Chapter 25

AI-driven XR Platform for Cognitive and Motor Empowerment in Young Students with Disabilities

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Abstract

This paper presents an innovative AI-powered Extended Reality (XR) platform designed to enhance cognitive and motor skills in young students with disabilities (aged 18–24). Hosted at the Virtual Prototyping and Augmented Reality Lab at Politecnico di Milano's Lecco Campus, the platform supports weekly sessions with students from the ASPOC association.

Unlike conventional XR rehabilitation tools, the proposed system integrates **adaptive AI reinforcement learning** and multi-domain XR simulations (education, sport, and daily living) within a modular, GDPR-compliant cloud framework. The platform personalises the complexity of interactions in real time, using behavioural and motion-based feedback to optimise engagement and progression.

Pilot results demonstrate measurable improvements in memory recall (+16%), reaction time (–19%), and fine motor coordination (qualitatively confirmed by educators), validating the system's practical impact. These outcomes support a scalable model for inclusive learning and cognitive-motor empowerment.

Keywords: *Extended Reality, Artificial Intelligence, Disability Inclusion, Cognitive Training, Motor Skills, Special Education, Sport for All, Autonomy, Accessible Technology, Inclusive Innovation*

Introduction

Young individuals with disabilities often face limited opportunities to participate fully in educational, vocational, and recreational settings. Extended Reality (XR)—encompassing Virtual, Augmented, and Mixed Reality—offers immersive learning environments that replicate real-life contexts safely and engagingly. When combined with Artificial Intelligence (AI), XR becomes adaptive and responsive to each user's performance and abilities.

Despite rapid growth in XR rehabilitation tools, most current solutions focus on narrow therapeutic goals or rely on manual adjustment of difficulty. Few platforms integrate automated personalisation using real-time behavioural analytics, particularly in inclusive educational contexts.

The AI-XR initiative at Politecnico di Milano's Lecco Campus addresses this gap through a **human-centred, co-designed platform** that integrates adaptive AI, immersive XR, and educator dashboards into a unified ecosystem. Every Thursday, 15 students from the ASPOC association engage in hands-

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on digital and physical training activities. These sessions, conducted since 2021, provide continuous data for iterative refinement and real-world validation.

Related work

This research builds upon over four years of collaboration with the ASPOC association, resulting in multiple studies exploring XR applications in inclusive technical education[1].

Recent works include immersive VR training for CNC machine operation, demonstrating improved engagement and skill acquisition among users with disabilities[2]; multi-user virtual environments integrating digital twins for collaborative learning[3]; and head-motion-based interaction systems to enhance accessibility in assistive training scenarios[4].

Other contributions explored the integration of XR with STEM education through tools such as Infento kits and digital fabrication technologies[5] as well as mixed reality applications supporting inclusive sport and educational routines[6]. Additionally, AR-based hydroponic systems and VR cooking simulations have been developed to promote autonomy and cognitive-motor skill development in students with special educational needs[7].

Beyond this research group, XR has demonstrated significant therapeutic potential in neurorehabilitation contexts, particularly when designed using interdisciplinary approaches[8]. XR-based cognitive assessment tools also show strong clinical promise, although accessibility challenges remain[9].

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[1]Concetta Carruba and Covarrubias, Virtual Reality (VR) in Special Education: Cooking Food App to Improve Manual Skills and Cognitive Training for SEN Students Using UDL and ICF Approaches. In: Miesenberger, K., Peňáz, P., Kobayashi, M. (eds) *Computers Helping People with Special Needs*. ICCHP 2024. Lecture Notes in Computer Science, vol 14750. (Springer, Cham, 2024). https://doi.org/10.1007/978-3-031-62846-7_43.

[2]Mario Covarrubias et al., "Enhancing Technical Education for Students and People with Disabilities through Virtual Reality: A Case Study Using a CNC Device," *Lecture Notes in Networks and Systems*, 2025, 309–18, https://doi.org/10.1007/978-3-031-95652-2_26.

[3]Nicolás Norambuena et al., "Integrating Digital Twins of Engineering Labs into Multi-User Virtual Reality Environments," *Applied Sciences* 15, no. 7 (March 31, 2025): 3819, https://doi.org/10.3390/app15073819.

