



Virtual Reality and Serious Games: Innovative Tools for Inclusion and Accessibility

Roberta-Georgiana Barba^{a,*}

^a*PhD Student, Faculty of Mathematics and Informatics, West University of Timișoara, Romania*

Abstract

As digital technologies continue to shape education and healthcare, Virtual Reality (VR) emerges as a powerful medium for immersive learning and therapeutic intervention. This paper explores the design and evaluation of a VR-based serious game prototype aimed at improving accessibility, cognitive training, and rehabilitation for persons with motor or cognitive impairments. The proposed system employs immersive and adaptive environments powered by AI-driven interaction to enhance user motivation, engagement, and learning outcomes. A user-centered design approach was adopted, with iterative testing conducted in collaboration with participants from accessibility-focused institutions. Preliminary results indicate improvements in user motivation and task completion rates, highlighting the potential of VR-based serious games as tools for inclusive education and therapeutic practice.

Keywords: Virtual reality, serious games, accessibility, inclusion, adaptive systems, rehabilitation.

2020 MSC: : 65C20, 97C70, 68T42, 93C40

1. Introduction

The rapid advancement of immersive technologies has opened new opportunities in education, healthcare, and assistive design. Virtual Reality (VR), in particular, offers a compelling platform for creating controlled, adaptive, and interactive environments that can be tailored to individual user needs. When combined with the design principles of Serious Games — games developed primarily for purposes beyond entertainment — VR becomes a powerful vehicle for cognitive training, motor rehabilitation, and inclusive learning experiences. Despite growing interest in the potential of VR-based applications for persons with disabilities, several challenges remain, including a lack of accessible interface designs, insufficient empirical evaluation with target user groups, and limited integration of artificial intelligence to adapt experiences in real time. This paper responds to these challenges by proposing and evaluating a VR serious game prototype designed specifically for users with motor or cognitive impairments, grounded in inclusive design and AI-driven adaptive interaction. The work is situated within an ongoing doctoral research project at the West University of Timișoara, with the overarching goal of contributing to the development of innovative assistive technologies for inclusive education and rehabilitation. The main research questions guiding this

*Corresponding author. Research area: Artificial Intelligence, Virtual Reality, and Human-Computer Interaction
E-mail address: barba.roberta2015@gmail.com (Roberta-Georgiana Barba)

study are: (1) How can VR environments be designed to improve accessibility for users with motor and cognitive impairments? (2) What role can AI-driven interaction play in personalizing therapeutic and educational experiences? (3) How do participants recruited from accessibility-focused institutions respond to such systems in terms of motivation and task completion? The remainder of this paper is organized as follows: Section 2 reviews related work on VR in rehabilitation and serious games for accessibility; Section 3 describes the methodology and system design; Section 4 presents the implementation details; Section 5 reports the evaluation and preliminary results; Section 6 discusses the findings; and Section 7 concludes with future directions.

2. Related work

2.1. Virtual reality in education and rehabilitation

Virtual Reality has been increasingly studied as a medium for therapeutic and educational intervention. Research by [Rizzo & Kim \(2005\)](#) demonstrated that immersive VR environments can enhance engagement in cognitive rehabilitation exercises for patients with acquired brain injuries. Similarly, studies in motor rehabilitation have shown that VR-based gaming can increase exercise adherence compared to conventional therapy due to its inherent gamification properties ([Laver et al., 2017](#)). In the educational domain, VR has shown promise for students with autism spectrum disorder (ASD) and other cognitive differences. [Parsons & Mitchell \(2002\)](#) reported that virtual social environments helped individuals with ASD practice social skills in a safe and repeatable setting. These findings support the notion that VR can provide a safe environment in which mistakes carry no real-world consequences, thereby potentially reducing anxiety and supporting learning outcomes for vulnerable user groups.

More recent evidence also indicates that virtual exercise and rehabilitation interventions can provide feasible and usable options for people with disabilities, with potential benefits for user experience and engagement ([Mintz et al., 2024](#)).

2.2. Serious games for accessibility and inclusion

Serious Games are designed for purposes beyond pure entertainment, such as training, education, or therapy ([Abt, 1970](#)), and have been deployed in a range of accessibility-focused contexts. [Rego et al. \(2010\)](#) reviewed the use of serious games in rehabilitation, highlighting the potential of game-based approaches to support cognitive and motor training across multiple platforms. Their review also emphasizes the importance of game-based mechanics, including rewards, progression, and challenge, in supporting user motivation over time. The integration of accessibility principles into game design remains an important research challenge. Accessible game design requires consideration of diverse input modalities, adjustable difficulty levels, and alternative sensory feedback channels. Few existing frameworks comprehensively address VR-specific accessibility across hardware, interaction, and content layers simultaneously ([Yuan et al., 2011](#)).

