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Through their eyes: enhancing teacher awareness of visual impairments via extended reality simulations (REALTER)

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Introduction: Understanding the lived experiences of students with visual impairments is essential for fostering inclusive educational practices. However, traditional teacher training often lacks experiential components that convey the functional impact of low vision. This study explores the use of gaze-contingent immersive simulation in extended reality (XR) to enhance teachers' awareness and empathy toward students with visual impairments.

Methods: We employed the REALTER system, a portable XR platform originally developed for visual rehabilitation and oculomotor research, to simulate juvenile macular degeneration. Eleven in-service teachers participated in task-based simulations replicating common classroom activities. The system introduced real-time, gaze-responsive visual distortions to emulate central vision loss. Following the simulation, participants completed a structured evaluation assessing perceived educational value, emotional impact, and potential applications in teacher training.

Results: Participants reported a significant increase in their understanding of the challenges faced by students with low vision. The immersive experience was rated as highly educational, with all participants recommending its integration into teacher education programs. Qualitative feedback highlighted increased empathy and a deeper appreciation for the need for adaptive teaching strategies.

Discussion: The findings support the effectiveness of gaze-contingent XR simulation as a tool for enhancing teacher preparedness in inclusive education. The REALTER system offers a promising avenue for interdisciplinary collaboration between educators and vision specialists, contributing to more empathetic and informed pedagogical practices.

KEYWORDS

extended reality, virtual reality, virtual training, visual impairments, gaze-contingency, altered reality, REALTER, education

1 Introduction

In recent years, emerging technologies have significantly transformed sectors such as industry, education, and healthcare. Among these, immersive technologies—namely Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR)—have evolved from experimental tools into essential components of modern systems. Collectively known as Extended Reality (XR), these technologies enable the creation of simulated or digitally enhanced environments that support experiential learning and enrich human-computer interaction (Suhand and Prophet, 2018). These systems evoke a strong sense of immersion—defined as the technological capacity to deliver vivid, interactive simulations (Slater and Garau, 2007)—and presence, the psychological sensation of being physically situated in a virtual environment (Witmer and Singer, 1998; Lee, 2004).

In medical training, immersive simulators allow learners to practice technical skills in safe, controlled environments, reducing patient risk and improving preparedness (McKnight et al., 2020). XR headsets offer features such as real-time feedback, eye and head tracking, and stereoscopic vision, which enhance procedural accuracy and long-term retention. Education has also embraced XR technologies. Specifically, a systematic review (2014–2023) highlights their transformative role in higher education, particularly in design, engineering, and educational sciences (Yu and Wang, 2025). As consequences, immersive environments foster critical thinking, creativity, and collaborative learning (Fonseca et al., 2014; Huang et al., 2016). The integration of XR with Artificial Intelligence (AI) further enables adaptive, personalized learning experiences (Kurni et al., 2023). Furthermore, beyond technical and pedagogical benefits, immersive technologies uniquely foster empathy—an essential component in both healthcare and education. In clinical training, XR can simulate patient perspectives, promoting compassionate, patient-centered care (May, 2024). In education, immersive storytelling and embodied simulations enhance emotional engagement and perspective-taking (Lacle-Melendez et al., 2024), supporting deeper understanding of complex social and ethical issues.

This empathetic potential is particularly relevant for fostering awareness of conditions that are often misunderstood or underestimated—such as visual impairments. These conditions, which profoundly affect perception and interaction with the environment, are difficult to convey through conventional instruction alone. By enabling users to engage with simulated perspectives, XR technologies can play a crucial role in cultivating empathy and cognitive insight, preparing learners and professionals to better understand the lived experiences of individuals with sensory disabilities.

1.1 Motivation

Visual impairments affect an estimated 1–2% of school-aged children worldwide (World Health Organization, 2023), often resulting from conditions that compromise central, peripheral, or partial areas of the visual field (Leat et al., 1999). These impairments, which cannot be corrected through conventional means such as glasses or surgery, require children to adapt to persistent and often progressive limitations in their visual perception (American Academy of Ophthalmology, 2021; Leat et al., 1999). Consequently, these disabilities compel affected children to coexist with their visual impairments on a daily basis.