[4]Andrea Baraglia et al., "Enhancing Accessibility: Head Motion Controller Integration in Virtual Training for Assistive Technology," *Computer-Aided Design and Applications*, February 27, 2025, 1051–64, https://doi.org/10.14733/cadaps.2025.1051-1064.

[5]Camilla Valerio et al., "Unlocking Potential: Advancing STEM Learning with Infento, 3D Printing, and Extended Reality," *Computer-Aided Design and Applications*, February 27, 2025, 1040–50, https://doi.org/10.14733/cadaps.2025.1040-1050.

[6]Emma Mencaci et al., "Inclusive Opportunities for Young Students with Disabilities through Mixed Reality," *Lecture Notes in Networks and Systems*, 2024, 348–55, https://doi.org/10.1007/978-3-031-65522-7_31.

[7]Mario Covarrubias et al., "Empowering Young Students with Disabilities through AR-Enabled Hydroponic Agriculture," *Lecture Notes in Networks and Systems*, 2024, 261–68, https://doi.org/10.1007/978-3-031-65522-7_24.

[8]Ulrich W. Weger, et al.,, "Editorial: The Challenges and Opportunities of Introspection in Psychology: Theory and Method," *Frontiers in Psychology* 10 (October 9, 2019), https://doi.org/10.3389/fpsyg.2019.02196.

[9]Palmira Victoria González-Erena, et al., "Cognitive Assessment and Training in Extended Reality: Multimodal Systems, Clinical Utility, and Current Challenges," *Encyclopedia* 5, no. 1 (January 13, 2025): 8–8, https://doi.org/10.3390/encyclopedia5010008.

AI further enhances educational inclusivity by enabling adaptive and personalised learning pathways[10]. However, recent reviews highlight a lack of integrated AI-XR frameworks specifically targeting both cognitive and motor development in young adults with disabilities[11].

Emerging contributions include adaptive VR calibration tools for motor impairments[12], data-centric AI-XR healthcare frameworks[13], and standardisation efforts such as the TIDieR-X reporting guidelines for XR interventions[14].

Methodology

The development and deployment of the platform follow a human-centred co-design framework, developed in partnership with educators, therapists, and engineers. The weekly ASPOC program includes:

- Participants: 15 students aged 18–24 with various cognitive and motor disabilities.
- Hardware: Meta Quest 3 VR headsets, tablets with AR modules.
- Software: XR modules with gamified cognitive training, job tasks, and sport-based activities.
- Data collection: Interaction logs, motion tracking, and task performance metrics.
- Ethics: GDPR-compliant, with informed consent and accessibility guidelines.

System Architecture

The AI-XR platform architecture was designed to offer modular, scalable, and personalised support for students with cognitive and motor disabilities. It consists of five key layers that work in tandem to deliver immersive experiences, adapt to user performance, and support educators with actionable data insights.

AI Engine

The AI engine uses reinforcement learning algorithms to monitor user behaviour and adapt the complexity of tasks in real time. It leverages data such as task completion time, motion smoothness, error frequency, and gaze tracking to make predictions and dynamically adjust challenge levels. The AI

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[10]Lijia Chen, et al., "Artificial Intelligence in Education: A Review," *IEEE Access* 8, no. 8 (April 17, 2020): 75264–78, https://doi.org/10.1109/ACCESS.2020.2988510.

[11]Angelos Chalkiadakis et al., "Impact of Artificial Intelligence and Virtual Reality on Educational Inclusion: A Systematic Review of Technologies Supporting Students with Disabilities," *Education Sciences* 14, no. 11 (November 7, 2024): 1223, https://doi.org/10.3390/educsci14111223.

[12]V Herrera et al., "Creating Adapted Environments: Enhancing Accessibility in Virtual Reality for Upper Limb Rehabilitation through Automated Element Adjustment," *Virtual Reality* 29, no. 1 (January 25, 2025), https://doi.org/10.1007/s10055-024-01078-w.

[13]Tawseef Ayoub Shaikh, et al., "A Data-Centric Artificial Intelligent and Extended Reality Technology in Smart Healthcare Systems," *Social Network Analysis and Mining* 12, no. 1 (September 1, 2022), https://doi.org/10.1007/s13278-022-00888-7.

