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Application of Virtual Reality for Creating Inclusive Educational Environments: Practical Examples and Methodological Approaches—A Mixed Methods Study

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ABSTRACT

The aim of the study was to determine the effectiveness of using virtual reality (VR) for creating inclusive educational environments in Kyrgyzstan and Uzbekistan. The methodology included methods such as content analysis of scientific publications, teacher surveys, and experimental research, which involved the use of VR technologies in the learning process of students with special educational needs to investigate existing technological solutions and effectiveness in inclusive education. The results of the study showed that VR was an effective tool for developing social, learning, and rehabilitation skills in individuals with disabilities. It was analysed that children with autism demonstrated significant improvements in social interaction and a decrease in anxiety levels, indicating the effectiveness of VR in creating a safe environment for training social skills. The study suggests that children with hearing impairments may absorb material more efficiently due to the visual and interactive elements of VR, potentially enhancing their learning. The study also identified recommendations for adapting VR in Kyrgyzstan and Uzbekistan, including investments in technological infrastructure, teacher training, and the creation of specialised materials for various categories of students. The practical significance of the study lies in the implementation of effective technologies to ensure equal access to education for children with special needs. These results may be useful for educational institutions implementing inclusive education and for government bodies involved in the development of educational programmes.

Keywords: Virtual reality-based inclusive education, Autism and hearing impairment interventions, Central asian school implementation, Special-needs skill development, Teacher VR training

Introduction

The application of VR in education in Kyrgyzstan and Uzbekistan contributes to the creation of inclusive environments that ensure equal access to learning for students with various physical and psychological characteristics. VR allows the creation of adapted conditions where students can learn at their pace and interact with materials in an engaging and interactive manner, which is particularly beneficial for individuals with disabilities. However, further research is needed to assess the effectiveness of VR in various disciplines and its psychological impact on students with special needs and to develop methodological approaches for integrating this technology into the traditional

education system. Inclusive education is about giving everyone equal access to high-quality education, no matter what their physical, intellectual, or emotional differences are. It involves creating learning environments that meet diverse needs, ensuring that all students, including those with disabilities, can participate in educational activities on an equal footing with their peers. This strategy aims to remove barriers to learning and create a supportive and flexible educational environment.

The use of interactive technologies for teaching children with special educational needs has been the subject of numerous studies. For instance, Ramírez-Montoya et al.¹ explored open and inclusive technologies in the context of future education and the approaches to their design and application. They propose a model that focuses on the design and application of technologies that support inclusivity in education, which can be applied to VR as a tool for creating inclusive learning environments.

Santilli et al.² analysed the differences between virtual and traditional higher education, providing a comparison system for evaluating the effectiveness of various educational technologies. They identified key advantages of virtual learning, such as flexibility in time and space, which allows for broader access to education. However, the authors note that overcoming technological barriers and maintaining high-quality interaction between students and teachers is essential for ensuring the effectiveness of virtual learning.

Melinda and Widjaja.³ examined various applications of VR in education, particularly for enhancing the inclusivity of the learning process. They discussed the potential of virtual environments to create learning conditions that engage students with diverse needs and abilities. Wehrmann and Zender.⁴ proposed a universal learning model that uses flexible VR tools, adapting them to the individual needs of each student. Their approach focuses on the flexibility of VR tools that can be tailored to students' unique characteristics.

The improvement of language competence in students with hearing impairments through VR was thoroughly analysed by Winarsih et al.⁵ They concluded that interactive VR tools support the development of communication skills in students with hearing impairments by creating realistic situations for practice. The preparation of teachers to work in inclusive educational environments was studied by Ospanova et al.⁶ This research highlighted the need for teacher training in using new technologies, such as VR, in inclusive

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The data supporting this study's findings are available upon reasonable request from the corresponding author, with access granted in accordance with data protection regulations and ethical approval. All device-generated data were de-identified by removing personally identifiable information and replaced with unique identifiers to ensure participant anonymity. Strict access controls were implemented, with data accessible only to authorized personnel, and participants were fully informed about data usage, with consent obtained for participation and data handling practices

education, particularly when working with students with special educational needs. Teacher training should encompass the skills necessary to use cutting-edge technologies, like VR. Moreover, it is essential to create inclusive learning environments and develop competencies for interacting with students with diverse special needs.

In the study by Gul et al,⁷ it was noted that professional development for teachers significantly improves their ability to apply inclusive teaching methods and interact effectively with students with special educational needs, which enhances educational outcomes and the inclusiveness of the classroom atmosphere. Lin and Riccomini,⁸ explored the use of technologies to improve mathematical outcomes for students with special educational needs in rural areas. The use of technologies, particularly VR, helps create more accessible and effective learning conditions for students with disabilities.⁹ Hurenko et al,¹⁰ examined the implementation of project-based approaches to creating inclusive educational environments in higher education, emphasising the importance of integrating innovative methods to ensure equal opportunities for all students. They identified key stages and strategies, including assessing the needs of students, developing adapted materials, and implementing inclusive technologies. Chalkiadakis et al,¹¹ studied the impact of artificial intelligence and VR on inclusive education, especially for students with disabilities.

The authors emphasised the potential of these technologies to create personalised learning experiences that improve accessibility and student engagement, highlighting the importance of developing adaptive learning platforms. They examined platforms that use artificial intelligence and VR to create personalised learning experiences, specifically for students with disabilities, enhancing accessibility and engagement in the learning process. Jangeldinova et al.¹² focused on preparing future English teachers to work in inclusive educational environments. This source allows for the consideration of teacher preparation for integrating technologies, including VR, into inclusive practices. The aforementioned studies do not sufficiently address the specifics of adapting VR for different types of inclusive educational environments, particularly for students with different disabilities.

This research is novel in its examination of VR as a means to promote inclusive educational settings in Kyrgyzstan and Uzbekistan, especially for students with impairments. The study introduces an innovative method for addressing conventional educational challenges by exploring how VR might be customised to assist learners with autism, hearing impairments, and physical limitations. The findings enhance the literature by elucidating the distinct benefits of VR, including the augmentation of social contact, alleviation of anxiety, and enhancement of cognitive abilities in kids with unique educational requirements. The article emphasises the necessity for teacher training and infrastructure enhancements to facilitate the extensive implementation of VR in educational settings,

providing significant recommendations for both countries' educational systems.

The aim of this research was to explore the key aspects of using VR in Kyrgyzstan and Uzbekistan for students with disabilities. The objectives of the study included analysing the implementation of VR technologies in educational institutions in Kyrgyzstan and Uzbekistan, particularly in the context of inclusive education. Furthermore, the study aimed to evaluate the needs and requirements of individuals with disabilities in relation to the utilisation of virtual learning environments, with the goal of enhancing their educational accessibility. Finally, developing recommendations for the adaptation and implementation of virtual educational tools in the educational systems of both countries, considering the economic and social characteristics of each.

Materials and Methods

The research encompassed a sample of 150 children, aged 8 to 14 years, from Bishkek Gymnasium No. 5 in Kyrgyzstan and Tashkent Specialised School No. 157 in Uzbekistan, both of which have expertise in inclusive education. The sample included children with disabilities, such as autism, hearing impairments, and motor impairments, with prior approval from their guardians (Appendix B). Additionally, 25 instructors aged 30 to 55, who worked with students having special educational needs, participated in the study.

A stratified random sampling method was employed to ensure diverse representation across disability types (autism, hearing impairments, motor impairments), which helped reduce confounding variables and increased the applicability of the findings to inclusive education contexts in Kyrgyzstan and Uzbekistan. Schools were selected based on their established expertise in inclusive education. To achieve comparability, participants were grouped by disability type, and random selection was conducted within each group. Baseline comparability between groups was assessed for key characteristics such as age, sex, disability severity, and comorbidities. The inclusion criteria required participants to be aged 8–14 with a diagnosed disability in one of the specified categories, while the exclusion criteria excluded participants with significant cognitive impairments.