Low vision pathologies in children can be congenital or acquired, resulting from various diseases or injuries affecting the eyes or visual pathways in the brain. One of the most prevalent and debilitating conditions in school-aged children is juvenile macular degeneration (JMD), often associated with Stargardt disease. This condition affects the macula, leading to progressive loss of central vision, difficulty seeing in low light, and the perception of dark or distorted spots in the visual field (Smith et al., 2001; Yanoff, 2023). Although less common than central vision loss, other low vision pathologies affecting school-aged children include hemianopsias, characterized by the loss of half of the visual field in one or both eyes (Handley et al., 2022; Haaga et al., 2018), and retinitis pigmentosa, which leads to tubular vision characterized by the loss of peripheral vision while maintaining central vision (Hartong et al., 2006; Mercado et al., 2018).

The educational implications of these impairments are profound. Children with low vision often face difficulties in reading, writing, drawing, and navigating classroom environments—activities that are foundational to learning and social participation. Reading difficulties are common, as children with low vision may struggle to see text clearly, leading to slower reading speeds and reduced comprehension, which can hinder their ability to keep up with classroom activities and assignments (World Health Organization, 2023). Writing is also affected, with children finding it challenging to see what they are writing, resulting in poor handwriting and difficulty completing tasks (Gunaratne, 2023). Drawing, an essential part of early education, can be particularly frustrating due to difficulties in seeing clearly or understanding spatial relationships (Jan et al., 1977). Furthermore, visual impairments can affect a child's social interactions and emotional well-being. They may feel isolated or different from their peers, leading to lower self-esteem and increased anxiety (Burton et al., 2021). These challenges highlight the need for tailored educational strategies and support systems to help children with low vision succeed academically and socially.

Awareness and understanding of visual impairments are essential for educators and visual rehabilitators to provide effective, individualized support to students with low vision. While traditional training can raise general awareness, replicating the perceptual experience of visual impairments remains a significant challenge due to their complexity and variability. Unlike total blindness, which can be approximated with simple tools like blindfolds, low vision is dynamic and gaze-contingent: its effects vary depending on where the individual is looking, how they move their head, and the specific characteristics of the impairment. This complexity makes it difficult to simulate using conventional approaches. In recent years, however, immersive technologies—have emerged as powerful tools for replicating these experiences in a controlled and interactive manner as powerful tools for experiential training and empathy-building in inclusive education contexts (Jones et al., 2020; Chow-Wing-Bom et al., 2020; Neugebauer et al., 2024; Barbieri et al., 2024; Guarese et al., 2023; Zwoliński et al., 2025).

In this context, the REALTER simulator (Wearable Egocentric Altered Reality Simulator) represents a significant outcome (Barbieri et al., 2023). Originally developed to support professionals in visual rehabilitation, REALTER uses real-time image processing (Agrebbe et al., 2023), eye tracking, and six degrees of freedom (6DoF) navigation to simulate low-vision conditions in ecologically valid environments. The system is based on the Altered Reality

(TR) paradigm, a subset of XR, which focuses on modifying the user's perception of the real world rather than augmenting it. By generating gaze-contingent, stereoscopic distortions, the system closely replicates the perceptual asymmetries and oculomotor alterations experienced by individuals with visual impairments (Barbieri et al., 2024).

1.2 Present study

The present study aims to explore the potential of immersive simulation as a tool for educating support teachers about visual impairments. Following an initial evaluation conducted with the involvement of experienced support teachers, we investigated the feasibility of using XR-based visual impairment simulations to raise awareness and improve pedagogical responsiveness in inclusive educational contexts. The focus was specifically on juvenile macular degeneration (JMD) associated with Stargardt disease, which, according to both educators and visual rehabilitation specialists involved in this study, represents one of the most prevalent visual conditions among children.

Given the alignment between the visual characteristics simulated by the REALTER system and those typically observed in pediatric low vision cases, we were encouraged to propose this novel approach to a targeted user group—namely, support teachers. During a university-level teacher training session led by one of the consortium members, a group of support teachers had the opportunity to experience the immersive simulation of JMD. The simulation included three common school-based tasks—reading, writing, and sketching a simple drawing—designed to replicate the challenges faced by students with this condition. The goal was to provide teachers with a first-person perspective on the functional limitations imposed by JMD, thereby offering valuable insights into how to better support these students in classroom settings.

While the findings are preliminary, they offer initial evidence supporting the feasibility and educational value of this approach. The results are intended to inform future research and iterative development of the system, with the long-term objective of integrating immersive simulation into inclusive teacher education programs. We hope that this work may contribute to the growing body of literature on experiential learning methods aimed at fostering empathy and pedagogical sensitivity in educational practice.

