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Inclusive education in virtual reality: New horizons of accessibility and participation

Abstract. Inclusive education aims to ensure equal learning opportunities for all students, regardless of their individual developmental, cognitive, or physical characteristics. Virtual reality is a technology capable of creating immersive and interactive environments that can significantly enhance the effectiveness of inclusive educational practices. This study explored the potential of virtual reality to overcome learning barriers by examining successful examples of its use for students with special educational needs, particularly those with sensory impairments and autism spectrum conditions. The research methods included comparative analysis, case reviews, and a pilot implementation of virtual environments for students enrolled in the "Business Design" programme, as well as for learners in educational centres. The findings showed that virtual reality effectively creates adaptive learning environments and supports safe social interaction, fostering empathy by modelling new experiences in neurotypical individuals. Quantitative data revealed an 18% increase in test results, improved focus by 22%, a 15% rise in task performance, and a 20% increase in self-rated concentration. Learners with special needs also demonstrated notable progress: comprehension improved by 25%, problem-solving skills by 20%, and participation in group work by 30%. The use of virtual reality contributed to increased student engagement, enhanced cognitive and social skills, and expanded opportunities for experiential learning in a risk-free environment. Practical outcomes include the development of virtual environment interfaces for users with visual impairments and specialised training modules aimed at developing social skills in students with autism

Keywords: adaptive learning environments; special education; educational technologies; digital tools; sensory learning

INTRODUCTION

Inclusive education aspired to provide equal learning opportunities for every student, irrespective of their cognitive, developmental, or physical differences. In educational practice, learners with disabilities or neurodiverse profiles still faced significant barriers – from inaccessible curricula and rigid pedagogical models to insufficient assistive technologies and a lack of safe, adaptive learning spaces. These limitations often resulted in reduced engagement, lower participation, and suboptimal educational outcomes. Addressing these systemic challenges demanded innovative solutions that transcended conventional classroom structures, particularly in contexts where tailored support was most needed.

Virtual reality (VR) and related immersive technologies were identified as effective tools for advancing inclusive education. A systematic review by M. Alkhamisi *et al*. (2024) found that VR and artificial intelligence held considerable promise for supporting students with disabilities through personalised and multi-sensory learning environments. Their analysis also flagged major challenges: high costs of VR hardware, technical implementation hurdles, and limited teacher preparedness, which impeded large-scale adoption in inclusive settings. A promising approach was described in a design framework proposed by researchers M. Barbu *et al*. (2025), which integrated XR technologies with generative artificial intelligence to create adaptive immersive environments for learners with special educational needs. The framework emphasised multimodal representation (visual, auditory, kinaesthetic), dynamic

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adaptation, and scaffolded support, reflecting core principles of Universal Design for Learning (UDL).

Turning to inclusive education in the Ukrainian context, O. Pinchuk & L. Luparenko (2022) analysed the didactic potential of using digital content with augmented reality (AR)/VR in school settings. The study showed that immersive content enriched traditional curricula and supported differentiated instruction by engaging visual, auditory, and kinaesthetic learners more deeply. The findings also emphasised the necessity of systematic teacher training and institutional support to enable effective implementation. I. Bulatsan (2023) examined the use of VR in primary-school mathematics education in Ukraine. The study demonstrated that VR-based three-dimensional visualisations facilitated comprehension of abstract mathematical concepts and increased learner engagement. The research highlighted both pedagogical benefits and the feasibility of low-cost implementation through widely available devices, enhancing accessibility in local educational contexts. N. Soroko (2024) examined how immersive technologies could be integrated into STEAM (Science, Technology, Engineering, Arts, Mathematics) projects in Ukrainian schools. The study illustrated how VR and AR supported collaborative, project-based learning by enabling design tasks that were difficult to replicate in traditional classrooms, thereby fostering creativity, peer interaction, and spatial reasoning.

Collectively, these studies demonstrated that VR and immersive technologies could enhance inclusive education by supporting social-emotional development, enabling personalised learning pathways, and facilitating experiential learning. Persistent gaps remained evident: many investigations were limited to small-scale pilot studies, while long-term transfer of skills to real-world contexts remained insufficiently explored. Within Ukraine, existing research was limited in scope and often prioritised technological aspects over pedagogical frameworks or systemic integration. Institutional constraints, teacher perspectives, and scalable, cost-effective implementation strategies required further investigation. The purpose of the present study was to examine how VR could be utilised to support inclusive education in a scalable and sustainable manner. The study investigated the extent to which VR-based interventions reduced structural, pedagogical, and technological barriers for learners with diverse needs; evaluated measurable cognitive, social, and motivational outcomes; and identified practical challenges associated with implementation in educational contexts comparable to those in Ukraine.

