Exploring AR, VR, and Educational Robotics for Inclusive Mathematics Education for Dyslexic Students

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Abstract

Dyslexic students often face challenges in comprehending mathematical concepts. Numeracy issues in dyslexia include symbol confusion, digit reversal, problem-solving challenges, slow calculations, and spatial perception difficulties, leading to a significant gap in learning outcomes. Inclusive learning approaches that cater to the specific needs of dyslexic students are essential to promote their mathematical understanding and engagement. The authors investigate the traditional inclusive learning approaches and explore the potential integration of augmented reality (AR), virtual reality (VR) technologies, and educational robotics (ER) to support dyslexic students with mathematics education. AR and VR in education have shown promising results in enhancing student learning experiences across various domains. By creating immersive and interactive environments, these technologies have the potential to enable dyslexic students to explore mathematical concepts in novel and engaging ways. ER integration can complement AR and VR experiences by providing tangible and interactive tools, bridging the gap between the physical and digital worlds. By leveraging AR, VR, and educational robots, educators can create an inclusive and supportive learning environment, promoting active participation and knowledge retention among dyslexic students. The paper also highlights the significance of professional development for educators, aiming to provide educators with essential knowledge and skills to effectively implement these technologies in the classroom and cater to the diverse needs of their students. By integrating current research and best practices, the paper aims to advance inclusive mathematics education to promote equitable learning opportunities to support all students in a holistic way for mathematics education.

Keywords: Dyslexia, Mathematics, Inclusion, Immersive environments, Virtual Reality (VR), Augmented Reality (AR), Educational Robotics (ER).

1. Introduction and Background

Dyslexia is a learning disability that hinders a student's learning ability. It affects their reading, spelling, and writing but can also impact the understanding and processing of mathematical concepts [3, 15, 19]. The prevalence of dyslexia varies significantly based on the definition used in research studies, with estimates ranging between 4% to 17% and an internationally agreed average worldwide estimate of 10% [30].

Dyslexia's impact on mathematical learning extends beyond reading difficulties, presenting significant barriers to inclusive mathematics education [43]. Dyslexia can sometimes make it harder for students to process sounds and put their thoughts into writing [43]. As a result, they may face challenges when trying to show their understanding through written assignments or exams. For dyslexic students, remembering mathematical facts can sometimes be a real challenge, and they might use less effective strategies [24], making them uneasy and hesitant when learning or answering questions. On top of that, some may find it hard to grasp the concepts of the number system, leading to a lack of 'number sense'. If these difficulties are not addressed early on, they can continue to impact their lives in a significant way [24]. The lack of suitable accommodations and support further highlights the importance of fostering inclusivity in mathematics education [46].

Educators support students with Specific Learning Disabilities (SLD) using tailored resources such as engaging activities with visual aids, hands-on projects, and interactive experiments [38]. These interactive approaches enhance comprehension and boost confidence in dyslexic students. Information Communication Technology (ICT) tools have aided dyslexic students [18]. Integrating ICT tools creates an inclusive learning environment, enabling students to overcome challenges and increase their confidence and motivation. Extensive visual aids in the learning process have been found to benefit dyslexic students [54]. VR/AR are additional tools that can support dyslexic students in their educational journey [7]. ER can be presented as learning about robots or learning with robots as educational tools. This paper focuses on the second approach, exploring how mathematics education can be enhanced through interaction with robots. ER offers promising opportunities to enhance inclusivity in mathematics education for dyslexic students. By engaging with tangible, hands-on robotic activities, dyslexic students can experience a multi-sensory learning approach that taps into their visual and kinaesthetic strengths, complementing traditional text-based methods.

2. Mathematics Teaching Methods for Dyslexic Students

Dyslexic students include a diverse group with varied characteristics, requiring targeted support at different educational levels [56]. In the primary school environment, dyslexic students are in the early stages of literacy development, necessitating early identification and intervention [12]. At the secondary level, dyslexic students face more complex academic demands and subject-specific content. Accommodations such as extended exam time, assistive technology integration, and individualised education plans become crucial to facilitate their academic success [12]. By understanding the challenges dyslexic students face at each level and employing appropriate interventions, educators can foster a supportive environment to help these students achieve and succeed academically. In order to create an inclusive learning environment for dyslexic students in mathematics, educators need to implement effective teaching strategies and utilise assistive technologies.