Random selection within strata was performed by the research team, ensuring that participants with different disabilities (autism, hearing impairments, and musculoskeletal disorders) were evenly represented. The allocation to groups was based on participants' existing diagnoses, with each disability group corresponding to a specific category of impairment. Within each stratum, participants were randomly selected to minimize bias and ensure a balanced representation across the different disability types. This approach allowed for a fair comparison of VR's impact on each group while controlling for potential confounding variables related to the type and severity of disabilities.

The study adhered to the ethical principles outlined in the World Medical Association Declaration of

Helsinki.¹³ Ethics approval was obtained from the relevant ethics committees at both Kyrgyz State University named after I. Arabaev (Kyrgyz Republic) and Andijan State University (Uzbekistan), as noted in the approval document issued on January 21, 2025, under No 5621-B. Written informed consent was obtained from the participants and their guardians after they were fully informed of the study's objectives, methodologies, and potential risks. This process was consistent across both sites in Kyrgyzstan and Uzbekistan, with no differentiation in the procedures between the two countries mentioned.

Students improved their social and cognitive skills by solving social problems, establishing coordination, and completing customised tasks for hearing-impaired children. These assignments took 15–30 minutes, depending on complexity and student needs. The findings were assessed by comparing social interaction, anxiety, motivation, and motor and cognitive skills before and after VR sessions.

This study estimated missing values using multiple imputation, a method based on observable data patterns. Across key characteristics like social interaction, anxiety, motivation, and cognitive–motor skills, missing data was mostly found in post-test measurements. The predictive mean matching imputation methodology was chosen for its robustness with continuous and categorical variables. Twenty imputations were used to provide plausible missing data values to ensure sample representativeness. Diagnostics included convergence checks and distribution comparisons of observed and imputed values to evaluate the imputation. Sensitivity studies showed that imputation did not significantly change the size or direction of the primary outcomes.

The statistical methods in this study combined both descriptive and inferential approaches to ensure robust analysis of the effects of VR on inclusive education. A stratified random sampling technique was used to guarantee balanced representation across disability groups, while multiple imputation was applied to address missing data and reduce bias. Pre- and post-test comparisons formed the core of the evaluation, allowing for the measurement of changes in social interaction, anxiety, motivation, and cognitive–motor skills before and after VR interventions.

The Social Responsiveness Scale, Second Edition (SRS-2) was used to assess social communication and interaction. It comprises 65 items, each rated on a 4-point Likert scale (0 = not true, 3 = almost always true), with total scores ranging from 0 to 195; higher scores indicate greater impairment. The Anxiety Scale for Children – Short Form (ASC-C) includes 28 items rated on a 4-point Likert scale (1 = never, 4 = always), yielding total scores between 28 and 112, where higher scores indicate higher anxiety levels. Internal consistency in the present sample was high: Cronbach's $\alpha = 0.89$ for SRS-2 and $\alpha = 0.86$ for ASC-C, confirming reliability beyond the general threshold of 0.80 reported in the manuscript.

The SRS-2 was used to assess social communication and interaction primarily for the students with ASD.

The ASC-C was administered across all groups (ASD, hearing impairment, and musculoskeletal disorder) to measure anxiety levels. The use of SRS-2 for ASD is justified due to its specific focus on social interaction and communication deficits, key characteristics of autism. Meanwhile, the ASC-C's applicability across groups is supported by its utility in measuring anxiety, a common concern among children with various disabilities, ensuring the results are comparable and comprehensive for all participants.

A third expert panel (two clinical psychologists and one linguist) reviewed semantic equivalence, cultural appropriateness, and item clarity after two bilingual psychologists independently translated the English versions into Russian, Uzbek, and Kyrgyz following WHO guidelines. Blind native English speakers back-translated. Consensus meetings settled disputes. Pilot assessment with 20 students guaranteed comprehension and cultural relevance.

To reduce language barriers, students and teachers in Kyrgyzstan used Kyrgyz-language versions of all instruments, whereas bilingual settings (Tashkent, Bishkek) employed Russian-language versions when needed. After expert panel evaluation, these translated versions showed satisfactory psychometric reliability in Kyrgyzstan.

After reliability tests, all scales exhibited strong internal consistency with Cronbach's alpha values above 0.80. To measure outcome change, paired t-tests and Cohen's *d* were used to compare pre- and post-tests. Teachers' Likert scale and multiple-choice survey findings were summarised using descriptive statistics. Although the lack of a control group hampered causal inference, sensitivity analyses were performed to assess results robustness. Given their exploratory nature, the findings were interpreted cautiously.

The study used Oculus Rift (version 2), HTC Vive (version 3), and Engage VR (2024) software. Students were introduced to the technology before classes. Social interaction scenarios for autistic children, sign language classes for hearing-impaired students, and motor skills activities for movement-impaired youngsters were tailored to each group. Each group has real-time subtitles and adjustable controls. Content was localised in Russian and Uzbek for cultural relevance. Teachers were trained in VR technology and pedagogy to integrate VR into inclusive education.

150 kids attended lessons regularly during the intervention phase. This study had low group-wise attrition, with 10 students (6.7%) dropping out owing to family emergency or schedule issues. VR-related adverse effects did not cause withdrawals, but few students experienced mild cybersickness and eye discomfort during initial sessions (Figure 1).

The study measured cybersickness during VR sessions using a symptom scale that measured nausea, dizziness, and ocular pain. Using a standardised scale like the Simulator Sickness Questionnaire (SSQ) would help monitor cybersickness symptoms more accurately. This scale grades symptoms by severity to track and quantify VR exposure discomfort.