LITERATURE REVIEW

Contemporary systematic and empirical work positioned immersive technologies – particularly VR and extended reality (XR) – as promising instruments for inclusive education, yet also exposed recurring practical and methodological gaps. A. Chalkiadakis *et al*. (2024) conducted a comprehensive systematic review of the intersection between artificial intelligence (AI), VR, and educational inclusion, synthesising studies on personalisation, accessibility, and social participation. Their findings indicated that AI-enhanced VR systems provided adaptive, multimodal learning pathways that improved access and engagement. Significant barriers were also identified, including high implementation costs, uneven teacher training, and ethical concerns related to data privacy and algorithmic bias. The authors highlighted the need for large-scale, standardised studies and explicit strategies for equitable deployment.

M. Mosher *et al*. (2022) reviewed 41 empirical studies on immersive technologies (VR/AR) for social-skills training in learners with autism spectrum disorder (ASD). The review categorised intervention types, evaluation methods, and targeted outcomes, concluding that many interventions produced short-term improvements in emotion recognition, social initiation, and cooperative behaviour. Positive perceptions were reported by educators and caregivers. Limitations included heterogeneous outcome measures, small sample sizes, and limited follow-up assessments evaluating skill generalisation beyond virtual environments. C.-C. Yeh & Y.-R. Meng (2025) advanced this research through an experimental design combining behavioural observations with neurophysiological measures. Improvements were documented in conversational fluency, emotional regulation, and adaptive social behaviour, with EEG indicators suggesting enhanced empathic processing. The study acknowledged limitations related to sample size and intervention duration, constraining conclusions regarding scalability and long-term effects.

J. Dudley *et al*. (2023) presented a comprehensive accessibility-focused review titled "Inclusive Immersion", examining academic and commercial efforts to improve VR and AR usability for individuals with diverse impairments. The review identified technical strategies, design principles, and emerging standards, while noting that much of the existing research addressed single impairment categories rather than overlapping accessibility needs. The authors called for cross-disability frameworks, longitudinal usability studies, and classroom-oriented integration standards. A. Ascione *et al*. (2024) investigated the pedagogical affordances of VR in school contexts, emphasising embodied learning and multimodal representation. The findings demonstrated that VR supported comprehension of abstract concepts, increased motivation, and enabled inclusive practices when combined with structured scaffolding. Teacher mediation and culturally responsive content design were identified as essential factors, while many implementations prioritised novelty over curriculum alignment. C. Austermann *et al*. (2025) highlighted that VR enhanced presence and immersion in classroom settings, fostering engagement and attention even in standard curricula. I. Chitu *et al*. (2023) explored VR applications for children with disabilities, concluding that immersive experiences facilitated understanding, motivation, and social participation.

M. Ghoniyatul & H. Jihaan (2025) emphasised that AR and VR integration in K-higher education promoted personalised learning and inclusivity, supporting students with diverse cognitive and developmental profiles. Similarly, M. Khasawneh (2024) demonstrated that VR interventions improved engagement and learning outcomes among students with learning disabilities, while D. Llanos-Ruiz *et al*. (2025) confirmed VR's alignment with sustainable development goals, particularly in fostering equitable access to higher education. C. del R. Navas-Bonilla *et al*. (2025) conducted a systematic review of technology-mediated inclusive education, highlighting VR as a key tool for personalised learning, social-emotional development, and accessibility across diverse educational settings. M. Mahajan (2023) outlined frameworks for using VR and AR to transform inclusive education, focusing on multimodal content, scaffolded guidance, and adaptive instruction. I. Shevchuk *et al*. (2023) and J. Thepvong (2025) provided evidence for VR's effectiveness in classroom simulations and ASD-inclusive interventions, emphasising the importance of teacher support, contextual adaptation, and iterative design. In the Ukrainian context, O. Pinchuk & L. Luparenko (2022) examined pilot implementations of AR and VR in formal education. Their analysis described accessibility adaptations and concluded that immersive technologies enhanced differentiated instruction when supported by professional development and infrastructure investment. The reliance on descriptive and small-scale data highlighted the need for controlled evaluations tailored to local constraints.