2.1. Conventional Approaches in Mathematics Education

One key challenge in mathematics education is relying heavily on traditional teaching methods. These methods may involve text-heavy explanations, a rapid pace, and a focus on memorisation of mathematical procedures [32]. For dyslexic students who struggle with processing written information and have difficulties recalling sequences and procedures, these conventional teaching approaches can be overwhelming and frustrating [29]. Consequently, dyslexic students may fall behind in mathematics, leading to a lack of confidence in their mathematical abilities and disengagement from the subject.

2.1.1 Visual Aids and Manipulatives to Enhance Understanding

Visual aids and manipulatives influence dyslexic students' understanding of mathematical concepts, and there is a link between dyslexia and visual-spatial talents [29, 49]. While some studies suggest strengths in visual-spatial thinking for dyslexic students, discrepancies exist due to varied definitions and assessment methods [55]. Educators should accommodate different learning styles by providing multiple representations of mathematical concepts and facilitating a deeper understanding of students' learning abilities or skills. Dyslexic students may excel in 3D spatial thinking connected to mechanics and complex visualisation, but conflicting views exist, with some studies showing lower scores on nonverbal spatial tasks [10, 22].

2.1.2 Breaking Down Complex Problems into Manageable Steps and Encouraging Verbal Expression

Complex mathematical problems can be overwhelming for dyslexic students, making it essential for educators to break them down into manageable steps, which allows students to focus on one component at a time, reducing cognitive load and promoting better knowledge retention [60]. This approach includes providing clear and structured learning materials, offering feedback that emphasises effort and improvement, and encouraging students to have more autonomy and choices in their learning process [24, 42, 43].

Encouraging dyslexic students to engage in verbal expression and discussion enhances their grasp of mathematical techniques. Group discussions allow students to articulate their thoughts and reasoning, allowing them to reinforce their understanding of concepts through active participation [40]. The collaborative nature of group discussions fosters a supportive learning environment where students can learn from each other's approaches and insights.

2.2. Assistive Technology for Dyslexic Students in Mathematics

The transformative process of adopting assistive technologies, particularly in empowering students with disabilities to unlock their utmost capabilities, entails a diverse array of specialised tools precisely designed to meet the diverse requirements of students with learning or sensory disabilities. These tools encompass a spectrum of solutions, ranging from fundamental aids like screen readers for vision-impaired students [8] to ubiquitous smartphone calendar applications, assisting students with specific cognitive challenges in organising their academic timetables.

Text-to-speech (TTS) software is a robust aid for dyslexic students in accessing and producing mathematical content. This software allows students to listen to mathematical instructions, problems, and explanations, providing an auditory reinforcement of the material. Additionally, the speech-to-text (STT) application enables dyslexic students to express their mathematical ideas and responses using spoken language, which can be especially beneficial for those with difficulties in writing or spelling [13, 31].

3. Exploring Multimodal Learning in Mathematics for Dyslexic Students

Early detection of dyslexia plays a crucial role in facilitating timely support during critical learning stages. By leveraging eye-tracking technology, valuable data can be collected from young students with dyslexia, aiding in the early identification of reading difficulties [5]. Eye-tracking studies suggest that analysing eye movements during reading can help design dyslexia-friendly interfaces and efficiently identify children at risk of long-term reading difficulties by detecting differences in eye movements between dyslexic and non-dyslexic individuals [36, 37]. In mathematics, students with dyslexia may experience challenges with understanding mathematical symbols, sequencing numbers, and solving word problems [29, 52]. Some established strategies for dyslexia and mathematics education include multimodal approaches, structured explicit instruction, and cognitive training [21]. Multimodal approaches involve engaging multiple senses, such as touch, sight, and hearing, to reinforce learning. For dyslexic students, this can mean incorporating tactile elements, visual aids, and auditory cues in the mathematics learning process. Structured explicit instruction entails breaking down complex mathematical concepts into smaller, more manageable steps, providing clear explanations and ample practice opportunities. Cognitive training focuses on enhancing cognitive functions such as working memory, attention, and processing speed, which can indirectly improve mathematics performance.

3.1. AR/VR Technologies

To effectively engage dyslexic students in mathematics, educators can adopt innovative teaching methods incorporating AR/VR technologies. These approaches offer a hands-on, interactive learning experience that caters to the diverse learning needs of dyslexic students, providing them with a multimodal and engaging platform to grasp mathematical concepts. Moreover, research has shown that utilising VR has improved attention skills in dyslexic children, indicating the potential for positive outcomes in their learning [44]. Using haptic feedback and spatial sound in AR/VR enhances dyslexic students' engagement by providing tactile interactions, kinaesthetic learning, and 3D auditory guidance. Dyslexic students may benefit from AR/VR immersive environments, where they can interact with and manipulate 3D models, facilitating a deeper understanding of subjects such as geometry. This multisensory approach, combined with real-time collaboration, personalises the learning experience,

fostering inclusive education for dyslexic individuals [20, 50]. Embracing these immersive technologies can lead to remarkable improvements in dyslexic students' academic outcomes.