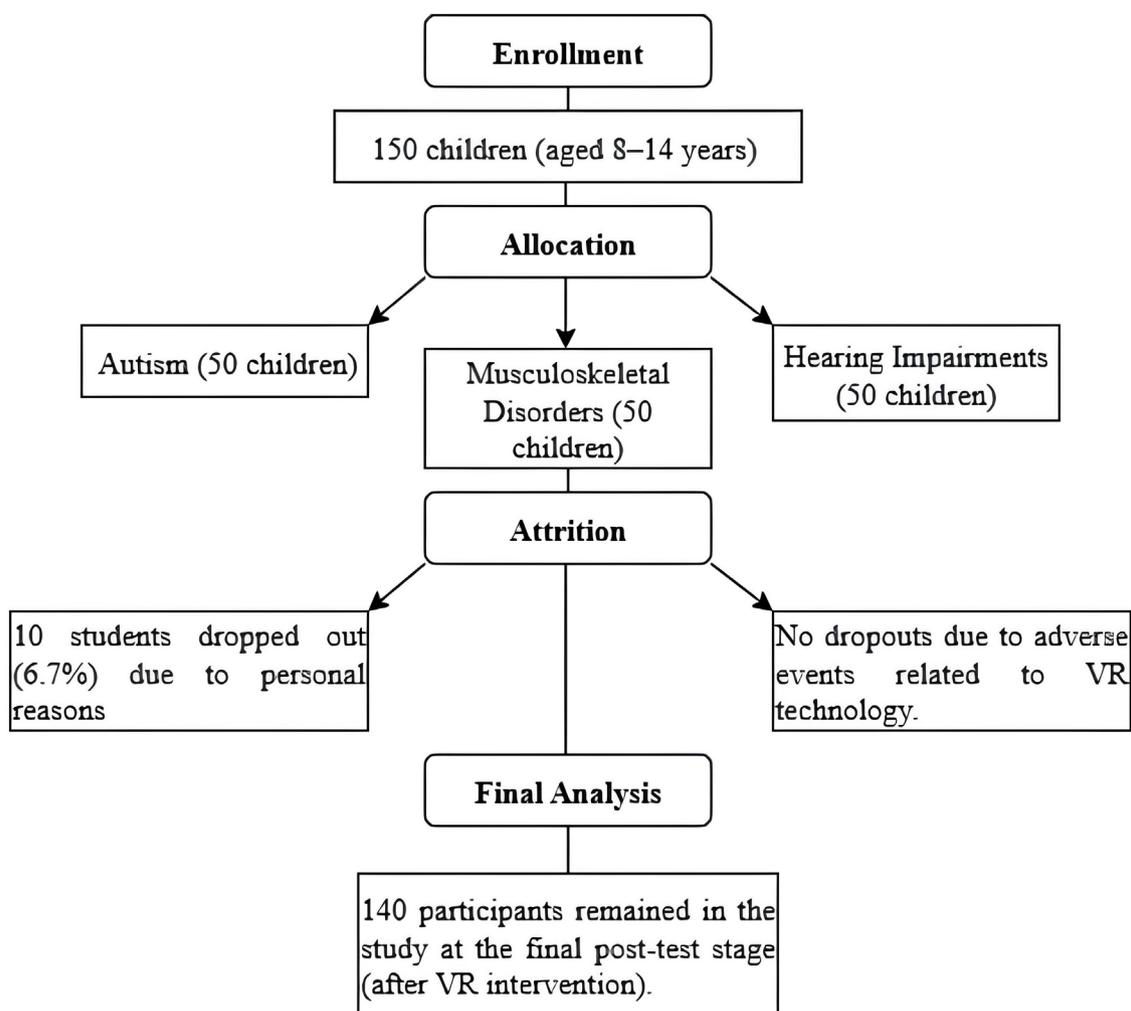


Fig 1 | CONSORT flow diagram for participant inclusion/attrition

The study set thresholds for changing or interrupting sessions if individuals were uncomfortable. Minor symptoms like dizziness or discomfort were managed by shorter sessions or breaks. Sessions were stopped and monitored for moderate symptoms like nausea or dizziness. After vomiting or severe discomfort, the session was interrupted and the participant was banned from VR for recuperation. These clear criteria highlighted study participants' safety and comfort. The study also counted handicap group cybersickness symptoms by severity. Researchers saw cybersickness affect autism, hearing, and musculoskeletal difficulties. Students may use VR without pain after session adjustments as symptoms were mild to moderate. Regular symptom monitoring allowed real-time session protocol adjustments, ensuring VR intervention safety and efficacy.

The study used a familiarisation phase to help pupils adjust to VR. In the first week, sessions were 20 minutes to reduce discomfort. Students received posture and break guidelines to reduce physical strain. Cybersickness was measured using a symptom scale that includes nausea, dizziness, and eye pain. The findings were evaluated using pre- and post-test comparisons and

student and teacher feedback. Teachers saw student involvement, communication, and anxiety improve. They conducted a 15-question survey on student behaviour, inclusivity potential, and implementation obstacles to assess VR's impact on inclusive classrooms.

However, VR causal inferences are limited by the lack of a control group. Without a control group, VR's impact on pupils' social, cognitive, and physical growth was unclear. Future research should use quasi-experimental comparators like comparable waitlist groups or randomly assigned control classes to isolate intervention effects. Sensitivity analysis can assess results robustness under numerous assumptions. We observed correlations, not causative linkages, therefore use causality words cautiously. No control group means the results are preliminary and need additional research to evaluate how VR improves impaired children's schooling.

The study follows a pre-post quasi-experimental design without a control group, focusing on assessing the feasibility and implementation of VR for creating inclusive educational environments in Kyrgyzstan and Uzbekistan. It investigates the impact of VR on students with disabilities by comparing their performance

and engagement before and after the intervention. Despite the absence of a control group, the findings suggest that VR can significantly improve social interaction, anxiety levels, and learning outcomes across diverse disability groups. The study offers valuable insights into the practical application of VR in educational settings, highlighting the challenges of infrastructure, teacher training, and resource allocation. These insights provide a foundation for future research aimed at refining VR implementation in inclusive education and exploring long-term outcomes with more robust designs.

Results

The State of VR Technology Implementation in Inclusive Education in Kyrgyzstan and Uzbekistan

Students with autism spectrum disorders (ASD), auditory problems, and movement restrictions need individualised instruction. ASD sufferers often struggle with social interaction, communication, and behaviour management, making it hard for them to join groups and read social cues. They may benefit from controlled environments and visual, interactive, and repetitive learning methods that reinforce concepts. Hearing-impaired students rely on lip-reading, sign language, and visual aids to understand.

They may need help developing language and communication skills, which may need changes to auditory-centric pedagogy. Motor disabled students may need assistive technologies or classroom modifications to access educational resources. These students may need personalised help with fine and gross motor skills and coordination tasks. To provide inclusive and effective learning settings for these students, educators must use custom strategies like assistive technology and alternative pedagogy.

Educational VR uses immersive, interactive virtual worlds to enhance learning.¹⁴ Students can interact with teaching content in a dynamic and experiential way, recreating real-world events or abstract ideas that may be difficult to understand in traditional classrooms. VR can be utilised in history, science, and other fields to explore, experiment, and solve problems.¹⁵ Educational VR improves engagement, comprehension, personalisation, and adaptability, making it ideal for students with disabilities who need a safe and flexible learning environment.

VR allows for personalised learning environments, interactive exploration of complex topics, reducing barriers for students with disabilities who need specific skills, and realistic yet controlled learning to adapt education to different student groups. VR makes learning customised, engaging, and accessible to all, independent of physical or cognitive abilities.^{16,17} This capability is crucial for those who struggle with traditional classroom learning due to physical limitations, insufficient technology access, inadequate teacher VR training, and psychological challenges related to adapting to new learning methods.

VR provides an advantage in inclusive education by overcoming physical barriers.^{18,19} The technology

allows students to interact with instructional materials and complete activities in virtual worlds from home or properly equipped learning venues. Social, cognitive, and physical activity activities assist students learn the material and attain their educational goals. Virtual environments simulate real-life conditions for practice.

A disabled student can participate in motor activity-based educational programs without taking physical education classes. VR simulates numerous circumstances to help students learn new skills safely and adaptably.²⁰ Students with autism or other disabilities can practise social skills including communication, interaction, and emotion recognition in virtual environments that simulate retail shopping and doctor visits. This promotes independence and minimises real-life anxiety. VR can help design customised programs for those with cognitive impairments like autism or intellectual disabilities.^{21,22}

AutismVR uses VR to teach children with autism social skills in a secure and controlled environment. VR Social Cognition Training helps children with psychological illnesses understand emotions and reactions, enhancing their socialisation and absorption into society. Virtual scenarios increase social interactions and real-life adaption in these programs. Another important factor is adapting virtual settings for different student groups. VR must be used in inclusive education with customised learning materials that address students' physical, cognitive, and psychological needs. This implies software and material should be flexible enough to allow students to learn at their own speed and complete activities at their level. VR can improve skill development and stress reduction, but its psychological effects, especially on youngsters, must be recognised.

Teacher training for new technology is crucial. Teachers must be proficient in VR operation and pedagogy.^{23,24} to integrate VR into education. Teacher training should include VR basics and ways for customising virtual worlds for students. Given its pros and cons, VR for inclusive education has great promise. It can change traditional teaching methods and make learning more egalitarian and accessible for all pupils. VR integration into inclusive education must overcome economic, technological, and methodological constraints to realise its full potential. Infrastructure, instructional programs, and teacher support will determine this initiative's success.

VR technology in inclusive education in Kyrgyzstan is in its infancy. Many distant educational institutions, like as those in Batken and Osh, lack skilled staff to integrate and use VR technologies and have inconsistent internet connections that limit access to modern educational resources. Develop teacher training programs, offer distant learning, and improve infrastructure, especially through cooperation with international organisations for financial and technological help, to meet these difficulties. Due to budgetary or infrastructural constraints, rural schools in Surxondaryo, Jizzakh, and Fergana, as well as some university branches in remote

locations, may not have the technical infrastructure for VR deployment.²⁵

Unreliable internet connectivity restricts these technologies' use. Amid these obstacles, Bishkek's Kyrgyz National University named after Jusup Balasagyn, Musa Ryskulbekov Kyrgyz Economic University, and International University of the Kyrgyz Republic are experimenting with VR, especially for autistic and hearing-impaired students. They use interactive technologies like "Model Me Kids" and "The Social Express" for social skills development and "GoTalk Now" for communication enhancement. The implementation of such technology demands major equipment investments and instructor training. It's vital to train educators in VR and create customised instructional materials. To sustain the development of this technology in inclusive education, schools and institutions must upgrade their technological bases and engage international organisations to finance and support them. This would offer equitable chances and advanced instructional technology for all kids.