To provide a clearer pedagogical context of this study, we draw on Kolb's Experiential Learning Theory (Kolb, 1984), which emphasized the role of concrete experience and reflective observation in the learning process. According to this model, immersive simulations such as REALTER provide a powerful platform for experiential learning by allowing participants to engage directly with the perceptual challenges of visual impairment, thereby fostering deeper understanding and retention.

Furthermore, the study is informed by Davis's multidimensional model of empathy (Davis, 1983), which distinguishes between cognitive empathy (the ability to understand another's perspective) and affective empathy (the capacity to share emotional experiences). The REALTER system aims to activate both components by offering an embodied simulation of visual disability, encouraging participants to not only recognize the functional limitations of students with low vision but also to emotionally connect with their lived experiences.

2 Methods

2.1 Participants

Participants in this study were in-service teachers enrolled in a postgraduate specialization program in support education at the University of Genoa, which also served as an institutional partner in the project funding this research. The simulation activity using the REALTER system was integrated into their formal training curriculum and framed as a professional development module aimed at deepening their understanding of central vision loss through immersive, experiential learning.

The sample comprised 11 individuals (age range: 25–55 years; $M = 41.14$, $SD = 8.55$), all with normal or corrected-to-normal vision. The study adhered to the ethical standards set forth in the Declaration of Helsinki (Experimentation, 1964).

2.2 The simulator of visual impairments

The REALTER system enables immersive simulation of low-vision conditions through a portable XR platform optimized for both performance and usability. Unlike traditional AR/VR systems, REALTER implements a novel paradigm known as Altered Reality (TR)—a perceptual simulation approach that focuses not on augmenting or replacing the visual environment, but on modifying the user's real-time visual experience to replicate the effects of visual impairments.

Specifically, TR leverages a video see-through (VST) architecture, where the user's view of the real world is mediated by cameras and displays. This setup allows for precise, gaze-contingent distortions—such as central scotomas, blur, or warping—that dynamically follow the user's point of fixation. Rather than overlaying digital content (as in AR) or immersing the user in a fully virtual environment (as in VR), TR alters the perception of the real world itself, creating an embodied simulation of pathological vision. This makes it particularly suitable for educational and rehabilitative applications where functional realism and perceptual fidelity are essential.

2.2.1 Components

The hardware core of the system is the HTC Vive Pro Eye, a head-mounted display (HMD) widely adopted in vision science (Imaoka et al., 2020; Sipatchin et al., 2021). It features dual 3.5-inch displays (1,440 × 1,600 pixels per eye) at 90 Hz, and an integrated Tobii eye tracker with 0.5°–1.1° accuracy and a 120 Hz sampling rate. The eye tracker enables real-time adaptation of simulated impairments based on the user's fixation point and supports the collection of raw ocular data, including gaze origin and direction for each eye. These data can be post-processed to detect oculomotor events such as saccades, fixations, and smooth pursuits, allowing for detailed mapping of gaze dynamics and fixation shifts.

To integrate real-world visual input, the system uses Stereolabs Zed Mini stereoscopic cameras, which capture the environment at 720 p resolution with a 90° horizontal and 60° vertical field of view. This enables the simulation of stereoscopic visual impairments in real time in the real environment. The system is powered by an HP VR Backpack G2, which enhances mobility and supports untethered immersive experiences.

2.2.2 Altering the human eye

The simulation environment, developed in Unity game engine, overlays real-world imagery with 2D and 3D visual effects using custom shaders. These effects simulate a range of visual impairments, including central scotomas, peripheral field loss, and partial obstructions. Techniques include pixel-level warping, temporal modulation, and gaze-contingent blur filters. The gaze-contingent architecture ensures that distortions remain aligned with the user's fixation point, as determined by the integration of eye and head tracking data from the HMD.

A key feature of the system is binocular rendering, which allows for independent simulation of visual input for each eye. This is essential for replicating asymmetric conditions such as binocular maculopathy. As illustrated in Figure 1, the simulated scotomas differ between eyes in terms of size, blur intensity, and warping, reflecting the heterogeneity often observed in clinical presentations.