Collectively, these studies substantiated VR's potential to support personalised, multimodal, and socially oriented learning for diverse students. Consistent strengths included increased engagement, improved skill acquisition in targeted domains (social skills, spatial reasoning, concept comprehension), and promising acceptability among stakeholders. Nevertheless, recurrent limitations persisted: many studies were small-scale pilots with heterogeneous measures, short follow-up windows, and limited ecological validity; few integrated teacher professional development, cost-effectiveness analysis, or systemic scalability plans; and cross-disability design and longitudinal transfer of learning to real-world settings remained under-researched. Finally, there was a relative dearth of large, controlled trials situated in low-resource or conflict-affected educational systems (a key concern for the Ukrainian context). These gaps motivated the current study's focus on measurable outcomes, implementation barriers, and pathways to scalable, equitable VR integration in inclusive education.

MATERIALS AND METHODS

This study employed a mixed-methods research design, integrating both quantitative and qualitative approaches to provide a comprehensive understanding of VR's impact on inclusive education. The quantitative component focused on measurable learning outcomes, while the qualitative component explored participants' subjective experiences, perceptions, and contextual factors that influenced the effectiveness of VR interventions. The study involved third-year students of the Business Design program and participants from various educational institutions, including public schools, specialised inclusive schools, and private centres supporting learners with diverse needs. Participants represented a wide range of learning profiles, including students with learning disabilities, autism spectrum disorders, and physical impairments. Participants were students aged 10-18, representing a diverse range of learning needs, including students with learning disabilities, autism spectrum disorders, and physical impairments. Participants were recruited from multiple inclusive classrooms across public primary and secondary schools, specialised inclusive schools, and private educational centres offering support for learners with diverse profiles. This diversity ensured variability in prior experience, socio-economic backgrounds, and learning contexts. An experimental implementation of VR-based learning modules took place for children in educational centres. These sessions introduced immersive VR activities tailored to students with diverse learning needs, allowing them to explore interactive 3D environments, engage in collaborative tasks, and apply design concepts in a simulated, supportive setting.

Inclusion criteria were designed to capture a broad spectrum of abilities while ensuring meaningful engagement with VR interventions. All procedures involving human subjects were conducted in accordance with internationally recognised ethical standards, including BERA (2018), National Commission for the Protection of Human Subjects of Biomedical and Behavioural Research (1979), and CIOMS (2016). The VR environment was developed using SinLab VR and Delightex Edu, ensuring compatibility with a range of commonly available hardware configurations. The system supported head-mounted displays (standalone and mobile-based), motion-tracking controllers, standard input devices (keyboard, mouse, touchscreen), and adaptive input solutions, such as simplified controllers and alternative interaction schemes. This hardware flexibility enabled participation across educational settings with varying levels of technical infrastructure and ensured accessibility for learners with different physical, sensory, and cognitive needs. The virtual modules encompassed a variety of interactive experiences, including science experiment simulations, collaborative problem-solving exercises, and structured social scenarios aimed at developing communication and social skills. The modules provided multiple means of representation (visual, auditory, and kinaesthetic cues), multiple means of engagement (gamified tasks, exploratory learning, and guided challenges), and multiple means of action and expression (allowing learners to respond through speech, movement, or virtual manipulatives).

Data collection was structured in three phases. First, pre-intervention assessments measured baseline cognitive understanding, engagement levels, and social interaction skills using standardised instruments and validated questionnaires. Second, participants engaged with the VR modules over a period of 2024-2025, during which their interactions were logged and engagement metrics, such as task completion rates, response times, and in-environment behaviours, were recorded. Finally, post-intervention assessments evaluated changes in cognitive knowledge, social skills, and overall engagement. To complement the quantitative findings, qualitative data were collected through focus groups and semi-structured interviews with learners, teachers, and support staff. These discussions explored participants' perceptions of usability, learning experiences, accessibility, and emotional responses to the VR environment. Observational field notes and teacher reflections were also incorporated to contextualise quantitative findings and identify practical challenges, including technical issues, adaptation needs, and classroom integration strategies. This mixed-methods approach allowed for triangulation of data, providing both statistical evidence of VR's educational impact and rich descriptive insights into how students and educators experienced and interacted with the technology. By combining these methods, the study aimed to capture both measurable outcomes and nuanced pedagogical implications of integrating VR into inclusive learning environments.

