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THE IMPACT OF AR/VR ON INCLUSION: BARRIERS AND DESIGN

Abstract. Introduction. In the era of rapid digital technology development, augmented reality (AR) and virtual reality (VR) are increasingly being implemented in education, culture, healthcare, and social services. These technologies offer new opportunities for interaction, communication, and learning; however, their inclusiveness remains a pressing issue. Despite their potential to overcome barriers, AR/VR technologies often create new ones due to poor design, high cost, or limited adaptability to the needs of people with disabilities. In this context, it becomes crucial to critically assess the impact of AR/VR on inclusion and to identify pathways for developing truly accessible digital environments.

Purpose. The purpose of this study is to analyze the impact of AR/VR technologies on inclusion processes, to identify the main barriers that arise during their use, and to justify the principles of inclusive design capable of ensuring equal access to digital resources regardless of users' physical or cognitive characteristics. The research also aims to explore practical applications of AR/VR in education, social engagement, and rehabilitation.

Scientific novelty. The scientific novelty lies in the interdisciplinary analysis of AR/VR as tools for inclusive interaction, covering aspects of accessibility, ergonomics, cognitive load, and social impact. For the first time, recommendations for creating AR/VR products based on universal design principles have been formulated, taking into account the needs of people with various types of disabilities. An approach to inclusive digital immersion has been proposed, combining technical and psycho-pedagogical components, along with an analysis of effective implementations of such solutions in international practice.

Conclusions. AR/VR technologies can become powerful tools for creating inclusive environments, but only if accessibility principles are respected and users with special needs are actively involved in content development. Successful inclusion requires a systemic approach, interface adaptation, affordable devices, and support at the level of educational and social policy. Further research should focus on assessing the emotional and cognitive effects of AR/VR experiences on different user groups and on identifying strategies to minimize potential risks.

Key words: AR/VR, inclusion, universal design, digital barriers, sensory interaction, co-design, educational inclusion, user experience, functional limitations.

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ВПЛИВ AR/VR НА ІНКЛЮЗІЮ: БАР'ЄРИ ТА ДИЗАЙН

Анотація. Вступ. У добу стрімкого розвитку цифрових технологій доповнена (AR) та віртуальна реальність (VR) дедалі активніше впроваджуються у сферу освіти, культури, охорони здоров'я та соціальних послуг. Вони відкривають нові можливості для взаємодії, комунікації та навчання, однак постає питання їхньої інклюзивності. Попри потенціал до подолання бар'єрів, ці технології часто самі створюють нові – через недосконалий дизайн, високу вартість або обмежену адаптованість до потреб осіб з інвалідністю. У цьому контексті актуалізується необхідність критичного осмислення впливу AR/VR на інклюзію та пошуку шляхів створення дійсно доступного цифрового середовища.

Мета. Метою дослідження є аналіз впливу AR/VR-технологій на процеси інклюзії, виявлення основних бар'єрів, що виникають під час їх використання, та обґрунтування принципів інклюзивного дизайну, здатного забезпечити рівний доступ до цифрових ресурсів незалежно від фізичних чи когнітивних особливостей користувачів.

вачів. Дослідження також спрямоване на вивчення практик застосування AR/VR у контексті освіти, соціального залучення та реабілітації.

Наукова новизна. Наукова новизна полягає у міждисциплінарному аналізі AR/VR як інструментів інклюзивної взаємодії, що охоплює аспекти доступності, ергономіки, когнітивного навантаження та соціального впливу. Уперше на основі принципів універсального дизайну сформульовано рекомендації для створення AR/VR-продуктів з урахуванням потреб осіб з різними формами інвалідності. Запропоновано підхід до інклюзивного цифрового занурення, який поєднує технічні й психолого-педагогічні компоненти, та проаналізовано приклади ефективного застосування таких рішень у міжнародній практиці.

Висновки. AR/VR-технології можуть стати потужним інструментом для формування інклюзивного середовища, однак лише за умов дотримання принципів доступності та залучення самих користувачів з ООП до розробки контенту. Успішна інклюзія потребує системного підходу, адаптації інтерфейсів, економічної доступності пристроїв і підтримки на рівні освітньої та соціальної політики. Подальші дослідження мають зосереджуватися на оцінці емоційного та когнітивного впливу AR/VR-досвіду на різні групи користувачів і пошуку шляхів мінімізації потенційних ризиків.