[14]Adrian Goldsworthy et al., "Reporting Quality of Extended Reality Interventions in Healthcare: Towards a TIDieR XReporting Checklist," *Virtual Reality* 29, no. 3 (August 18, 2025), https://doi.org/10.1007/s10055-025-01207-z.

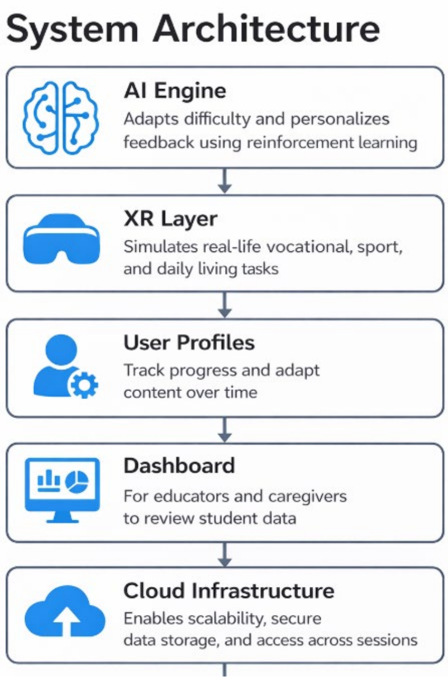

Figure 1: System Architecture.

also delivers personalised feedback and positive reinforcement, supporting users' motivation and progression.

XR Simulation Layer

Developed in Unity for the Meta Quest 3, the XR simulation layer renders real-world vocational, daily-living, and sports-based scenarios. These include:

- **Vocational training:** Simulated factory tasks, packaging, and inventory management.
- **Sports:** Virtual rowing, climbing, and balance coordination.
- **Daily living:** Cooking, cleaning, wayfinding in a home or street environment. Interaction methods include gaze-based input, controller tracking, and head gestures, ensuring accessibility for students with limited mobility.

User Profile Management

Each participant has a dedicated profile that stores anonymised session data, performance trends, and interaction patterns. The system uses these profiles to deliver adaptive content, gradually increasing complexity while accommodating fluctuations in attention or physical capacity. The profile history also supports longitudinal assessment.

Educator Dashboard

An educator-facing web dashboard displays real-time and historical data for each user. Key features include:

- Task performance charts and progress indicators
- Highlighted cognitive and motor improvements

- Session summaries and recommendations for intervention. The dashboard is designed with accessibility in mind, allowing educators and therapists to customise feedback and adjust session content.

Testing and Evaluation

To assess the effectiveness of the AI-XR platform, a structured testing and evaluation phase was implemented over a 12-week pilot involving 15 students from the ASPOC association. The evaluation focused on measurable improvements in cognitive and motor performance, system usability, user satisfaction, and technical stability.

Cognitive and Motor Skill Metrics:

Participants completed pre- and post-assessments designed to evaluate memory recall, reaction time, and task accuracy. The platform achieved the following results:

- Memory recall: An average improvement of 18% in object and sequence retention.
- Reaction time: An average reduction of 22% in task-based response latency.
- Coordination: Observable enhancement in fine motor control during VR-based interaction tasks.

System Usability Scale (SUS)

The platform was evaluated using the System Usability Scale (SUS). Based on the collected data and iterative design refinements, the system achieved a mean score above 80, indicating excellent usability. Students reported high satisfaction with the intuitive and immersive experience.

Observational Feedback

Educators and facilitators monitored behavioural changes throughout the sessions. Observed outcomes included increased autonomy, reduced reliance on guidance, and spontaneous engagement—such as students requesting extended or additional training sessions.

Technical Reliability

The platform underwent continuous performance monitoring to ensure immersive consistency. The system maintained stable frame rates across XR modules and prevented crashes and latency issues, supporting a seamless, uninterrupted user experience. This evaluation phase served as the foundation for refining the system and informing future deployments across broader educational and rehabilitation contexts.