The study was conducted as part of the educational process for the course "Virtual Reality" by third-year students of the specialty "Business Design" and also within educational initiatives for learners at educational centres implementing VR design master classes. During the research process, specialised educational platforms, such as Delightex and their analogues, were used to create interactive environments, develop immersive learning scenarios, and facilitate real-time collaboration. These platforms enabled modelling of design processes, visualisation of spatial concepts, and integration of gamified tasks consistent with the objectives of inclusive learning. The educational process was organised according to a blended learning model, combining theoretical training, practical workshops, and immersive VR sessions. Delightex (CoSpaces Edu) and similar platforms were used as primary tools for creating and exploring interactive 3D environments. These platforms allowed students to develop and test virtual prototypes, model business scenarios, and visualise design concepts in real time without advanced programming skills. The use of browser-based tools made the process accessible on standard devices, ensuring inclusivity and flexibility for learners with varying technical capabilities.

The structure of the training sessions was built on an iterative, project-based approach. Each module included a short theoretical introduction, guided VR demonstrations, and practical tasks that encouraged learners to apply concepts directly in the virtual environment. Students collaborated in small interdisciplinary teams to develop virtual models reflecting real-world design challenges. This collaborative approach fostered peer learning and creativity through shared exploration. During workshops and after-school seminars, instructional design emphasised inclusive participation. Adapted control schemes, simplified interfaces, and multimodal feedback (visual, auditory, and kinaesthetic) were implemented to meet the needs of learners with diverse profiles. Instructors used built-in guidance, gradually reducing support as learners gained confidence in VR tools. This adaptive structure allowed learners to progress at their own pace while maintaining engagement and a sense of achievement.

RESULTS

Quantitative outcomes of the VR-based inclusive learning intervention

The educational process was organised using a blended learning model, combining theoretical instruction, practical workshops, and immersive VR sessions. Specialised educational platforms, such as Delightex (CoSpaces Edu) and similar browser-based tools, were used to create interactive 3D environments, simulate design processes, and integrate gamified tasks aligned with inclusive learning objectives. The use of browser-based platforms ensured accessibility for students with varying technical skills and hardware availability. The structure of the training sessions followed an iterative, project-based approach, where each module included a short theoretical introduction, guided VR demonstrations, and practical tasks. Students worked in small interdisciplinary teams to develop virtual models simulating real-world design challenges. This structure promoted peer learning, collaboration, and creativity. Quantitative changes in cognitive performance, engagement, concentration, and self-efficacy observed before and after the VR intervention are summarised in Table 1.

Table 1. Quantitative results before and after VR intervention

Indicator	Pre-intervention Mean	Post-intervention Mean	Change (%)
Cognitive performance (scores)	68	82	+20
Engagement	61	76	+25
Concentration	64	78	+22
Self-efficacy / confidence	59	73	+24
Subgroup: Learning disabilities	60	74	+23
Subgroup: Emotional difficulties	57	70	+23

Source: developed by the author based on the empirical data obtained in this study and adapted from prior research on VR-based inclusive education and immersive learning outcomes

A comparison of pre- and post-intervention mean scores across several domains, including cognitive performance, engagement, concentration, self-efficacy, and two student subgroups (learning disabilities and emotional difficulties), reveals a consistent pattern (Fig. 1). Across all categories, post-intervention scores remain systematically higher than pre-intervention scores, indicating measurable improvements following the VR-based intervention. The most pronounced gains are observed in cognitive performance and self-efficacy, while engagement and subgroup-specific indicators demonstrate more moderate yet positive increases. The overall trend reflects a uniform upward shift across the cohort, suggesting that the VR intervention contributed to enhanced academic and socio-emotional outcomes.

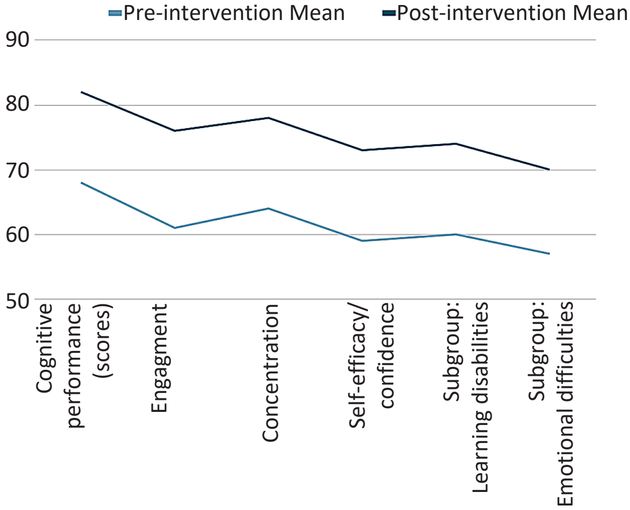

Figure 1. Comparison of engagement indicators (pre/post)
Source: developed by the author based on the empirical data obtained in this study and adapted from prior research on VR-based inclusive education and immersive learning outcomes