Reading skills are essential in comprehending mathematics curriculum, which is one of the major problems dyslexic students have. In a recent study, the researchers examined the effects of the Virtual Reality Rehabilitation System (VRRS) on dyslexic children. While VRRS has been applied to improve cognitive and language deficits in patients with neurological impairments, its impact on children with dyslexia remained unexplored. Thus, the study aimed to evaluate the effectiveness of VRRS as an intervention for children with dyslexia. The results showed a significant improvement in word-reading skills, suggesting that VRRS can lead to enhanced outcomes through active exploration, increased engagement, and the provision of motivation and enjoyment via VR [33].

3.2. Educational Robotics (ER)

ER involves the integration of robots and computational tools into the learning process to foster a deeper understanding of mathematical concepts and enhance the overall learning experience for students [59]. Research has indicated that robots have the potential to facilitate students' problem-solving skills and foster their understanding of mathematics [6, 17]. It can offer significant new educational benefits at all levels [16]. As dyslexic students learn best through observation, demonstrations, diagrams, or hands-on activities [6], it is important to explore the potential of ER to support the learning process. Robots usually have multiple sensors, such as sound, light, distance and colour. They can be programmed to assist teachers in presenting mathematics curricula in an interactive and customised format. Incorporating robots in the learning process positively impacts dyslexic students, offering interactive experiences and ample time for tasks, capturing their attention, and enhancing their overall learning experience [23, 41].

Robots could offer real-time feedback, adaptive challenges, and interactive simulations [47], fostering a deeper engagement and motivation for dyslexic students and optimising their mathematical skills and confidence. For example, LEGO Mindstorms EV3 robots can provide interactive and dynamic platforms for students to explore mathematical concepts, enhancing their understanding of abstract topics through concrete, real-world applications [2, 26]. Additionally, the collaborative nature of robotics activities promotes social interaction and teamwork, which can further support dyslexic students' learning experiences. The combination of experiential learning, visual aids, and social engagement in ER creates an inclusive and effective learning environment [4, 59] that caters to the diverse needs of dyslexic students in mathematics education. To address the visual and spatial difficulties experienced by dyslexic students, the ROBIN project [45] provides empirical evidence that the robot-maze activity is a beneficial exercise; by employing screen-guided robot navigation and physical robot imitation, the intervention proves to be effective in enhancing the visual-spatial skills of dyslexic students.

4. Recognising The Needs of Dyslexic Students in Mathematics

It is essential to recognise and address the unique needs of dyslexic students in mathematics to create an inclusive learning environment. Understanding how dyslexia affects their mathematical learning helps educators and policymakers develop evidence-based strategies that enhance mathematics education for these students, fostering a more supportive and inclusive setting.

4.1. Challenges Faced by Dyslexic Students in Mathematics

AHEAD [1], an Irish organisation supporting persons with disabilities, identified common challenges dyslexic students face in mathematics, such as organising information, comprehending word problems, and recalling procedures [20, 52]. These challenges emphasise the importance of inclusive mathematics education that considers the unique needs and strengths of dyslexic students. By acknowledging the

specific challenges faced by dyslexic students and tailoring teaching strategies to meet their needs, educators can take proactive steps to foster inclusivity in mathematics classrooms. In a recent study, researchers developed an AR content to teach English vocabulary to dyslexic students. The study findings revealed that students with dyslexia acknowledged the challenges they face in memorising English vocabulary but expressed a positive outlook on the potential of AR technology to assist them in this regard [25]. Considering the integration of English concepts within mathematics, such AR-based content shows promise for effectively teaching mathematical concepts to dyslexic students as well.