Recent research has further emphasized the importance of inclusive design in immersive technologies. [Dudley et al. \(2023\)](#) reviewed accessibility efforts across virtual reality, augmented reality, and the metaverse, identifying both emerging design strategies and persistent accessibility challenges for users with disabilities. These findings reinforce the need to consider accessibility at multiple levels, including interaction, hardware, and content design ([Dudley et al., 2023](#)).

2.3. AI-driven adaptive systems

The integration of Artificial Intelligence (AI) into VR environments enables dynamic adaptation of content difficulty, pacing, and feedback based on user performance metrics. Reinforcement learning and rule-based systems have both been explored for adaptive interaction and rehabilitation applications. Recent research has also examined the integration of AI into virtual rehabilitation. [Abedi et al. \(2024\)](#) identified a range of AI approaches used in virtual rehabilitation, including rule-based methods, template matching, and deep neural networks, particularly for analyzing user performance and supporting adaptive feedback.

AI-driven adaptive approaches are particularly relevant for users whose cognitive or physical capacities may vary across sessions. In the proposed system, adaptation is based on observable performance indicators, including task completion time, error rates, and interaction patterns. This approach allows the difficulty level and amount of guidance to be adjusted according to individual user performance while avoiding the need for large training datasets.

3. Methodology

3.1. Research design

This study employs a mixed-methods approach combining user-centered design (UCD), iterative prototyping, and empirical evaluation with target user groups. The UCD process was structured in four phases: (1) requirements gathering through interviews and workshops with accessibility specialists and potential users; (2) prototyping of the VR environment and game mechanics; (3) iterative testing and refinement; and (4) preliminary evaluation to assess user responses and observed outcomes. Participants were recruited from two accessibility-focused institutions in western Romania. Inclusion criteria required participants to have a diagnosed motor or cognitive impairment and to be capable of providing informed consent. Exclusion criteria included severe photosensitive epilepsy due to known contraindications associated with VR exposure. Ethical approval was obtained from the relevant institutional review board prior to data collection.

3.2. VR environment design

The VR environment was designed using Unity 3D with the OpenXR plugin, targeting standalone headset deployment using the Meta Quest 2. The game scenario consists of a series of structured interactive tasks embedded within a calm, nature-inspired virtual environment designed to minimize cognitive overload and reduce anxiety. Key accessibility design decisions included adjustable interaction modalities, with support for both hand tracking and controller-based input to accommodate varying motor capabilities; visual accessibility features, including high-contrast user interface elements, adjustable text size, and colourblind-friendly palettes; and audio cues and haptic feedback as complementary sensory channels to support users with visual or cognitive processing differences. An adaptive difficulty mechanism dynamically adjusts task complexity based on observed performance, aiming to maintain an appropriate challenge-skill balance as described by flow theory ([Csikszentmihalyi, 1990](#)).

3.3. AI-driven interaction module

The adaptive AI component is based on a rule-based expert system that dynamically adjusts task difficulty according to observable user performance indicators. User interaction data, including task completion time, error rates, and input patterns, are collected at runtime and processed by a performance model. Based on these indicators, the system adjusts difficulty parameters, such as task duration, the number of simultaneous stimuli, and the level of guidance provided between game sessions. This approach supports personalization without requiring large training datasets, which is particularly relevant given the relatively small sample sizes commonly encountered in accessibility research.

4. Implementation

The prototype was developed over a six-month period and consists of three main components: (1) the VR Game Engine, implemented in Unity 3D using C#; (2) the AI Adaptation Module, implemented in Python and responsible for adaptive difficulty adjustment; and (3) the Data Logging System, implemented using a FastAPI backend for collecting and storing user performance data. The system is designed to connect the user's VR interactions with the adaptive AI component and the data analytics layer. Figure 1 presents the high-level architecture of the proposed VR serious game platform.