2.2.3 The impact of altered reality in visual rehabilitation and oculomotor research

The Altered Reality (TR) has shown significant potential in visual rehabilitation as a training method. By simulating various stages of maculopathy (juvenile macular degeneration, age-related dry and wet macular degeneration, diabetic retinopathy), hemianopsia (homonymous and heteronymous), and tubular vision (various levels of narrowing), it serves as a comprehensive tool for understanding and addressing low-vision conditions (Barbieri et al., 2023; Agrebbe et al., 2023). These simulations, validated by ophthalmologists at the Chiossone Foundation for Blind and Low Vision in Genoa, accurately replicate the appearance and behavior of these impairments, aiding in visual rehabilitators' training. It is particularly valuable for training visual rehabilitators, providing them with realistic simulations to better prepare for real-world scenarios (Barbieri et al., 2024).

In addition to its rehabilitative use, we explored TR's role in oculomotor research. Our goal was to determine if TR technology could induce oculomotor alterations in healthy-sighted subjects that mimic those observed in patients with low vision. This approach aims to create a digital twin of visually impaired patients, allowing us to obtain valuable insights into oculomotor behavior generated by low vision. By studying normally sighted individuals under simulated low-vision conditions, we can avoid causing stress to actual patients. To achieve this, healthy-sighted subjects performed tasks such as reading, pouring water, and interacting with objects under simulated low-vision conditions. The results showed distinct oculomotor alterations for each simulated disability, closely resembling those found in actual patients (Barbieri et al., 2024).

2.3 Procedure: an immersive training

In this study, 11 in-service teachers enrolled in a postgraduate specialization program in support education directly engaged with the REALTER system. Each participant wore the immersive headset and explored a controlled indoor environment for $\sim$ 3 min in simulated JMD. This binocular condition is characterized by central scotomas that occlude the fixation point in both eyes, resulting in blurred and distorted central vision. The simulation accounted for interocular asymmetries in scotoma size, blur intensity, and distortion patterns.

The primary objective of the procedure was to provide participants with an embodied understanding of the perceptual challenges faced by students with visual impairments. To this end, participants were asked to complete three tasks simulating typical classroom activities: (1) reading an A3-sized printed text placed on a lectern (see Figure 1C), (2) writing their name with a pen (with hand selection based on handedness), and (3) drawing a stereotypical house beneath their signature. All tasks were performed while sitting (see Figures 1A, B), allowing free movement of the head and hands to encourage spontaneous adoption of compensatory strategies. A time limit of 5 min was imposed for the reading task, while the writing and drawing tasks were self-paced and concluded upon completion by the participant.

Before the experimental tasks, a brief training phase was conducted. This included system calibration using the HTC Vive Pro Eye's built-in procedures to align the eye tracker with each participant's gaze. Following calibration, participants were given a short familiarization period during which they experienced the JMD simulation, allowing for initial perceptual adaptation before task execution.

As this study was designed as a formative user experience evaluation, no quantitative data were collected regarding task performance or eye/head movement metrics. The focus was instead on assessing participant engagement and gathering qualitative feedback on the pedagogical value of the immersive simulation.

2.4 Evaluation

To assess the perceived educational value and usability of the REALTER system, a structured questionnaire was administered to all participants following the immersive simulation. The instrument was designed to evaluate the system's effectiveness in enhancing understanding of central vision loss and its potential application in teacher training contexts.

The questionnaire comprised eight items: six closed-ended questions using a 5-point Likert scale (1 = "Not effective", 5 = "Very effective") and two multiple-choice questions. The Likert-scale items aimed to measure participants' perceptions regarding the system's educational impact, its capacity to foster empathy, and its relevance to specific classroom activities affected by visual impairments, such as reading, writing, and drawing. The multiple-choice items explored participants' willingness to recommend the system and their preferences regarding its implementation in teacher training programs.