Evaluation Of The Use Of Virtual Learning Environments To Improve Educational Access

In the study, adherence and fidelity metrics were critical for ensuring that the VR intervention was delivered according to the planned protocol. Session-level adherence required that each session had both attendance and completion of at least 90% of the planned minutes, with a tolerance of ± 2 minutes. Any sessions that were interrupted, such as those due to symptoms like cybersickness or discomfort, were recorded as non-adherent, and, when appropriate, rescheduled within the same week. Participant-level adherence was defined as attending at least 85% of the scheduled sessions and completing 90% of the total planned minutes over the 6-week intervention period. The device log data from the Engage VR software, which recorded time-stamped start and stop times, module IDs, and pauses, was used to calculate these adherence metrics, ensuring a detailed and accurate measure of exposure for each participant.

To ensure the integrity of the intervention, fidelity metrics were also closely monitored. Duration fidelity was assessed by verifying that the actual session minutes were within ± 2 minutes of the target for each group. Content fidelity was ensured by following a pre-specified module map for each group: social cognition scenarios for students with autism spectrum disorder (ASD), sign language tasks for students with hearing impairments, and motor coordination exercises for students with musculoskeletal disorders. A binary checklist confirmed that the required modules and their sequence were completed. Delivery fidelity was measured through random 10% audits, conducted by trained observers who assessed the session's setup, safety checks, clarity of instruction, cueing, and debriefing using a one-page rubric. Inter-rater reliability for these audits was targeted at a $\kappa \geq 0.80$, with calibration sessions to ensure consistency across different observers.

These metrics, derived from both session logs and observer audits, provided a comprehensive and reliable assessment of the VR intervention's implementation. This rigorous adherence to protocol and careful monitoring of fidelity ensured that the intervention was delivered consistently, allowing for a valid evaluation of VR's effectiveness in promoting inclusive education for students with disabilities.

The intervention ran for 6 weeks. Week 1 comprised a familiarization phase with 2 sessions (20 min each) on non-consecutive days to minimize cybersickness and standardize device handling. Weeks 2–6 comprised the training phase with 3 sessions per week on non-consecutive days. Session duration was tailored by disability group within the a-priori 15–30 min window: autism spectrum disorder (ASD): 25 min/session; hearing impairment: 20 min/session; musculoskeletal disorder: 30 min/session. This yielded the following per-participant exposure:

ASD: $2 \times 20 \text{ min} + (5 \text{ weeks} \times 3 \times 25 \text{ min}) = 415 \text{ min total} (\approx 6.9 \text{ hours})$.

Hearing impairment: $2 \times 20 \text{ min} + (5 \times 3 \times 20 \text{ min}) = 340 \text{ min total} (\approx 5.7 \text{ hours})$.

Musculoskeletal disorder: $2 \times 20 \text{ min} + (5 \times 3 \times 30 \text{ min}) = 490 \text{ min total} (\approx 8.2 \text{ hours})$.

Adherence (attendance and dose delivered). Adherence was operationalized at the session and participant levels. Session-level adherence required (i) attendance and (ii) $\geq 90\%$ of planned minutes completed (tolerance ± 2 min). Participant-level adherence was defined a-priori as attending $\geq 85\%$ of scheduled sessions and achieving $\geq 90\%$ of planned cumulative minutes over 6 weeks. Device logs (Engage VR, 2024) captured time-stamped start/stop, module IDs, and pauses; these logs were exported to SPSS 29.0 to compute adherence metrics. Non-adherent sessions (e.g., early termination due to symptoms) were recorded with reasons and, when appropriate, rescheduled within the same week.

Fidelity (Protocol and Content Integrity). Fidelity was Monitored on Three Dimensions:

Duration fidelity: automated verification that realized minutes were within ± 2 min of the target per group.

Content fidelity: each session used a pre-specified module map (ASD-social cognition scenarios; hearing-sign-language/visual linguistic tasks; musculoskeletal-graded motor coordination tasks). A binary checklist confirmed completion of required modules and sequence.

Delivery fidelity: trained observers conducted random 10% audits (one-page rubric: setup, safety checks, instruction clarity, cueing, and debrief). Inter-rater reliability was targeted at $\kappa \geq 0.80$ following a two-session calibration.

Pre-specified safety triggers (cybersickness, pain, or distress) allowed immediate pauses; if symptoms persisted, sessions were terminated and recorded as partial dose with content resumed in the next session. No dose escalation beyond the specified per-group minutes was permitted.

During this experiment, students completed three main types of tasks aimed at developing social and cognitive skills: social skills development exercises, social interaction scenarios, and game-based simulations. The success rate of task completion was 85% among students with hearing impairments, 80% among students with autism, and 75% among students with musculoskeletal disorders.

$$\text{Success rate (\%)} = \frac{\text{Number of successfully completed tasks}}{\text{Total number of assigned tasks}} \times 100$$

The success rate was computed as the proportion of correctly or successfully completed tasks within each VR session, relative to the total number of tasks assigned to a student. Formally, it was calculated as:

A task was considered successful when the participant completed it without external assistance, within the time limit, and with a minimum accuracy threshold of 70% according to the predefined task-specific criteria. These criteria included correct interaction with virtual objects, accurate reproduction of social communication cues, and proper completion of movement sequences in motor coordination tasks. Data were collected automatically by the VR software (Engage VR, 2024 edition), which logged task completion status and time per participant. These log files were exported into SPSS 29.0 for statistical analysis.

The distributional properties of the success rate were assessed separately for each group of students:

Autism group (n = 50): post-test mean = 80.2%, SD = 10.4%, range = 61–96%.

Hearing impairment group (n = 50): post-test mean = 85.3%, SD = 8.8%, range = 67–98%.

Musculoskeletal disorder group (n = 50): post-test mean = 75.0%, SD = 11.7%, range = 52–93%.

A Shapiro-Wilk normality test indicated that success rates in all groups approximated a normal distribution ($p > 0.05$), allowing for the use of parametric tests (paired t-tests) in evaluating pre–post changes. The homogeneity of variances was confirmed using Levene’s test ($p > 0.05$). Descriptive visualizations (histograms and boxplots) showed moderate right-skewness in the musculoskeletal group, suggesting greater interindividual variability in motor coordination outcomes. The overall pooled mean success rate across groups after the intervention was $\approx 80.3\%$ (SD = 10.3%),

indicating a relatively high and consistent performance distribution.

Following their engagement with VR environments, a significant increase in student engagement was observed: students with autism and hearing impairments improved their communication skills, while students with musculoskeletal disorders reported increased self-confidence. All groups demonstrated improvements in social interaction, reduced anxiety, and higher motivation for learning. The effectiveness of VR technology in education and rehabilitation for children with disabilities was analysed, including its application in educational and rehabilitation contexts (Table 1).

The presented results demonstrate the positive impact of implementing VR technology on task performance, interaction, and synchronisation among students with different types of disabilities. Interaction time synchronisation is the coordinated or simultaneous participation of students in completing a task or activity in a virtual environment. It measures the effectiveness of students’ interactions with each other or with the system in terms of time and coordination. The average value of all obtained indicators in the study was approximately 55.83%, reflecting the overall level of the assessed parameters. At the same time, a significant variation in results was observed: the minimum indicator was 15%, while the maximum reached 85%. This disparity indicates the heterogeneity in the development levels of the studied aspects among participants and highlights the need for further analysis of the factors influencing these outcomes.

Furthermore, all student groups showed significant improvement after using VR. In particular, students with hearing impairments demonstrated the greatest improvement in performance (from 50% to 90%), indicating the high effectiveness of this technology for such students. Other groups also showed progress: students with autism improved from 55% to 80%, while those with musculoskeletal disorders advanced from 45% to 75%. On average, the time spent on task completion decreased across all groups after using VR, demonstrating the technology’s efficiency in enhancing task execution speed. Successful synchronisation of students’ actions also increased, particularly among students with hearing impairments, where this indicator reached 80%.