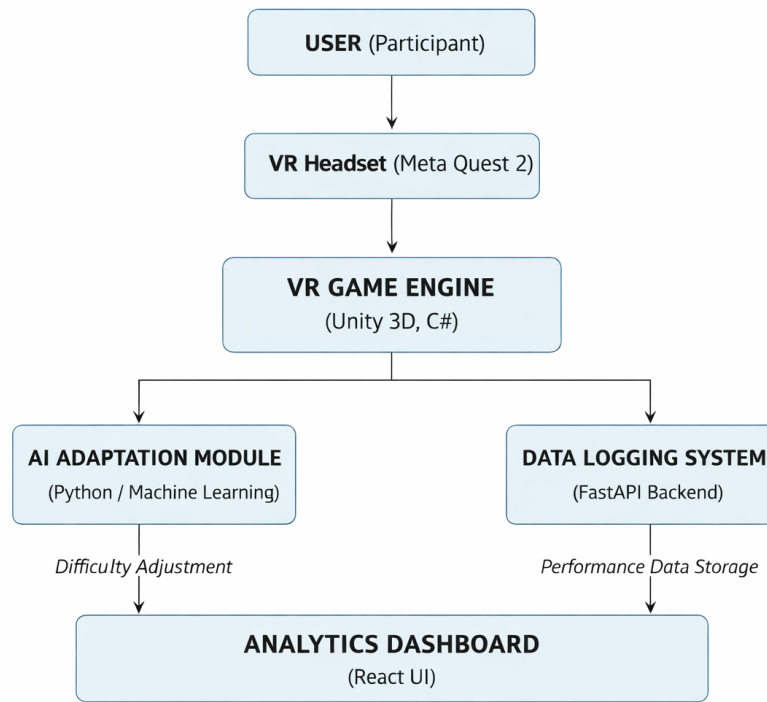


Figure 1. High-level architecture of the VR serious game platform.

The system architecture follows a sequential interaction and data-processing flow. The user interacts with the VR application through a Meta Quest 2 headset, which provides access to the game environment and interactive tasks. The VR Game Engine, developed in Unity 3D using C#, manages the virtual environment, game mechanics, user interactions, and task execution.

During gameplay, relevant performance data are collected and processed by the backend services. The AI Adaptation Module uses user performance indicators to adjust the difficulty of subsequent tasks according to individual capabilities and progress. In parallel, the Data Logging System stores relevant interaction and performance data for further analysis.

The collected information is presented through the Analytics Dashboard, implemented using a React-based frontend. The dashboard provides therapists and researchers with an overview of user performance and progress, supporting the analysis of task completion, errors, and performance trends.

5. Evaluation and preliminary results

5.1. Study setup

A preliminary evaluation study was conducted with 12 participants (7 male and 5 female; mean age = 34.2 ± 9.8 years) recruited from two partner institutions. Participants were divided into two cohorts: one consisting predominantly of participants with motor impairments ($n = 6$) and the other consisting of participants with cognitive impairments, including mild intellectual disability and attention deficit disorder ($n = 6$). Each participant attended three sessions of approximately 30 minutes, with a one-week interval between sessions.

5.2. Measures

The primary outcome measures were (1) Task Completion Rate (TCR), defined as the percentage of assigned tasks successfully completed during each session, and (2) User Motivation, measured using the short form of the Intrinsic Motivation Inventory (IMI) administered after each session. Secondary measures included perceived usability, assessed using the System Usability Scale (SUS), and qualitative feedback collected through semi-structured interviews.

5.3. Preliminary results

The preliminary results indicate a positive trend across the primary outcome measures. The mean TCR increased from 58.3% in Session 1 to 74.7% in Session 3, corresponding to an improvement of approximately 28%. IMI scores also increased, with the Interest/Enjoyment subscale increasing from a mean score of 5.1 in Session 1 to 6.3 in Session 3 on a 7-point Likert scale.

The mean SUS score was 72.4, indicating a good level of perceived usability. Qualitative feedback highlighted the importance of audio guidance and the calm virtual environment. Several participants reported reduced anxiety compared with their previous experiences with physical therapy or traditional computer-based tasks.

The AI adaptation module was also positively perceived by the participating therapists. They reported that the automatic adjustment of task difficulty reduced the need for manual configuration between sessions and facilitated the personalization of the intervention.

6. Discussion

The preliminary findings suggest that the proposed VR serious game platform has potential as a supportive tool for rehabilitation and inclusive education. The increase in Task Completion Rate (TCR) observed across the three sessions is consistent with findings reported in previous research on VR-based rehabilitation and serious games (Laver *et al.*, 2017; Rego *et al.*, 2010). These results indicate that participants with motor and cognitive impairments were able to engage with the system and progressively improve their task performance despite the novelty of the VR interaction modalities.

The mean System Usability Scale (SUS) score of 72.4, together with the positive qualitative feedback, provides preliminary support for the accessibility-oriented design approach. In particular, participants highlighted the usefulness of audio guidance and the calm, nature-inspired virtual environment. These observations suggest that multimodal feedback and reduced environmental complexity may contribute to a more comfortable interaction experience for users with different accessibility needs.

However, several limitations must be acknowledged. First, the study involved a relatively small sample of 12 participants, which limits the generalizability of the findings. Second, the absence of a control group prevents direct comparison with conventional rehabilitation or educational approaches and limits the ability

to establish causal relationships. Third, the evaluation was conducted over only three sessions, meaning that the long-term effects of the proposed system remain uncertain.

