learning and under what conditions (Buchner et al., 2022; Buchner & Kerres, 2023). Research should systematically examine individual difference variables that may moderate the effectiveness of AR interventions, including age, gender, baseline cognitive abilities, socioeconomic status, technology experience, and learning style. Additionally, studies should investigate potential mediators, such as engagement, motivation, and self-efficacy, to better understand the mechanisms through which AR exerts its effects.

Future research should examine whether improvements in visual perception following AR intervention transfer to academic skills such as pre-reading, pre-writing, and early mathematics performance, outcomes that early visual processing and visual-motor integration have been shown to predict (Khatib et al., 2022; Yang & Meng, 2020). Such studies would provide evidence for the practical utility of AR interventions in supporting school readiness and preventing academic difficulties. Researchers should consider developing and evaluating AR interventions targeting other cognitive and perceptual skills relevant to learning disorders, such as phonological awareness, auditory processing, working memory, and executive functions. These efforts would contribute to the development of

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comprehensive technology-based early intervention programs.

To better understand the neural mechanisms underlying AR-based perceptual training, future studies could incorporate neuroimaging techniques (e.g., EEG, fMRI) or neuropsychological assessments to examine changes in brain activation patterns, connectivity, and cognitive processing associated with AR intervention. Research should investigate the optimal dosage (e.g., number of sessions, session duration) and intervention duration for achieving meaningful and lasting improvements in visual perception. Meta-analytic evidence that treatment duration moderates the impact of AR (Chang et al., 2022) makes this a priority. Understanding dose-response relationships would inform the design of efficient and effective intervention protocols. Given the crucial role of teachers in implementing educational technologies, future research should examine how AR interventions can be effectively integrated into preschool curricula, what training and support teachers need, and what factors facilitate or hinder successful implementation in real-world classroom settings. Cost-effectiveness studies would help determine whether AR-based interventions represent a good investment of educational resources compared to alternative approaches. Such evaluations should consider the costs of technology development, hardware, training, and implementation relative to the benefits in terms of improved outcomes.

Preschools should consider integrating AR-based activities into their regular curricula to support children's perceptual development, particularly for those identified as at-risk for learning disorders. Activities such as interactive shape recognition, spatial orientation games, and visual matching tasks can be seamlessly incorporated into play-based learning experiences. Teacher training programs should include modules on AR technology, its applications in education, and strategies for effectively implementing AR-based activities with young children. Educators should develop skills in selecting appropriate AR applications, facilitating children's engagement, and monitoring progress. Evidence that children aged 4–5 years can operate AR applications independently and that teachers and children enjoy using them (Law et al., 2025) supports the feasibility of such integration.

AR-based activities should be tailored to address individual children's specific perceptual weaknesses, as identified through comprehensive assessments like the Frostig Visual Perception Test. Personalized intervention plans can maximize the effectiveness of AR technology by targeting the skills most in need of development. Preschools should foster collaboration between general educators, special education teachers, occupational therapists, and educational technology specialists to design and implement comprehensive perceptual training programs that incorporate AR alongside other evidence-based approaches.

Parents should be informed about the potential benefits of AR technology and provided with guidance on how to support their children's perceptual development at home. Parent-friendly AR applications and activities could extend intervention benefits beyond the classroom. Educational institutions should invest in the necessary technology infrastructure (e.g., tablets, AR-compatible devices, reliable internet connections) to support the implementation of AR-based interventions. Ensuring equitable access to technology is essential for preventing digital divides in educational opportunities.

Policymakers should consider allocating resources to support the integration of emerging technologies like AR into early childhood education, particularly for children at risk for learning difficulties. This could include funding for technology acquisition, teacher training, and program evaluation. Educational authorities should develop standards and guidelines for the appropriate and effective use of AR technology in preschool settings. These standards should address content quality, age-appropriateness, screen time considerations, and integration with developmentally appropriate practices.

Research funding agencies should prioritize studies investigating the effectiveness of technology-based early interventions for children at risk for learning disorders. Well-funded, rigorous research is essential for building the evidence base needed to inform educational policy and practice. Partnerships between educational institutions, technology companies, and research organizations could accelerate the development, testing, and dissemination of effective AR-based educational interventions. Such collaborations could ensure that innovations are grounded in educational theory and rigorous research. Policymakers and developers should ensure that AR applications designed for children with special needs are accessible to all children, including those with physical disabilities, visual impairments, or other conditions that might affect their ability to interact with AR technology.

Authors' Contributions

Authors equally contributed to this article.

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Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

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Declaration of Interest

The authors report no conflict of interest.

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Ethics Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

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