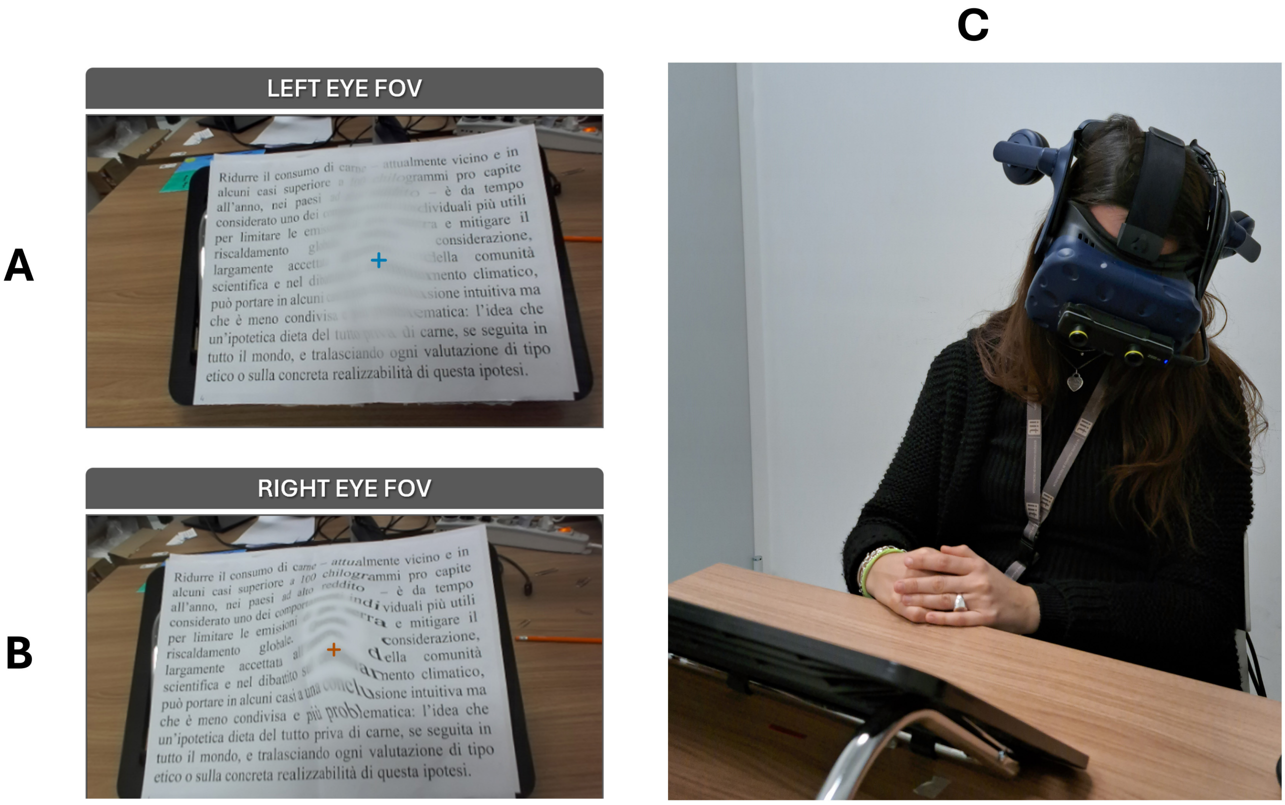

FIGURE 1
(A, B) Distorted vision caused by juvenile macular degeneration as seen through the left eye **(A)** and right eye **(B)**. The images depict what the user was viewing, illustrating the effects of binocular juvenile macular degeneration with a central scotoma in the form of a blurred and distorted image. The difference between the two scotomas varies in size and in the intensity of metamorphopsia, in terms of blurred and warping effects. The visual impairment follows the gaze-contingent paradigm, as the central scotomas update their position based on the user's point of fixation (blue cross for left eye fixation's point; orange cross for right eye fixation's point). **(C)** A user utilizing the REALTER system while reading a text placed on an A3-sized lectern.

The full list of questionnaire items is as follows:

- **Q1:** *How effective do you think the REALTER system was in helping you understand the effects of low vision pathologies?*
- **Q2:** *How useful do you think the REALTER system could be for educating support teachers working with children affected by low vision pathologies?*
- **Q3:** *How well do you think the REALTER system helps a sighted person empathize with those suffering from low vision pathologies?*
- **Q4:** *How do you think the REALTER system helps in understanding the difficulties children face in reading activities due to low vision pathologies?*
- **Q5:** *How do you think the REALTER system helps in understanding the difficulties children face in writing activities due to low vision pathologies?*
- **Q6:** *How do you think the REALTER system helps in understanding the difficulties children face in drawing activities due to low vision pathologies?*
- **Q7:** *Would you recommend the REALTER system to a colleague support teacher for gaining knowledge about low vision pathologies?* (Yes/No)
- **Q8:** *If you answered "Yes" to the previous question, what do you think is the best way to use the system with support teachers?* (Options: Online tutorial / Direct experience)

Responses were collected anonymously and used to qualitatively assess the system's perceived impact on professional awareness and pedagogical preparedness. Quantitative analysis of the Likert-scale responses is presented in the following section.