Another important challenge concerned the calibration of the AI adaptation module for users with highly variable performance profiles. In some cases, the rule-based component responded too strongly to short-term performance fluctuations, resulting in changes in task difficulty that some users perceived as disorienting. To address this issue, a smoother averaging mechanism has been incorporated into the next iteration of the prototype. Future evaluations should investigate whether this modification provides more stable and predictable difficulty adaptation.

Overall, the preliminary findings provide an encouraging basis for further investigation. However, larger and controlled studies are required before firm conclusions regarding the effectiveness of the proposed platform can be established.

7. Conclusions

This paper presented a VR-based serious game platform designed to support accessibility and inclusion for users with motor and cognitive impairments. The proposed system integrates adaptive AI mechanisms with a set of accessibility-oriented features to provide personalized and engaging virtual experiences for rehabilitation and inclusive education.

The preliminary evaluation involving 12 participants showed an increase in task completion rates and user motivation across the three evaluation sessions, together with a mean System Usability Scale (SUS) score indicating good perceived usability. Qualitative feedback further highlighted the potential value of audio guidance and a calm virtual environment in supporting user engagement and improving the perceived comfort of interaction.

Despite these encouraging preliminary findings, the current study is limited by its small sample size, short evaluation period, and lack of a control group. Future research will therefore focus on expanding the participant cohort, conducting controlled efficacy studies, refining the AI-based adaptation mechanism, and extending the task library to address a broader range of rehabilitation and educational objectives.

In the long term, the proposed platform is intended to support deployment in both clinical and educational settings. Further validation will be necessary to determine its effectiveness, usability, and scalability across different user populations and application contexts. The broader objective is to contribute to the development of inclusive digital technologies that can support accessibility, participation, and user empowerment.

Acknowledgments

The author gratefully acknowledges the guidance and support of Prof. Dr. Marc Frîncu, doctoral supervisor at the West University of Timișoara, as well as the support of the partner accessibility institutions and their participants who contributed to this research.

This work was conducted within the doctoral program at the West University of Timișoara, Faculty of Mathematics and Informatics.

References

- Abedi, A., T. J. F. Colella, M. Pakosh and S. S. Khan (2024). Artificial intelligence-driven virtual rehabilitation for people living in the community: A scoping review. *npj Digital Medicine* 7, 25. <https://doi.org/10.1038/s41746-024-00998-w>.
- Abt, C. C. (1970). *Serious Games*. Viking Press.

- Csikszentmihalyi, M. (1990). *Flow: The Psychology of Optimal Experience*. Harper & Row.
- Dudley, J., L. Yin, V. Garaj and P. O. Kristensson (2023). Inclusive immersion: A review of efforts to improve accessibility in virtual reality, augmented reality and the metaverse. *Virtual Reality* **27**, 2989–3020. <https://doi.org/10.1007/s10055-023-00850-8>.
- Laver, K. E., B. Lange, S. George, J. E. Deutsch, G. Saposnik and M. Crotty (2017). Virtual reality for stroke rehabilitation. *Cochrane Database of Systematic Reviews* **11**, CD008349. <https://doi.org/10.1002/14651858.CD008349.pub4>.
- Mintz, M., J. Rimmer, J. Wilroy, R. Oster, L. Bray, R. Lanzi and B. Lai (2024). Current trends in virtual exercise interventions among people with disabilities: A scoping review. *Archives of Rehabilitation Research and Clinical Translation* **6**(4), 100373. <https://doi.org/10.1016/j.arrct.2024.100373>.
- Parsons, S. and P. Mitchell (2002). The potential of virtual reality in social skills training for people with autistic spectrum disorders. *Journal of Intellectual Disability Research* **46**(5), 430–443. <https://doi.org/10.1046/j.1365-2788.2002.00425.x>.
- Rego, P., P. M. Moreira and L. P. Reis (2010). Serious games for rehabilitation: A survey and a classification towards a taxonomy. In: *Proceedings of the 5th Iberian Conference on Information Systems and Technologies (CISTI)*. IEEE. pp. 1–6. <https://doi.org/10.1109/CISTI.2010.5468467>.
- Rizzo, A. A. and G. J. Kim (2005). A SWOT analysis of the field of virtual reality rehabilitation and therapy. *Presence: Teleoperators and Virtual Environments* **14**(2), 119–146. <https://doi.org/10.1162/1054746053967094>.
- Yuan, B., E. Folmer and F. C. Harris (2011). Game accessibility: A survey. *Universal Access in the Information Society* **10**(1), 81–100. <https://doi.org/10.1007/s10209-010-0189-5>.