Ключові слова: AR/VR, інклюзивність, універсальний дизайн, цифрові бар'єри, сенсорна інтеракція, ко-дизайн, освітня інклюзія, користувацький досвід, функціональні обмеження.

Introduction. The technological transformation initiated by mobile computing, high-speed internet, and the advancement of artificial intelligence has triggered the rapid expansion of augmented reality (AR) and virtual reality (VR). In Europe, AR/VR inclusivity is recognized not only as a social and legal imperative (for example, Directive 2019/882 “European Accessibility Act”) but also as a source of competitive advantage for producers of such content. In 2023, John Dudley, Lulu Yin, Vanja Garaj, and Per Ola Kristensson introduced the construct of *Inclusive Immersion* as a project concept aimed not merely at providing access, but at enabling the most comfortable and inclusive immersion in VR/AR for people with various physical, sensory, and cognitive impairments. In their review of over 70 scientific and commercial approaches to enhancing VR/AR accessibility, they emphasize the importance of synthesizing universal design with adaptive strategies for diverse user groups [7].

The local scientific discourse in Ukraine also reflects this global trend. For example, O. Sokolyuk and A. Yatsyshyn, in their article, focus on determining the impact of AR/VR technologies on educational practices, noting the weak systematicity of research and the need for standardized methodologies for implementing AR/VR in various learning environments [3, pp. 108–116]. Viktoriia Ivanova, analyzing the use of immersive technologies in the New Ukrainian School, highlights that AR/VR can become a tool for practical inclusion of children with special educational needs: through interactive immersion, even complex socio-civic scenarios can be presented at an individually controlled level, taking into account the specificities of different age and physical capabilities of students [2].

In European studies, particularly those involving Sanjit Samaddar and Helen Petrie, VR and robotics technologies demonstrate high potential in rehabilitation and inclusive education for children with disabilities and older adults. A review conducted within the framework of ICCHP AAATE 2022 shows that even with identical educational or health objectives, the integration of VR and robotics requires careful design that considers typical motor, cognitive, or sensory barriers [9].

Assessing the current state of the scientific base reveals that, although there are isolated successful cases of AR/VR involvement in rehabilitation, education, and intercultural integration, the inclusive design of these technologies remains rather fragmented. The prevailing strategies focus on “adapting the application” to the user rather than proactively “embedding” diversity considerations into the project from the outset (universal design principles). This gap is particularly noticeable in the Ukrainian academic environment: many practical innovations lack proper theoretical justification or systematic analysis of risks related to cybersecurity, cyber fatigue, and the psychological comfort of immersion.

Therefore, this study aims to formulate clear methodological approaches to the inclusive design of AR/VR environments that would not only compensate for barriers but also proactively integrate accessibility principles into every stage of the design process.

Analysis of Recent Research and Publications. In *Inclusive Immersion: a review of efforts to improve accessibility in virtual reality, augmented reality and the metaverse* (2023), British researcher John Dudley and co-authors (including Lulu Yin, Vanja Garaj, and Per Ola Kristensson) proposed the analytical framework “Inclusive Immersion,” which positions AR and VR as spaces for the broadest possible interaction. The authors analyze levels of accessibility encompassing perception, motor activity, and cognitive functions, and highlight the absence of industrial standards for inclusive design. They systematize strategies such as multimodal feedback (sensory intervention), individual freedom

to configure interfaces, and adaptive navigation schemes, ultimately calling for deeper integration of Adaptive UX and Inclusive Design recommendations into AR/VR application development [7].

In the publication *Inclusive AR/VR: accessibility barriers for immersive technologies*, Chris Creed, a researcher from Birmingham City University, together with colleagues, presented the results of two focus workshops involving AR/VR industry professionals and people with various disabilities. They formulated a detailed barrier matrix: physical (challenges in physical movement and input), cognitive (interface overload), sensory (visual, auditory; issues with cybersickness), and communicational. Their conclusions present the “Research Agenda” model, which underscores the necessity of involving people with disabilities in the AR/VR content and service design process from the very beginning of the project [6, pp. 59–73].