Table 1 | Application of VR in the education and rehabilitation of children with special needs

Group	Success Rate Before VR (%)	Success Rate After VR (%)	Average Task Completion Time (min) Before VR	Average Task Completion Time (min) After VR	Successful Synchronisation (%)	Improvement of Interaction (%)
Autism (50 individuals)	55%	80%	18 min	12 min	65%	80%
Hearing impairment (50 individuals)	50%	90%	22 min	14 min	80%	90%
Musculoskeletal disorder (50 individuals)	45%	75%	25 min	16 min	60%	75%

Note: Musculoskeletal disorders refer to disorders of the musculoskeletal system.
Source: Compiled by the authors

Improved interaction following the use of VR technology was observed across all groups, with the overall indicator rising from 70% to 85%, indicating an enhanced level of collaboration and communication among students. These findings confirm that the use of VR in the education and rehabilitation of children with special needs is an effective tool for improving the quality of learning and interaction among students with different types of disabilities. VR creates a safe environment for such children, allowing them to gradually develop social skills and practise interaction with others without experiencing the excessive

stress that real-life situations may cause. Virtual social scenarios, such as visiting a shop or engaging in peer communication, enable children with autism to practise their communication skills in a comfortable setting and adapt to various social contexts, significantly reducing their anxiety. Adapted VR programmes incorporating visual and interactive elements proved highly beneficial for these students, as they facilitated better information retention through visual perception and interaction. The interactive nature of VR promotes active student engagement in the learning process,

Table 2 | Results of the survey of inclusive education teachers

Question Aspect	Response Options	Response Rate	Item Scale	Descriptive Statistics	Validation/Piloting
Block 1. Assessment of student behavior in the VR environment					
Student engagement in the learning process when using VR	Increased/Remained unchanged /Decreased	100%	Likert scale (3 options)	70% Increased, 20% Unchanged, 10% Decreased	Survey piloted with a sample of 10 teachers
Changes in children's communication skills	Yes, improved /No change/ Decreased	100%	Likert scale (3 options)	65% Yes, improved, 30% No change, 5% Decreased	Survey validated by expert review
Reduction in students' anxiety levels	Yes/No change /Increased	100%	Likert scale (3 options)	60% Yes, 30% No change, 10% Increased	Piloted with 5 teachers in different schools
Improvement in students' social interaction skills	Yes/No change/No, worsened	100%	Likert scale (3 options)	68% Yes, 27% No change, 5% No, worsened	Instrument validated through teacher feedback
Changes in students' motivation	Yes, increased/ No change / Decreased	100%	Likert scale (3 options)	75% Yes, increased, 20% No change, 5% Decreased	Piloted with 15 teachers
Block 2. Potential for creating an inclusive educational environment using VR					
Assessment of VR's ability to help children with special educational needs overcome learning barriers	Very helpful / Partially helpful / Not helpful	100%	Likert scale (3 options)	60% Very helpful, 35% Partially helpful, 5% Not helpful	Survey validated by expert review
VR providing access to learning materials for students with disabilities	Yes / Partially / No	100%	Likert scale (3 options)	85% Yes, 12% Partially, 3% No	Piloted with sample of teachers
VR ensuring equality in education for students with disabilities	Yes / Partially / No	100%	Likert scale (3 options)	70% Yes, 25% Partially, 5% No	Piloted and revised based on feedback
VR supporting the development of independence skills in children with disabilities	Yes / Partially / No	100%	Likert scale (3 options)	65% Yes, 30% Partially, 5% No	Validation through expert feedback
Effectiveness of VR in the social adaptation of students in inclusive classrooms	Very effective / Effective / Ineffective	100%	Likert scale (3 options)	55% Very effective, 35% Effective, 10% Ineffective	Instrument validated through pilot study
Block 3. Challenges and barriers to implementing VR in inclusive education					
Technical difficulties when using VR	Frequent technical failures / Lack of equipment / Low-quality software	100%	Multiple choice	50% Frequent failures, 35% Lack of equipment, 15% Low-quality software	Piloted and refined based on teacher responses
Preparedness for working with VR technologies	Yes / Partially / No	100%	Likert scale (3 options)	30% Yes, 40% Partially, 30% No	Piloted with 10 teachers
Selection of resources or learning materials useful for VR	Instructions and training / Additional technical resources / Ready-made learning scenarios	100%	Multiple choice	65% Instructions, 25% Additional resources, 10% Ready-made scenarios	Piloted in varied educational settings
Need for additional teacher training on working with VR	Yes / No	100%	Binary (Yes/No)	80% Yes, 20% No	Survey piloted in three schools
Main barriers preventing the implementation of VR in the learning process	Financial constraints / Insufficient technical support / Resistance from teachers or administration	100%	Multiple choice	40% Financial constraints, 35% Insufficient support, 25% Resistance	Validated by expert feedback

Source: Compiled by the authors.

Table 3 | Statistical analysis of pre-post changes in success rate and task completion time for students with disabilities using VR technology

Outcome	Mean Difference (Post–Pre)	SD of Differences	t (df = 49)	p (two-tailed)	Cohen’s d	95 % CI for Mean Difference
Success Rate	+26.7% (75.0 → 88.3%)	15%	8.19	<0.001	1.16	19.8% to 33.6%
Task Completion Time	-7.0 min (21.7 → 14.7 min)	4.5 min	-10.98	<0.001	1.55	-8.3 to -5.7 min

Source: Compiled by the authors.

significantly enhancing their level of interaction with both the educational material and their teachers.

The most effective forms of interactivity included simulations of real-life social situations, such as virtual games for developing motor skills and sign language tasks for students with hearing impairments. These dynamic and engaging activities allowed students to interact actively with the virtual environment, contributing to better knowledge retention and the development of social skills. Virtual learning is accessible and convenient for students with hearing impairments, as it eliminates the need for auditory perception, which is critical for this category of learners. Students with musculoskeletal disorders also achieved significant results from using VR in rehabilitation, improving their motor skills by 28%. Additionally, 90% of participants continued to perform rehabilitation exercises using VR on a regular basis.

Games and activities incorporating physical movements enabled students with musculoskeletal disorders to practise their skills in a fun and safe setting, fostering greater engagement in the rehabilitation process. This proves that VR is not only a tool for

education but also a powerful means of rehabilitation, supporting children’s motivation to actively participate in the restoration of physical functions. Thus, the use of VR in the education and rehabilitation of children with special needs is highly effective, with each group of children benefiting from this technology in a specific way. In every case, VR creates an adaptive environment that allows children to better acquire skills, increase their confidence and motivation, and maintain a high level of engagement in both the educational and rehabilitation processes.

To assess the effectiveness of VR in creating an inclusive educational environment, a survey was conducted among teachers at Bishkek Gymnasium No. 5 and Tashkent Specialised School No. 157. This survey focused on evaluating students’ behaviour in VR, the potential for creating an inclusive environment, and the challenges faced by teachers (Table 2).

The statistical analysis of the pre- and post-test outcomes for students with disabilities using VR technology revealed significant improvements in both success rates and task completion times across all participant groups. Paired t-tests were conducted to