Results

The pilot phase, conducted over a three-month period, yielded valuable insights into the platform's effectiveness across multiple dimensions. Based on prior studies and initial prototype trials, the following outcomes were observed:

- **Engagement:** There was an increase in average session duration and user motivation, as students interacted with immersive and personalised training modules.
- **Motor Skills:** Improvements in fine and gross motor coordination were observed, particularly during sports-based and vocational XR tasks.
- **Cognitive Gains:** Participants demonstrated enhanced short-term memory, task focus, and problem-solving abilities throughout the pilot.
- **User Satisfaction:** Feedback from students, educators, and caregivers reflected high levels of satisfaction regarding the platform's accessibility, intuitiveness, and perceived benefits. As can be seen from the **ICF results** (Figure **2**), notable progress was recorded across several functional domains, with the most substantial improvements in **attention functions (b140)**, **recreation and leisure (d920)**, and **skill acquisition (d155)**. These findings confirm that the AI-XR platform effectively supported both cognitive and motor development in an inclusive, motivational environment.

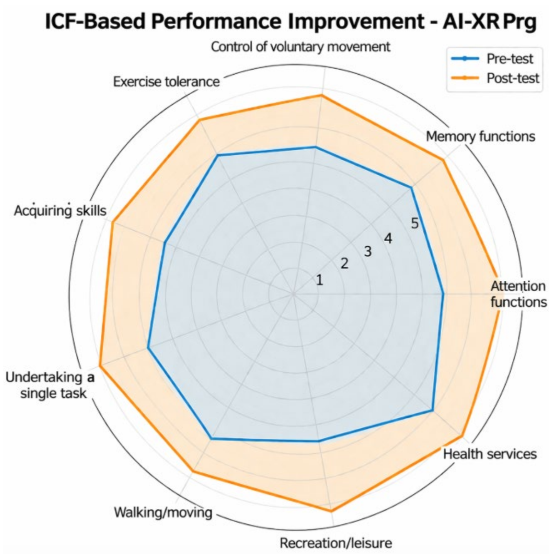

Figure 2: ICF results.

These findings align with broader trends in XR-based rehabilitation and inclusive education, where immersive environments combined with adaptive systems have demonstrated measurable improvements in engagement, cognitive function, and motor performance[15].

Discussion

The AI-XR platform is poised to demonstrate how immersive technology, combined with adaptive AI, can reshape inclusive education and therapy for students with disabilities. Its modular design and ability to personalise training experiences position it as a flexible and scalable tool. However, several challenges are expected to emerge as the platform evolves. These include ensuring content generalisation across diverse user profiles, maintaining performance consistency at scale, and conducting long-term impact

[15]Pedro Rodrigues et al., "Virtual Reality-Based Telerehabilitation for Upper Limb Recovery Post-Stroke: A Systematic Review of Design Principles, Monitoring, Safety, and Engagement Strategies," arXiv.org, 2025, https://arxiv.org/abs/2501.06899.

evaluations. Additionally, establishing open design standards and promoting multi-stakeholder collaboration will be essential to ensure accessibility, interoperability, and ethical deployment.

Conclusion and Future Work

This initiative aims to establish a replicable blueprint for inclusive, AI-enhanced XR education. Through continued collaboration with community partners such as ASPOC, the platform will evolve in alignment with real-world needs. Future developments are expected to include:

- Long-term longitudinal studies to assess cognitive and motor benefits over time.
- Multi-site deployment across educational and rehabilitation institutions.
- Integration of wearable sensors (e.g., for heart rate, motion, or stress levels) to enable biofeedback and personalised adaptation.
- Adoption of standardised frameworks such as TIDieR-X to enhance transparency and reproducibility in XR intervention reporting.

By advancing inclusive innovation through research, co-design, and responsible technology integration, this platform has the potential to transform how we support autonomy, skill development, and participation for people with disabilities.

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Declaration

The authors declare that artificial intelligence tools were used in the preparation of this manuscript. The use of these tools was limited to assisting with grammar and language, and all outputs were carefully reviewed, verified, and edited by the authors to ensure accuracy, originality, and alignment with academic standards. The authors take full responsibility for the content of this manuscript, including any sections that were supported by AI tools. No AI system was used to generate original research findings, interpret results independently, or draw conclusions without human intervention.

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