4.1.1 Impact of Mathematics Anxiety on Dyslexic Students

Mathematics anxiety is a negative emotional response to numbers and mathematical equations. For dyslexic students, this anxiety is even more pronounced, affecting their ability to work with numbers and solve mathematical problems, ultimately hindering their overall learning experience in mathematics [9]. VR and AR can offer interactive visualisations of mathematical concepts, making them more concrete and easier to grasp [53, 58]. VR and AR can create a safe space for students to practice without fear of making mistakes [11]. Students who feel less judged and anxious about errors are more likely to explore and learn from their mistakes, leading to better mathematical comprehension. Integrating gamification elements into VR and AR mathematical applications can make learning enjoyable and less stressful for dyslexic students [39]. Additional mathematics-specific applications also offer customised exercises, visualisations, and step-by-step guidance, catering to students' learning needs. These applications often incorporate gamification elements, making the learning process enjoyable and motivating for dyslexic students. One significant advantage for students is that their mistakes go unnoticed by others, allowing them to enjoy the process of striving for personal improvement. Such applications include Maths Tricks, Maths Workout, and Maths Pieces (Maths puzzle game). With these applications, students can explore the intricacies of numbers and patterns at their own pace, making learning a fun and engaging experience. Students can monitor their progress and work towards achieving their best performance in a supportive and private environment [57].

4.1.2 Impact of Memory on Dyslexic Students

Having a strong short-term and working memory is essential for mental arithmetic. A student with weak short-term and working memories may struggle with mental mathematics, emphasising the importance of good memory skills for overall mathematics performance [27, 30]. Mathematical calculations and problem-solving require a cognitive process, often involving sequential steps. As a result, working memory (short-term memory) plays a significant role in children's mathematical progress [27]. AR/VR can serve as promising tools in supporting dyslexic students facing memory-related challenges. These technologies enable the creation of memory-enhancing games and exercises that address the learning needs of dyslexic students. Dyslexic students may struggle with spatial awareness and orientation. VR simulations can help them practice and improve these skills, which are essential for memory and learning [14].

4.2. Supporting Dyslexic Students in Mathematics Education: Strategies and Considerations

Continuous assessment is crucial for supporting students who encounter difficulties, especially dyslexic students. Technology's flexibility, providing the ability to adjust screen colours and fonts, makes it highly suitable for use on computers and interactive whiteboards by dyslexic students [24]. In a recent project [51], researchers developed a mobile app with the specific aim of enhancing the reading, comprehension, and mathematical skills of dyslexic children. Throughout the initial phase of the application, they actively gathered invaluable feedback and faced challenges related to font selection, text layout, and an excessive number of alternative answers. Therefore, these adjustments play a significant role in developing educational materials tailored to the needs of dyslexic students. Insufficient training may cause teachers to lack the required skills to teach mathematics to dyslexic students effectively [28]. As a result, they end up depending heavily on mathematics textbooks for both content and teaching methods [34]. So, it is necessary to provide comprehensive and specialised training for all

teachers (including mathematics teachers) that helps them close the achievement gap for dyslexic students. For instance, the National Council for Special Education in Ireland provides essential support for students with dyslexia in the education system. They offer valuable factsheets to second-level schoolteachers, helping them understand dyslexia's impact and ways to aid and support [35].

Another promising option involves using VR and AR technologies to immerse teachers in simulations replicating dyslexia-related challenges. By experiencing first-hand the obstacles dyslexic students face, educators can gain deeper insights and develop more effective teaching strategies tailored to their needs. Teachers often need help implementing differentiation strategies in their classrooms for various reasons. First, they need more time to plan and prepare lessons tailored to each student's needs. Second, some teachers may feel they lack the necessary expertise to address the diverse learning needs of their students [28]. One critical area that needs attention is preparing Individual Iducation Plans (IEPs) to create a more inclusive and supportive learning environment. These plans are personalised for students with diverse learning needs, and teachers need proper training on creating, implementing, and assessing them effectively [35]. VR can provide a multi-sensory learning environment for dyslexic students [31], offering a different approach to exploring information. VR can be a powerful tool for teachers to differentiate dyslexic students, offering personalised and immersive learning experiences that cater to their learning needs. Through VR experiences, students can engage with content using multiple senses, including visual, auditory, and sometimes tactile elements [14].

5. Conclusion

This paper highlights the challenges dyslexic students face in understanding mathematical concepts, leading to numeracy issues and probably mathematics anxiety. It also explores the integration of AR/VR and ER to support dyslexic students in their mathematics education. AR/VR technologies create interactive and immersive environments, while ER provides tangible tools, bridging physical and digital learning. This paper underlines the importance of professional development for educators to effectively implement these technologies, promoting inclusive mathematics education and equitable learning opportunities for dyslexic students. The authors investigate the possibility of developing inclusive mathematical learning materials by leveraging the capabilities of AR/VR with ER. The main objective is to design a mathematical interactive content (educational game) that meets dyslexic students' learning needs, ensuring their inclusion in the learning process. Overall, the research contributes to the field of inclusive education and advocates for innovative teaching methods to benefit dyslexic learners and the broader educational community.

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