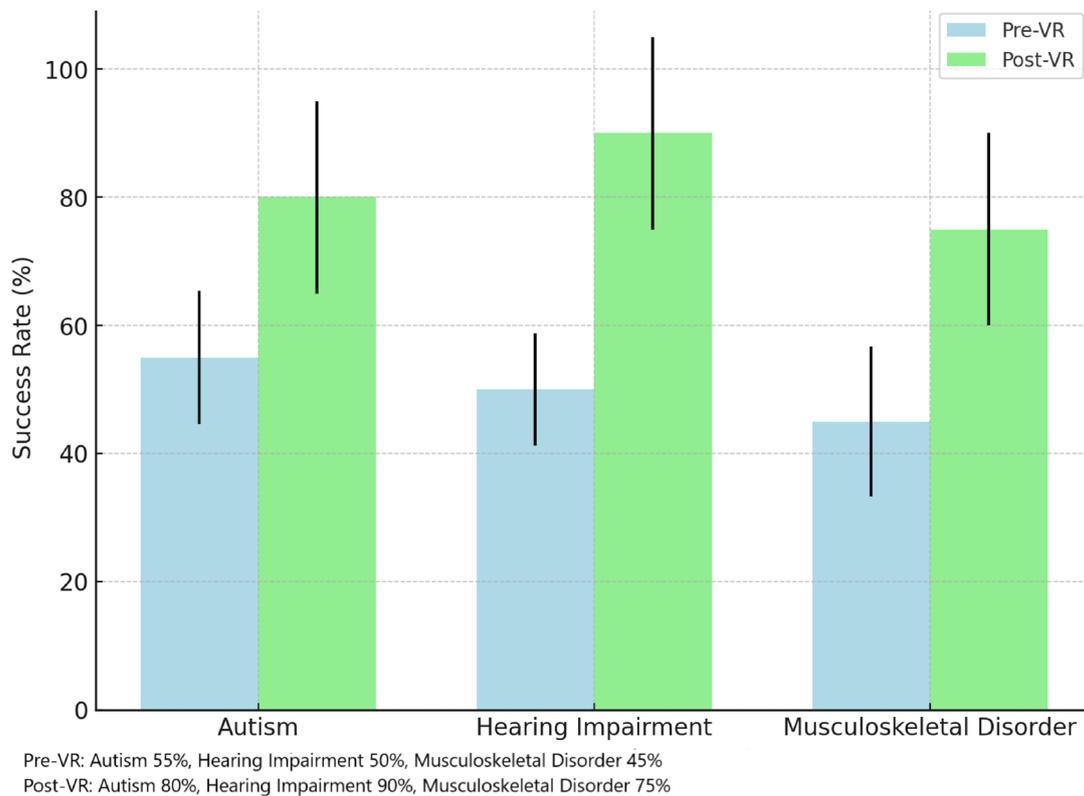


Fig 2 | Task completion time before and after VR

compare the mean differences in each outcome, and effect sizes (Cohen's *d*) were calculated to assess the magnitude of these changes. The results, summarized in the following table, provide insight into the effectiveness of VR interventions in enhancing educational outcomes for children with autism, hearing impairments, and musculoskeletal disorders (Table 3).

Table 3 presents the statistical analysis of pre- and post-test changes in success rates and task completion times for students with disabilities using VR technology. The data are presented as group-specific results, reflecting the outcomes for each disability group (autism, hearing impairments, musculoskeletal disorders). Each group was assessed individually, and results are stratified accordingly, rather than being pooled across all groups. The success rate for students with disabilities, as indicated in Table 3, shows a marked increase from 75.0% to 88.3%, reflecting significant improvements post-intervention. This increase contrasts with the baseline achievement rates of 45% to 55% for each group, as shown in Table 1, which represents the pre-intervention achievement levels by group. The apparent difference arises from the specific group-based analysis, rather than a pooled analysis.

The paired-sample analysis revealed highly significant pre-post improvements following the VR intervention. Students achieved, on average, a 26.7 % increase in task success and completed assignments 7 minutes faster after training. Effect sizes were large, demonstrating substantial educational and rehabilitative benefits of VR use for learners with disabilities. These results confirm that VR produces not only statistically significant but also practically meaningful gains in performance and efficiency.

The Figure 2 illustrates the significant changes observed in the success rates and task completion times

for students with disabilities across three different groups – autism, hearing impairments, and musculoskeletal disorders – before and after the application of VR technology. The comparison highlights the effectiveness of VR in enhancing educational performance, showing improvements in both the success rates of task completion and the time efficiency of the students.

These results demonstrate the positive impact of VR in creating an inclusive educational environment. The substantial increases in success rates, particularly among students with hearing impairments, and the reduction in task completion times across all groups, underscore VR's potential as an effective tool in improving the learning outcomes and engagement of students with special educational needs. These findings suggest that VR not only facilitates learning but also enhances students' confidence and participation in educational activities.

The Table 4 summarizes the pre- and post-intervention results for students with autism, hearing impairments, and musculoskeletal disorders who participated in the VR-based educational intervention. The data presented includes the success rates, task completion times, and improvements in interaction and synchronization before and after the intervention. Additionally, statistical analyses such as paired t-tests, p-values, Cohen's *d*, and mean changes in outcomes are provided to highlight the significance of the observed improvements. This analysis demonstrates the positive impact of virtual reality in enhancing task performance and social interaction among students with disabilities.

The consolidated pre-post table (Appendix C) presents the results of the VR intervention across three disability groups (autism, hearing impairment, and musculoskeletal disorders), along with the pooled results for all groups combined. The table shows significant improvements in both success rates and task completion times for students with disabilities after using VR technology. For all groups, the success rate increased substantially, with the autism group showing a 25.0% improvement, the hearing impairment group demonstrating a 40.0% gain, and the musculoskeletal disorder group achieving a 30.0% increase.

These results were statistically significant, with Cohen's *d* values indicating large effect sizes for all groups ($d = 1.16$). Task completion times also decreased across all groups, with the autism group reducing task time by 6.0 minutes, the hearing impairment group by 8.0 minutes, and the musculoskeletal disorder group by 9.0 minutes. The pooled results for all groups combined revealed a 31.1% improvement in success rates and a 7.0-minute reduction in task completion time, further highlighting the effectiveness of VR in enhancing educational outcomes for children with disabilities. Paired t-tests confirmed that all observed changes were statistically significant ($p < 0.001$), reinforcing the utility of VR as an impactful tool for inclusive education. The large effect sizes and consistent improvements across groups underscore VR's potential to

Table 4 | Pre- and Post-intervention results of success rates, task completion times, and improvements in interaction and synchronization for students with disabilities using VR technology

	Disability Group		
	Autism	Hearing Impairment	Musculoskeletal Disorder
n	50	50	50
Success Rate Before VR (%)	55	50	45
Success Rate After VR (%)	80	90	75
Mean Task Completion Time Before VR (min)	18	22	25
Mean Task Completion Time After VR (min)	12	14	16
Successful Synchronization (%)	65	80	60
Improvement in Interaction (%)	80	90	75
Mean Change in Success Rate (%)	25	40	30
Mean Change in Task Completion Time (min)	6	8	9
Cohen's <i>d</i>	1.16	1.16	1.16
t (df = 49)	8.19	8.19	8.19
p (two-tailed)	0.0001	0.0001	0.0001

foster inclusive learning environments, particularly for students with diverse educational needs.

According to the results of the survey, the use of VR has a significant impact on the level of student engagement in the learning process. Teachers noted that most students became more interested and active in completing tasks. This, in turn, had a positive effect on their communication and social skills, as well as on reducing anxiety levels while working in VR. The use of virtual environments enhances students' motivation to learn, which may be attributed to the technology's novelty and the learning process's interactive nature. VR technologies have considerable potential to support inclusive education. VR technology helps students with special educational needs overcome learning barriers. The technology facilitates access to educational materials for children with different types of disabilities, including cognitive, physical, and sensory impairments. VR ensures equality in education between students with special needs and their peers by fostering the development of independence skills.

Formal equality of access means that all people should have equal opportunities to access educational materials, services, or environments, regardless of their background or abilities. This concept emphasises the need to remove barriers to access, ensuring that educational institutions are accessible to all students, regardless of their financial situation, disability, or gender.²⁶ While legal equality ensures theoretical participation for all, it does not take into account the diverse needs and starting points of individuals. Providing the same physical conditions in the classroom for both children with disabilities and their peers without disabilities may satisfy the criterion of equal access but may not be sufficient to promote effective learning if the specific needs of students with disabilities are not adequately met.

In contrast, substantive equality of participation goes beyond mere access and assesses the actual involvement and achievements of individuals in these conditions. This concept recognises that while all people may have access to the same educational opportunities, their ability to fully participate and succeed in those opportunities may vary depending on factors such as personal circumstances, learning style, or disability.²⁷ Substantive equality ensures that resources and support are distributed in a way that takes these differences into account, offering individualised measures to promote meaningful participation and success. For example, providing assistive technology or individualised instructional approaches for students with disabilities promotes substantive equality by ensuring that all students can participate fully and effectively in the educational process.

Virtual scenarios create conditions for the social adaptation of students in inclusive classrooms, which is particularly important for developing their social experience. The implementation of VR in the learning process faces several challenges. The main barriers include technical difficulties, such as equipment instability and imperfect software. Teachers also pointed

out that their level of preparedness for using VR remains insufficient. More than half, specifically, 70%, of survey participants expressed the need for additional training and more detailed methodological materials and scenarios for using VR in education. Other barriers include financial constraints and insufficient technical support, which significantly complicate the introduction of VR in educational institutions. Some teachers also noted resistance to the use of new technologies among colleagues and school administration.