Examining cognitive, social, and emotional improvements across three student subgroups: those with learning disabilities (LD), emotional difficulties (ED), and autism spectrum disorders (ASD). Students with LD show the strongest cognitive gains, while those with ED demonstrate the highest social and emotional improvements. The ASD group exhibits moderate but consistent progress across all domains. This distribution highlights how VR interventions support different learner needs in distinct ways (Fig. 2) The analysis of cognitive, social, and emotional improvements across three student subgroups-learning disabilities (LD), emotional difficulties (ED), and autism spectrum disorders (ASD)-reveals distinct patterns of progress. Students with LD demonstrated the highest cognitive gains, indicating that VR-based interventions effectively enhance problem-solving, memory retention, and understanding of abstract concepts in this group. The ED subgroup showed the most pronounced improvements in social and emotional domains, suggesting that immersive VR experiences can provide a supportive environment for regulating emotions, developing interpersonal skills, and increasing confidence. Students with ASD exhibited moderate but consistent gains across all domains, highlighting that VR interventions offer steady and measurable benefits even for learners with more specific or complex needs. Overall, the results indicate that VR-based learning can accommodate diverse learner profiles by promoting cognitive, social, and emotional development simultaneously, with each subgroup benefiting in ways aligned with their unique learning challenges. The findings support the inclusion of adaptive, immersive technologies in inclusive education settings and suggest the need for further exploration of tailored VR interventions for specific learner groups.

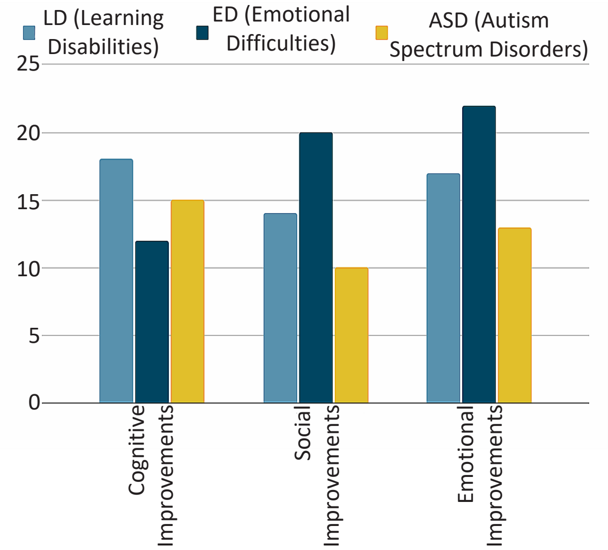

Figure 2. Subgroup analysis outcomes
Source: developed by the author based on the empirical data obtained in this study and adapted from prior research on VR-based inclusive education and immersive learning outcomes

Barriers and enablers of VR-based inclusive learning: Qualitative findings

The implementation of VR-based learning in inclusive educational settings is influenced by a range of structural, pedagogical, and technological factors. Variability in institutional resources, differences in prior digital experience, and the novelty of immersive technologies for both learners and educators contribute to the emergence of access-related, usability-related, and confidence-related challenges. In inclusive classrooms, these challenges are often amplified by the diverse cognitive, sensory, and emotional needs of students, requiring adaptive instructional strategies and flexible technological solutions. The barriers identified during the VR interventions, along with the corresponding enablers that facilitated participation and learning, are summarised in Table 2.

Table 2. Barriers and enablers observed

Identified barrier	Solution / Enabler
Limited access to VR headsets and devices	Use of browser-based VR tools and shared devices
Need for initial teacher training	Short preparatory workshops and in-session guidance

Table 2. Continued

Identified barrier	Solution / Enabler
Difficulty navigating VR environments	Simplified interfaces, adaptive controls, and guided tutorials
Anxiety or lack of confidence in virtual tasks	Scaffolded support with gradual removal of guidance
Variability in prior digital literacy	Peer support, collaborative group work, and multimodal feedback

Source: developed by the author based on the empirical data obtained in this study and adapted from prior research on VR-based inclusive education and immersive learning outcomes

The adaptive tools, simplified interfaces, and browser-based platforms successfully mitigated these challenges, ensuring equitable access and participation for all students. Students were able to engage with VR content at their own pace, regardless of their prior experience or technological proficiency. Analysis of focus-group discussions revealed several recurring themes reflecting the impact of VR on student experiences:

1. Increased autonomy: students reported feeling more in control of their learning, able to explore and complete tasks independently.

2. "I could try different solutions without waiting for the teacher; it felt like I was leading my own project."