A group of Irish researchers led by M. Hamash (Dublin City University) in 2024 published *Breaking through Barriers: A Systematic Review of Extended Reality in Education for the Visually Impaired*. They analyzed 71 articles (2013–2023) from Scopus, ERIC, and other databases: higher education studies prevailed; VR was applied more frequently than AR. Thematic clusters included educational games, orientation and mobility, cognitive spatial mapping, authoring tools, and audio-tactile visualization. The authors concluded that Europe has the highest number of publications and identified clear design guidelines (e.g., 3D audio, spatial cues, gamification, and sensory support) for inclusive education of students with visual impairments [4; 8].

Within an EU-funded project, a team of researchers led by engineer M. Navas Bonilla (Spain, 2025) developed an AR/VR environment for children with special educational needs, incorporating tactile mapping and an adaptive interface. The experiment involved students with dyslexia, ADHD, and motor disorders; assessments covered not only educational impact but also psycho-emotional comfort (stimulating autonomy through adaptive scenarios). The publication emphasizes multidisciplinary collaboration (project designers, educators, neuropsychologists, and parents), co-design methods, and interface individualization—serving as an example of a successful European approach to inclusive XR research [5].

In 2017, a group of Ukrainian researchers led by Stirnenko and Hordiienko, together with Spanish specialist J.R. López Benito, proposed the concept of an intelligent multimodal interface combining AR and brain–computer interface (BCI) technologies for people with functional impairments. This development envisioned multimodal sensory modification (visual-auditory stimuli, feedback via brain signal scanning) to minimize motor barriers and enable adaptive interface control. Although still at the conceptual stage, the system demonstrates the potential of user-centered design for people with special needs—a promising basis for active implementation in inclusive AR/VR scenarios in Ukraine [10].

Purpose of the Study. A comprehensive analysis of the potential and challenges of using augmented and virtual reality technologies to create an inclusive environment, identification of the main barriers to their use for people with different needs, and development of principles for inclusive AR/VR design solutions capable of ensuring accessibility, ergonomics, and effective participation for all categories of users.

Presentation of the Main Research Material. In AR/VR research, one of the less explored yet critically important aspects is the impact of these technologies on the emotional engagement of users with disabilities. Interface developers often focus on technical adaptation—reducing headset weight, implementing voice control, or ensuring the scalability of interface elements. At the same time, the depth of inclusion depends not only on physical accessibility but also on whether an AR/VR system can evoke an emotionally safe sense of presence, particularly for individuals with sensory regulation disorders or anxiety conditions. In the study by Dudley et al. (2023), a separate category of challenges is identified as “audiovisual overload”—sensory stimuli in AR/VR can lead to disorientation or even trigger panic reactions in users with sensory hypersensitivity. The authors emphasize that genuine inclusivity begins not with adding functions, but with rethinking the immersion experience itself as a safe and controlled environment for various user scenarios [1; 7].

The national context also shows attempts to integrate VR into rehabilitation environments. For example, in the publication by Stirenko, Gordienko, and López Benito (2017), an innovative concept of a multisensory AR BCI interface was proposed, enabling adaptive interaction between a user with limited motor skills and a virtual environment through a neural interface. This approach opens pros-

pects not only for physical control but also for self-expression, which is vital for users with limited speech or motor abilities. This type of design focuses on “interface empathy,” where the technology not only reacts but anticipates opportunities for interaction that the user may not have had in real life [10].

From the perspective of educational inclusion, M. Hamash et al. (2024) emphasize the practices of creating cognitive spatial maps in VR for students with visual impairments. Their review shows that the most effective interfaces are those where spatial landmarks are combined with audio prompts and tactile feedback. Such design not only ensures navigation but also builds the user’s own mental model of space, enhancing confidence in independent movement in both digital and real environments [8].