3 Results

The questionnaire assessed the perceived impact and utility of the REALTER System among support teachers. The questions are grouped by number in this section, with the full text of each question provided in the previous paragraphs. The responses evaluated on a Likert scale are visualized in Figure 2.

The closed-ended questions revealed that participants rated the system's effectiveness in helping them understand the effects of low vision pathologies (Question 1: mean = 4.71, SD = 0.49). Moreover, participants also evaluated its usefulness for educating support teachers working with children affected by low vision pathologies (Question 2: mean = 4.71, SD = 0.49) and its ability to foster empathy by allowing sighted individuals to experience visual impairments (Question 3: mean = 4.71, SD = 0.49). Additionally, participants rated the impact of low vision pathologies on children's reading (Question 4: mean = 4.57, SD = 0.53), writing (Question 5: mean = 4.57, SD = 0.53), and drawing activities (Question 6: mean = 4.57, SD = 0.53).

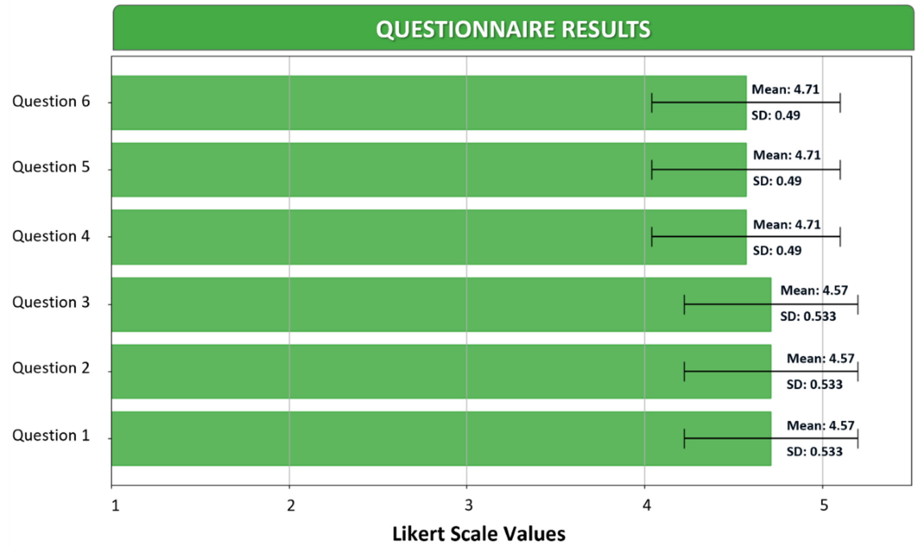

FIGURE 2
Results of the questionnaire showing mean responses and standard deviations for each question on a Likert scale. The data highlights participants' perceptions and experiences related to various aspects of low vision pathologies and their impact. Overall, the initiative to propose the system was well received, as the Likert scale values were never below 4. For the full text of each question, refer to the "Evaluation" section of the text.

The multiple-choice questions were designed to explicitly inquire whether the teachers would recommend the use of the REALTER system to their colleagues through multiple-choice responses. These responses varied for each question (see previous section). However, both questions received unanimous responses: all participants recommended the use of REALTER (Question 7) and suggested that the most effective training method is through direct experience by wearing the headset (Question 8).

Overall, the high ratings across all questions reflect a strong positive perception of the REALTER system's educational value and its effectiveness in enhancing both understanding and empathy toward visual impairments.

4 Discussion

This study investigated the use of the REALTER system—which employs Altered Reality (TR) technology to simulate visual impairments—as a training tool for support teachers. The results suggest that direct, embodied simulation of low vision conditions may enhance teachers' awareness, empathy, and pedagogical sensitivity toward students with visual impairments. Participants reported a high level of perceived effectiveness, particularly in understanding the functional and emotional challenges associated with juvenile macular degeneration (JMD), one of the most impactful conditions in school-age populations.

Through the simulation of everyday school tasks such as reading, writing, and drawing, teachers were able to experience firsthand the perceptual limitations imposed by central vision loss. This experiential approach appeared to improve their understanding of the practical difficulties faced by students, while also fostering greater emotional engagement—particularly in recognizing the risk of social exclusion and psychological distress. These findings are consistent with existing literature on the role of XR in education, which highlights the potential of immersive technologies to support empathy, experiential learning, and inclusive pedagogical practices.