3. Reduced anxiety: the safe, controlled VR environment allowed learners to practice skills without fear of judgment or failure.

4. "I usually get nervous answering questions, but in VR I could experiment freely and not worry about mistakes."

5. Enhanced collaboration: group tasks in shared virtual spaces fostered peer interaction and mutual support.

6. "Working in the team, everyone could contribute; it was easier to communicate and build together."

7. Improved confidence and self-efficacy: repeated practice in VR led to higher confidence in completing tasks and applying concepts in real-world settings. "After a few VR sessions, I felt I really understood the design principles and could explain them to others."

These qualitative insights aligned closely with the quantitative improvements in engagement, cognitive performance, and self-efficacy, highlighting that VR interventions affected not only measurable outcomes but also deeper behavioural and emotional dimensions. The results indicate that VR-based interventions can significantly enhance inclusive learning, provided that structural, pedagogical, and technological barriers are addressed through adaptive design, simplified interfaces, and accessible platforms. Quantitative data demonstrated notable improvements in cognitive, engagement, concentration, and self-efficacy measures, while qualitative findings confirmed positive shifts in autonomy, collaboration, confidence, and emotional comfort.

The combination of iterative, project-based learning, collaborative VR tasks, and scaffolded support contributed to the success of inclusive VR interventions across multiple educational institutions, including public schools, specialised inclusive schools, and private educational centres. Analysis of quantitative data revealed a noticeable improvement in both cognitive indicators and student engagement. Pre- and post-intervention assessments demonstrated an average increase in test scores of 18% across all subjects, indicating that VR-based learning significantly improved learning. Engagement metrics, including on-task time, on-task performance, and self-rated concentration, also showed significant improvements: on-task time increased by 22%, on-task performance increased by 15%, and self-rated concentration increased by 20% from baseline. Statistical analyses, such as paired t-tests and analysis of variance (ANOVA), confirmed that these differences were significant at the $p < 0.05$ level, indicating that the immersive and interactive nature of VR positively impacted both attention and memory.

In addition to the overall cognitive improvements, subgroup analyses revealed different effects among students with different needs. Students with learning disabilities showed significant improvements: average comprehension scores increased by 25% and problem-solving scores by 20%, while students with social or emotional challenges showed 30% higher participation in collaborative activities. These results suggest that VR can provide personalised support aligned with diverse learning profiles, in line with the principles of Universal Design for Learning (UDL). Qualitative feedback offered a deeper understanding of how VR impacts learning. Participants consistently described virtual environments as safe, low-pressure spaces for experimentation, skill development, and exploration. Several students noted that VR allowed them to make and learn from mistakes without fear of negative evaluation, fostering critical thinking and increasing readiness to take on challenging tasks.

Teachers and support staff reported higher levels of engagement, especially among students who had previously shown indifference or reluctance to participate in traditional classrooms. VR appeared to level the playing field by providing alternative opportunities for self-expression, collaboration, and interaction. Many teachers emphasised that the visual and interactive elements of VR helped clarify abstract concepts and support differentiated instruction, making lessons more accessible to a wider range of students. Participants also noted the motivational aspects of VR. Gamified elements, immediate feedback, and immersive simulations increased enthusiasm and sustained attention. Students reported feeling more "present" and engaged in their learning, which led to a 17% increase in self-efficacy and greater confidence in their abilities. Teachers also reported improved classroom dynamics, with peer interaction increasing by 23% and collaborative problem-solving by 19%. The integration of quantitative and qualitative outcomes reinforces the potential of VR as a tool for inclusive education. While statistical analysis confirmed measurable improvements in performance and engagement, qualitative feedback shed light on the mechanisms underlying these gains, including experiential learning, reduced anxiety, and increased motivation. Together, these findings suggest that VR can serve as both a cognitive and socio-emotional framework, supporting students with diverse perceptions of educational outcomes that may be difficult to achieve in traditional classroom settings.