In the context of AR/VR design for people with dyslexia or on the autism spectrum, the Spanish project led by M. Navas Bonilla (2025) introduced flexible interaction scenarios, where the user can choose the intensity of feedback, the speed of information delivery, and visual cues. This shifts the paradigm from “adapting to a standard” to creating an environment shaped around the user—an approach aligned with the principles of participatory design and Universal Design for Learning [4].

Thus, the experience of European and Ukrainian researchers demonstrates that the future of inclusive AR/VR is linked not so much to the unification of solutions as to the personalization of design, where users are not merely subjects of testing but full co-authors of the technological environment.

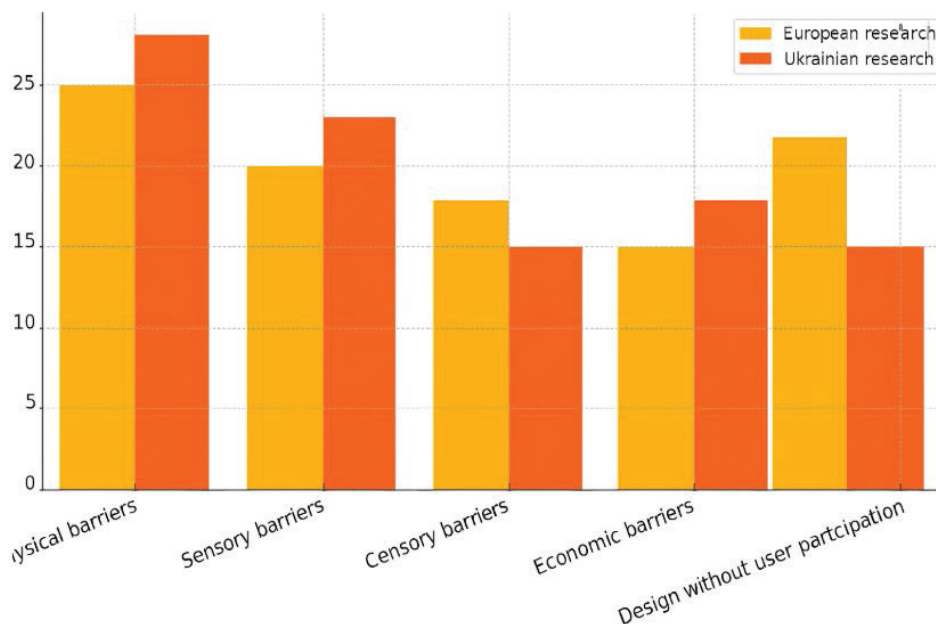


Fig. 1. Types of barriers in AR/VR regarding inclusion: comparison between Europe and Ukraine

This diagram illustrates a comparison of common barriers to the application of AR/VR technologies for inclusion between European and Ukrainian studies.

Key observations:

- Physical barriers (e.g., headset weight, hand controls) are mentioned more frequently in Ukrainian studies.
- Cognitive barriers (interface complexity, overload) are notable in both European and Ukrainian works.
- Economic factors (device cost, infrastructure) are more often highlighted in Ukraine.
- Lack of user participation in design is more frequently mentioned in European works as a challenge for inclusive UX.

Conclusions and Prospects for Further Research. Based on the conducted analysis, it can be concluded that augmented reality (AR) and virtual reality (VR) technologies have significant potential in shaping an inclusive digital environment; however, this potential is only partially

realized. The main barriers remain the physical limitations of devices, cognitive overload of interfaces, economic inaccessibility, and insufficient involvement of users with special needs in the design process. Successful examples of inclusive AR/VR exist in both Ukrainian and European scientific contexts, but they are fragmented and require further generalization and systematization.

Future research should focus on several key areas: first, the development of co-design methodologies that involve the active participation of users with disabilities in creating AR/VR solutions; second, the assessment of the psycho-emotional and cognitive impact of immersive content; and third, the creation of tools for adapting interfaces to individual needs without loss of functionality. An interdisciplinary approach is also relevant—engaging designers, programmers, educators, rehabilitation specialists, and the users themselves in creating an effective inclusive experience in AR/VR environments. Studying the local Ukrainian context in comparison with European practices can serve as the basis for developing national digital inclusion strategies.

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