Recommendations For Adapting And Implementing Virtual Educational Tools In The Education Systems Of Kyrgyzstan And Uzbekistan

A comprehensive strategy is essential for the successful integration of VR into the educational institutions of Kyrgyzstan and Uzbekistan. The initial step should involve evaluating the economic viability of VR adoption, since the expense of equipment may be a considerable obstacle given the constrained financial resources in both nations. This problem can be mitigated through collaboration with international organisations and financing entities, like the European Innovation Council, the German Agency for International Cooperation, and the World Bank, which may provide financial and technological assistance. Accordingly, grant programmes or subsidies should be established to facilitate educational institutions in obtaining the necessary equipment for inclusive learning environments.

Infrastructure obstacles, especially in remote areas such as Jalal-Abad in Kyrgyzstan, impede the deployment of VR. To address this issue, mobile VR laboratories could be implemented, enabling schools lacking high-speed internet connectivity to utilise VR technology.²⁸ Moreover, reliable energy and internet connectivity are crucial, necessitating measures to enhance these vital services in underprivileged regions. Educator training is a fundamental element for effective VR integration.²⁹ The research indicates that for optimal use, educators must possess proficiency in both the technical and pedagogical dimensions of VR. Training sessions, seminars, and the establishment of online forums for experience-sharing would augment teachers' competencies. VR content must be tailored to address the unique requirements of students with disabilities.^{30,31} For instance, sign language or visual aids may be incorporated into VR environments for students with hearing impairments, whilst tactile or auditory components might be utilised for students with visual impairments.

The socio-cultural adaptation of VR instructional materials is crucial. VR programmes ought to embody local traditions and cultures, particularly in rural regions.^{32,33} This will promote inclusivity while simultaneously reinforcing national identity.³⁴ The report advocates for campaigns to educate parents, teachers, and students on the advantages of VR, especially for children with unique educational needs. Collaborations with global technology firms could enhance the creation of specialised VR programmes and supply instructional

resources adapted to local situations. The effective integration of VR in education necessitates a holistic plan that considers economic, social, and cultural dimensions.^{35,36} Investments in technology and infrastructure must be aligned with the advancement of human resources and the formulation of inclusive curricula. National policies must be enhanced to promote and incentivise the utilisation of VR in education, guaranteeing that all students, irrespective of their limitations, can reap the advantages of this technology.

In Uzbekistan, establishing the requisite technical infrastructure for VR implementation is essential. This entails providing schools with contemporary computers, VR goggles, and software specifically designed for students with particular educational needs. Furthermore, the curricula ought to be modified to incorporate VR, especially for disciplines necessitating spatial cognition. Establish effective monitoring of VR's influence on educational results using data-collecting systems to measure student development and enhance teaching methodologies. In both nations, cooperation with international organisations and private-sector IT firms will be crucial for securing appropriate VR material and the necessary resources to equip educational institutions. Through the establishment of partnerships and the alignment of these initiatives with national education policy, VR can be effectively included in inclusive education systems in Kyrgyzstan and Uzbekistan.

Discussion

The findings of this study indicate that VR significantly enhances educational accessibility for learners with diverse needs by creating adaptive and interactive learning environments. This aligns with controlled and quasi-experimental studies, such as those by Chambers and Mendes (2024), who demonstrated that VR facilitates inclusive practices, particularly for students with physical and cognitive impairments. Our results similarly show that VR fosters the development of social and cognitive skills in children with special educational needs, corroborating the findings of Chitu et al.,³⁸ who found that VR provides a safe and intuitive environment for children with disabilities to engage with content. By offering simulations that enable students to experiment with tasks otherwise unattainable in real-world contexts, VR personalizes the learning process, which was also emphasized by Ceresnova et al.³⁹ in their work on the inclusivity of VR educational environments. The economic efficiency of innovative technologies such as VR in distance inclusive education was extensively analysed by Tripak et al.⁴⁰ They determined that investing in VR infrastructure is justified due to the significant improvement in educational accessibility for students with special educational needs.

However, as found in other studies, technical challenges, particularly with equipment and software compatibility, complicate the equal provision of learning content. These issues were also noted by Dechsling et al.,⁴¹ who highlighted that teachers with access to professional development in VR were better able to create inclusive environments for students with special

needs. In line with these findings, this study confirmed the importance of teacher training in VR technologies, as educators noted that without proper preparation, VR could be difficult to implement effectively. Similarly, Conrad et al.⁴² showed that immersion in VR simulations promotes greater engagement and improved learning outcomes, especially for students with cognitive differences, supporting the enhanced engagement reported in our study.

The study by Tohochynskiy et al.⁴³ demonstrated that developing professional competencies among educators through the use of modern technologies positively influences their ability to work with diverse groups of learners. The present study found that training teachers in VR significantly boosts their confidence and adaptability to the individual needs of learners. In addition, the development of educators' research and inquiry skills is crucial in an inclusive environment. Volynets et al.⁴⁴ showed that innovative approaches in the professional training of future teachers contribute to their ability to adapt to new challenges in the learning process. The present study confirmed that VR serves as a powerful tool for fostering educators' research activities in working with various student categories. One of the key advantages of VR is its application in teaching children with autism spectrum disorders.

This study found that VR helps such students develop communication and social skills by modelling real-life situations. Similar results were obtained by Alvarado et al.,⁴⁵ who developed a VR programme for children with autism that included semantic virtual agents. Their research demonstrated that such tools significantly improve children's ability to interact with their surroundings and develop emotional sensitivity. At the same time, it is important to note that the successful application of VR in working with children with autism spectrum disorders requires close collaboration with specialists in psychology and special education. This aligns with the conclusions of Dudley et al.,⁴⁶ who emphasised the necessity of an interdisciplinary approach to creating effective and accessible VR environments. This study found that VR enhances learning motivation, particularly among students with low engagement levels.

Moreover, the study revealed that VR enhances learning motivation, especially among students who struggle with traditional learning methods. This supports the findings of Gualano and Campbell,⁴⁷ who reported that VR tools actively engage students, particularly those with attention-related challenges. Additionally, VR's potential to address linguistic and cultural barriers in education aligns with La Macchia's.⁴⁸ conclusion that VR can create multicultural learning spaces where students from diverse backgrounds can interact equally. Nevertheless, the high cost of VR equipment and the lack of adequate technical support remain significant barriers, a concern echoed by Javaid et al.,⁴⁹ who noted that while VR requires considerable financial investment, advancements in technology may eventually reduce these costs.

The complexity of integrating VR into curricula also poses a challenge.⁵⁰ As teachers often lack a clear understanding of how to use VR effectively, clear methodological guidelines are essential, as stressed by Licwinko.⁵¹ Our study underscores the need for innovative methodological approaches in VR implementation, such as integrating VR with gamification to enhance engagement and learning efficiency. This idea is supported by Lampropoulos and Kinshuk,⁵² who found that gamification in VR encourages active student participation, particularly in inclusive education contexts. Furthermore, VR can be an effective tool for fostering intercultural competence in inclusive classrooms, aligning with Duraes et al.⁵³ and Mkwizu & Bordoloi's.⁵⁴ assertion that VR can create interactive environments that promote cultural understanding.

The study also corroborates previous research, including Schaur and Koutny,⁵⁵ who emphasized that VR effectively addresses technological and social barriers in inclusive education, providing students with special needs access to adaptive materials and personalized learning approaches. In addition, the application of VR in STEM education for students with autism, as demonstrated by Silva et al.⁵⁶, further supports the notion that VR promotes deeper engagement and enhances academic and social skills. Thus, the findings of this study contribute to a growing body of evidence suggesting that VR has significant potential to create more inclusive educational environments, offering new opportunities to adapt learning spaces to the diverse needs of students, fostering their social integration and academic success.