In addition to its pedagogical relevance, the TR integrates key technological features that make it particularly suitable for simulating visual impairments in realistic contexts. The immersive TR environment, combined with gaze-contingent rendering and full six degrees of freedom (6DoF) tracking, allows users to move naturally through space while experiencing dynamic visual distortions anchored to their point of fixation. This combination of spatial freedom and real-time gaze responsiveness is essential for replicating the perceptual instability and compensatory behaviors typical of individuals with low vision. As such, the system may support more ecologically valid training and research scenarios.

We hope that the protocol developed in this study—based on short, task-oriented immersive sessions—can serve as a starting point for integrating TR-based simulations into teacher training programs. It may also be adapted for use in higher education, such as in ophthalmology courses or interdisciplinary modules involving educators and healthcare professionals. The portability and flexibility of the REALTER system make it a promising tool for diverse educational settings.

Although the system is capable of acquiring detailed eye and head tracking data—as demonstrated in our previous work (Barbieri et al., 2024)—such quantitative measures were not collected in the present study. This was a deliberate methodological choice: since the goal was to evaluate the educational impact of the simulation, monitoring oculomotor behavior was not considered necessary.

However, we acknowledge that the limited sample size ($N = 11$) represents a constraint in terms of generalizability. While the qualitative feedback was consistently positive, future studies should aim to involve larger and more diverse cohorts of teachers to strengthen the robustness and external validity of the findings. This would also allow for more nuanced subgroup analyses (e.g., by teaching experience or educational background).

Furthermore, no validated psychometric instruments were used in this study to quantitatively assess changes in empathy. Since the primary objective was exploratory and formative, we focused on subjective impressions and perceived pedagogical value. Nevertheless, future research should incorporate pre- and post-intervention assessments using standardized tools such as the Interpersonal Reactivity Index (IRI) (Keaton, 2017) or the Toronto Empathy Questionnaire (TEQ) (Spreng* et al., 2009). These instruments would allow for a more rigorous evaluation of the simulation's impact on both affective and cognitive dimensions of empathy, and could be complemented by behavioral or physiological measures where appropriate. These methodological enhancements—larger samples and validated empathy metrics—would contribute to a more comprehensive understanding of how immersive simulations can support inclusive education and teacher training.

While the simulation protocol was co-designed with educators and focused on common school activities, the current data acquisition remains limited. A more comprehensive analysis would require larger samples and extended observation periods. Moreover, since JMD can also impair spatial navigation and mobility—due to the loss of central vision and the resulting difficulty in perceiving obstacles or reading environmental cues—it would be valuable to extend future simulations to include locomotor or navigation-based tasks. These could provide further insight into the broader functional challenges faced by students with low vision, beyond those related to reading, writing, and drawing. Despite these limitations, the positive feedback from participants and the high ratings across all evaluation items are encouraging. We hope that this study may contribute to the growing interest in XR technologies for inclusive education, and inspire further research into their role in fostering empathy and improving teacher training.

5 Conclusion

The results of this study suggest that REALTER system and Altered Reality (TR) approach hold promise as an educational tool for raising awareness about low vision conditions. Based on participant feedback, several potential applications emerge. First, the system can support teacher training by offering an immersive experience that helps educators better understand the functional and emotional challenges faced by students with visual impairments. Participants emphasized that direct, hands-on use of the system was more impactful than traditional learning methods.

Second, while the system may not be directly suited for educating children with visual impairments, it could be effectively integrated into higher education contexts—such as ophthalmology programs or interdisciplinary training modules—to help students and professionals better understand the lived experience of visual disability. This approach may foster greater empathy and clinical sensitivity in future practitioners.

Finally, REALTER could serve as a shared training platform for both teachers and ophthalmologists, encouraging interdisciplinary collaboration and improving support strategies for visually impaired students.

In conclusion, we hope that by bridging the domains of visual rehabilitation and education, the REALTER system can contribute to more inclusive and empathetic teaching practices. The positive reception from participants and the encouraging evaluation results support further exploration of immersive TR technologies in educational and training contexts.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Comitato Etico, ASL 3, Genova, Italy. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MB: Data curation, Writing – original draft, Methodology, Investigation, Conceptualization, Software. VP: Writing – review & editing, Validation, Supervision. SS: Supervision, Writing – review & editing. MG: Validation, Funding acquisition, Supervision, Writing – review & editing, Resources.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

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