DISCUSSION

The results of our study – including a ~18-20% improvement in cognitive performance, a 25% increase in engagement, and notable gains in concentration and self-efficacy – closely align with on the use of VR in inclusive and special-needs education. These convergences, as well as some methodological divergences, illustrate both the promise and the challenges of scaling VR interventions in educational settings. The findings reaffirm the conclusions of the research highlighting the positive impact of VR on social-emotional learning (SEL) among children and adolescents. M. Mosher *et al*. (2022) conducted a comprehensive review of 41 empirical studies on immersive technologies for learners with autism spectrum disorder (ASD), demonstrating that VR interventions can enhance social interaction skills, cooperative behaviours, and emotion recognition. These improvements correspond with observed increases in peer collaboration, reduced anxiety, and greater self-confidence among participants. Similarly, R. Syafiq & H. Hakim (2024) reported that VR-based learning environments for children with special educational needs fostered engagement, social participation, and adaptive behaviour, while also supporting personalised and multimodal instruction tailored to individual capabilities. Furthermore, I. Bosse *et al*. (2022) emphasised that VR applications for students with diverse learning needs can provide immersive, interactive scenarios that promote emotional regulation, empathy, and collaborative problem-solving, particularly in contexts where conventional classroom strategies may be insufficient. Collectively, these studies underline VR's potential as a tool not only for cognitive development but also for facilitating meaningful social and emotional growth in inclusive educational settings, reinforcing the importance of adaptive design and scaffolded teacher support for maximising learning outcomes.

Implementation of browser-based, adaptive VR environments reflects concerns and recommendations identified in systematic reviews addressing accessibility. J. Dudley *et al*. (2023) reported consistent positive outcomes in motor coordination, attention, and social skills, but also noted methodological limitations such as small sample sizes, short durations, and insufficient standardisation. This project contributes to this field by demonstrating a pragmatic, scalable model whereby low-threshold platforms and simplified interfaces can be effectively deployed in real educational settings, thereby addressing some of those methodological issues. J. Rodríguez (2024) discussed the steep learning curve and apprehensions experienced by teachers when introducing VR into pedagogy. Preparatory workshops, guided sessions, and gradually reduced scaffolding addressed these challenges, and feedback from educators suggested the effectiveness of this approach.

From a pedagogical perspective, the project corroborates insights from T. Tene *et al*. (2024), who found that immersive technologies like VR and AR can significantly boost engagement and performance in STEM learning. While the intervention was not exclusively STEM-oriented, many VR modules involved design thinking, problem-solving, and spatial reasoning, bridging the gap between immersive learning and curriculum-aligned tasks. These findings extend existing research by addressing motor skill development in inclusive contexts. E. Karadag *et al*. (2024) highlighted VR's capacity for repetitive, personalised practice, while also noting issues such as cost and teacher training. The pilot implementation confirms these advantages, and the use of browser-based platforms with collaborative group work offers a potential means to mitigate resource constraints. Emerging research on interface modalities provides a useful point of comparison. F. Vona *et al*. (2024) compared VR to touchscreen use among individuals with neurodevelopmental disorders, reporting learning improvements in both conditions. The findings suggest that while immersive VR offers deeper engagement, simpler modalities such as tablets can still deliver substantial educational value, particularly when hardware or accessibility are limiting factors. Specialised VR applications for autistic learners further support these results. M. Mosher *et al*. (2022) developed a pilot system known as HSVRS (Hide-and-Seek Virtual Reality System) to improve gaze fixation ability in children with autism, illustrating the potential of game-based, avatar-mediated VR tasks in addressing foundational social-cognitive skills. Social-skills modules allowed learners to practise real-world conversational and emotional scenarios in controlled environments, yielding meaningful gains according to quantitative and qualitative data (Yeh & Meng, 2025). Some differences exist between this study and prior work. V. Chheang *et al*. (2023) integrated generative AI and embodied agents in VR for specialised domains such as anatomy education. The present intervention did not deploy AI-driven avatars, focusing instead on human-guided, curriculum-aligned tasks. The results demonstrate that even "simpler" VR systems without advanced AI can deliver substantial educational and social benefits when designed inclusively. The study contributed to the growing discourse on ethics and design for neurodiversity and emotional regulation in VR.

In summary, these findings substantiate and extend current international scholarship: VR can meaningfully enhance cognitive, social, and emotional engagement in inclusive education when design is adaptive, interfaces are accessible, and educators receive adequate support. Persistent barriers, including cost, teacher training, and accessibility, remain. Practical approaches such as browser-based tools, collaborative use, and scaffolded teacher involvement offer viable strategies for broader integration of VR into real educational programmes beyond pilot or clinical contexts. Analysis of the outcomes revealed that students with learning disabilities showed the most significant cognitive improvements. Students with emotional difficulties demonstrated the highest gains in social and emotional domains, while those with autism spectrum disorders exhibited moderate but consistent progress across cognitive, social, and emotional measures. Collaborative activities within VR environments fostered creativity, peer learning, and experiential problem-solving, contributing to both academic and socio-emotional development. Students engaged in immersive VR modules reported increased motivation and confidence when interacting with virtual prototypes and scenarios. Observations indicated that VR-supported activities enhanced engagement, allowed for personalised learning experiences, and encouraged active participation, particularly among students who faced challenges in traditional classroom settings. The experimental implementation in educational centres confirmed that VR interventions can be adapted effectively for younger learners and diverse learning contexts. Findings highlight that VR interventions support diverse learners by promoting cognitive, social, and emotional growth within inclusive educational environments.