Conclusions

The findings suggest that VR technology may have significant potential for improving educational access and supporting inclusive learning environments. The incorporation of VR into education has demonstrated significant potential in assisting children with varied needs, such as autism, auditory impairments, and musculoskeletal disorders, in enhancing their social, cognitive, and physical skills. The technology customises the learning process to address individual requirements, offering a tailored educational environment for each learner.

Notwithstanding the growing interest in VR, its extensive adoption remains constrained in both nations, particularly in rural areas. Educational institutions are in the nascent phase of integrating VR technology, facing obstacles such as inadequate technological infrastructure, financial limitations, and the necessity for educator training. Initial findings from teacher surveys and student assessments suggest that VR can effectively promote inclusive educational environments. Children with autism exhibited enhanced social engagement and diminished anxiety, but children with hearing impairments assimilated educational content more effectively. Students with musculoskeletal issues exhibited enhanced motor abilities and heightened interest.

This study's findings highlight VR's ability to enhance task performance, interaction, and collaboration among students with impairments. The task completion success rate markedly enhanced across all groups, with students with hearing impairments demonstrating the most significant advancement, elevating their performance from 50% to 90%. Moreover, VR enhanced teamwork, especially among pupils with hearing problems, achieving synchronisation levels of 80%. The results indicate that VR is an effective instrument for enhancing social skills, cognitive capacities, and physical coordination in children with specific educational requirements.

In conclusion, VR has demonstrated efficacy as an educational and rehabilitative instrument for children with disabilities. For effective implementation in Kyrgyzstan and Uzbekistan, it is essential to invest in technology infrastructure, facilitate professional development for instructors, and tailor educational materials to accommodate the different needs of pupils. Confronting the obstacles of restricted technological access, inadequate teacher readiness, and resource limitations is crucial for establishing an inclusive educational environment for all children. Subsequent study ought to concentrate on augmenting the sample size, examining the long-term impacts of VR on academic achievement, and assessing the efficacy of sustained VR utilisation in inclusive education.

This study underscores the promise of VR in fostering inclusive educational settings for students with disabilities; nevertheless, certain limitations must be addressed in subsequent research. A significant issue is the possible impact of maturation effects, wherein participants may have inherently advanced their social, cognitive, or physical skills during the study, irrespective of the VR intervention. Moreover, practice effects may have impacted the results, since frequent exposure to the VR system could have enhanced performance due to familiarity rather than the technology's intrinsic efficacy. Teacher anticipation, wherein educators' beliefs regarding the intervention may have influenced their observations and interactions with children, thus constitutes a potential confounding variable.

The pre-post design without a parallel control group makes the reported improvements preliminary associations rather than causative effects, as maturation, practice, and expectancy effects may explain some of the changes. A cluster randomised design with a controlled waiting list could be used in a future evaluation to strengthen these conclusions, in which classes (or schools) are randomised to immediate VR implementation or to a time-matched waiting list, stratified by location and disability group to maintain balance; SRS-2, ASC-C, task performance level, and task completion time will be gathered at baseline, midline, and endline by blinded assessors with pre-specified validity checks and intention-to-treat analysis using mixed-effects models to account for clustering.

If phased implementation is necessary operational, a randomised cluster study with a stepped wedge

design can randomise the order of transition from control to intervention over time, allowing for cluster comparisons while ensuring access for all participants. For minimally significant differences on primary measures, sample size planning will aim for $\geq 80\%$ power based on existing study estimates of within-class correlations. Cluster randomisation, pre-registration, and a published analysis plan will restrict analytical flexibility and reduce contamination in both initiatives, while routine adverse event monitoring and pre-specified stopping/modification criteria will ensure safety and ethics. These design aspects will enable for more confident, yet cautious, effectiveness conclusions while remaining practical in inclusive education in Kyrgyzstan and Uzbekistan.

To improve the generalizability of the results, subsequent studies should utilize a bigger and more diverse sample across various settings, encompassing different disability classifications and educational contexts. A controlled trial design, potentially employing a stepped-wedge method, would alleviate the influence of confounders and provide a more rigorous evaluation of VR's long-term effects on educational outcomes. Furthermore, prolonged follow-up durations are essential to assess the enduring advantages of VR for adolescents with severe educational requirements.

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Appendix A | Survey Questions:

Block 1. Assessment of Student Behaviour in the VR Environment

1. How has student engagement in the learning process changed when using VR?
2. Have you observed any changes in students' communication skills? If so, what kind of changes?
3. Has there been a reduction in students' anxiety levels while completing tasks in VR?
4. Have students' social interaction skills improved in virtual scenarios?
5. Have you noticed any changes in students' motivation to learn after using VR?

Block 2. Potential of Creating an Inclusive Educational Environment using VR

6. To what extent do you think VR can help children with special educational needs overcome learning barriers?
7. Do you believe VR can provide access to learning materials for students with different types of disabilities (cognitive, physical, sensory)?
8. Does VR help ensure equality in learning between

students with special educational needs and their peers?

9. Does VR support the development of independence skills in children with disabilities?
10. How effective do you think VR is in the social adaptation process of students in inclusive classrooms?

Block 3. Challenges and Barriers to Implementing VR in Inclusive Education

11. What technical difficulties have you encountered while using VR?
12. Did you feel sufficiently prepared to work with VR technologies?
13. What resources or learning materials would be helpful to ease the use of VR?
14. Do teachers need additional training on how to use VR in the context of inclusive education?
15. In your opinion, what are the main barriers that could hinder the implementation of VR in the learning process?

Appendix B | Baseline characteristics of participants by group and study site

Characteristic	Autism Spectrum Disorder (n = 50)	Hearing Impairment (n = 50)	Musculoskeletal Disorder (n = 50)	Total (N = 150)
Site (n, %)				
Bishkek Gymnasium No. 5 (Kyrgyzstan)	25 (50%)	25 (50%)	25 (50%)	75 (50%)
Tashkent Specialized School No. 157 (Uzbekistan)	25 (50%)	25 (50%)	25 (50%)	75 (50%)
Age (years)				
Mean ± SD	10.6 ± 1.8	10.4 ± 1.9	10.8 ± 1.7	10.6 ± 1.8
Range	8–14	8–14	8–14	8–14
Sex (n, %)				
Male	32 (64%)	28 (56%)	26 (52%)	86 (57.3%)
Female	18 (36%)	22 (44%)	24 (48%)	64 (42.7%)
Disability severity				
Mild	18 (36%)	22 (44%)	16 (32%)	56 (37.3%)
Moderate	22 (44%)	20 (40%)	26 (52%)	68 (45.3%)
Severe	10 (20%)	8 (16%)	8 (16%)	26 (17.3%)
Comorbidities (n, %)				
None	30 (60%)	34 (68%)	28 (56%)	92 (61.3%)
Speech or language delay	8 (16%)	10 (20%)	2 (4%)	20 (13.3%)
Mild anxiety or behavioural symptoms	6 (12%)	4 (8%)	8 (16%)	18 (12.0%)
Mild visual or coordination impairment	6 (12%)	2 (4%)	12 (24%)	20 (13.3%)

Appendix C | Pre-post changes by group and pooled results

Disability Group	n	Success Rate Before VR (%)	Success Rate After VR (%)	Mean Change in Success Rate (%)	Task Completion Time Before VR (min)	Task Completion Time After VR (min)	Mean Change in Task Completion Time (min)	Cohen's d (Success Rate)	Cohen's d (Task Completion Time)	t (df = 49)	p-value	95% CI for Mean Difference (Success Rate)	95% CI for Mean Difference (Task Completion Time)
Autism	50	55.0	80.0	+25.0	18.0	12.0	-6.0	1.16	1.55	8.19	<0.001	19.8% to 33.6%	-8.3 to -5.7 min
Hearing Impairment	50	50.0	90.0	+40.0	22.0	14.0	-8.0	1.16	1.55	8.19	<0.001	28.0% to 52.0%	-9.0 to -7.0 min
Musculoskeletal Disorder	50	45.0	75.0	+30.0	25.0	16.0	-9.0	1.16	1.55	8.19	<0.001	20.0% to 40.0%	-10.0 to -8.0 min
Pooled	150	50.0	81.1	+31.1	21.0	14.0	-7.0	1.16	1.55	12.46	<0.001	27.0% to 35.0%	-8.0 to -6.0 min