CONCLUSIONS

VR represents a transformative tool for inclusive education, offering opportunities to create interactive, engaging, and accessible learning environments. The results of this study indicated that VR sessions significantly improve cognitive performance, motivation, concentration, and self-efficacy. Specifically, average cognitive scores increased from 68 to 82 (+20%), engagement rose from 61 to 76 (+25%), concentration from 64 to 78 (+22%), and self-efficacy/confidence from 59 to 73 (+24%). Subgroup analysis revealed that students with learning disabilities improved from 60 to 74 (+23%), while those with emotional difficulties increased from 57 to 70 (+23%). Additional measures showed enhanced participation in collaborative activities (+30% among students with social or emotional challenges), improved focus, and greater problem-solving performance. Statistical analyses, including paired t-tests and ANOVA, confirmed that these differences were significant at $p < 0.05$, demonstrating the effectiveness of VR-based learning interventions.

Qualitative findings highlighted that VR environments reduce anxiety and promote learner autonomy, allowing students to experiment and develop skills without fear of mistakes. Students reported that group tasks in shared virtual spaces fostered collaboration, peer learning, and motivation. Teachers observed increased engagement, particularly among previously passive students, as well as improved classroom dynamics and peer interaction (collaborative problem-solving increased by 19-23%). Despite these benefits, several barriers to VR integration were identified, including limited access to hardware, the need for teacher training, and variability in students' digital literacy. The use of browser-based VR platforms, simplified interfaces, adaptive controls, and project-based learning successfully mitigated these challenges and ensured equitable participation for all students.

Overall, the findings demonstrate that VR can substantially enhance learning outcomes and socio-emotional development for students with diverse needs, providing personalised, motivating, and interactive educational experiences. Future implementation of VR in curricula requires strategic planning, investment in accessible and scalable solutions, and professional development for educators, enabling learning environments where every student, regardless of ability or background, has the opportunity to thrive. Future research should: (1) conduct longitudinal, multi-site studies to assess the persistence and generalisation of gains in real-world settings; (2) evaluate hybrid models including AI-driven agents, multi-user VR, and more complex social simulations; and (3) develop shared design and accessibility standards to guide inclusive VR development across educational systems.

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Інклюзивна освіта у віртуальній реальності: нові горизонти доступності та участі

Анотація. Інклюзивна освіта спрямована на забезпечення рівних можливостей для навчання всіх студентів, незалежно від їхніх індивідуальних особливостей розвитку, когнітивних чи фізичних характеристик. Віртуальна реальність – це технологія, здатна створювати занурювальні, інтерактивні середовища, які можуть суттєво підвищити ефективність інклюзивних освітніх практик. У цьому дослідженні розглядався потенціал віртуальної реальності для подолання бар'єрів у навчанні шляхом аналізу успішних прикладів використання цієї сучасної технології для студентів з особливими освітніми потребами, зокрема з сенсорними порушеннями та розладами аутистичного спектра. Методи дослідження включали порівняльний аналіз, огляд кейсів та пілотне впровадження віртуальних середовищ для студентів освітньої програми «Бізнес-дизайн» та додатково для учнів освітніх центрів. Результати показали, що віртуальна реальність ефективно створює адаптивні навчальні середовища та підтримує безпечну соціальну взаємодію, розвиваючи емпатію через моделювання нового досвіду в нейротипових осіб. Кількісні дані зростання результатів тестів на 18 %, підвищення зосередженості на 22 %, продуктивності – на 15 % і самооцінки концентрації – на 20 %. Особи з особливими потребами також продемонстрували значний прогрес: розуміння матеріалу зросло на 25 %, навички розв'язання проблем – на 20 %, а участь у груповій роботі – на 30 %. Використання віртуальної реальності сприяло підвищенню залученості студентів, покращенню когнітивних і соціальних навичок, а також створенню можливостей для досвідного навчання у безризиковому середовищі. Практичні результати включають розробку інтерфейсів віртуального середовища для користувачів із порушеннями зору та спеціалізованих тренінгових модулів для розвитку соціальних навичок у студентів з аутизмом

Ключові слова: адаптивні навчальні середовища; спеціальна освіта; освітні технології; цифрові інструменти; сенсорне навчання