Metaverse Basic and Applied Research. 2024; 3:.97
doi: 10.56294/mr2024.97

AG EDITOR

ORIGINAL

Immersive learning in the metaverse: a review of evidence on pedagogical effectiveness and implementation gaps in Higher Education

Aprendizaje inmersivo en el metaverso: una revisión de evidencias sobre efectividad pedagógica y brechas de implementación en la educación superior

Víctor Hugo González Torres[1], Pedro Luis Bracho-Fuenmayor[2], Elisabeth Viviana Lucero Baldevenites[3], Marco Vinicio Carrillo Guerrero[4], Roberto David Santander Erazo[5]

[1]Universidad de Guanajuato; Celaya; Gto; México.
[2]Universidad Tecnológica Metropolitana; Santiago de Chile; Chile.
[3]Universidad de Las Palmas de Gran Canaria; Las Palmas de Gran Canaria; España.
[4]Universidad Internacional del Ecuador (UIDE); Quito; Ecuador.
[5]Universidad de Castilla La Mancha; Quito Ecuador.

Cite as: González Torres VH, Bracho-Fuenmayor PL, Baldevenites EVL, Carrillo Guerrero MV, Santander Erazo RD. Immersive learning in the metaverse: a review of evidence on pedagogical effectiveness and implementation gaps in Higher Education. Metaverse Basic and Applied Research. 2024; 3:.97. https://doi.org/10.56294/mr2024.97

Submitted: 06-01-2024 **Revised:** 11-05-2024 **Accepted:** 16-10-2024 **Published:** 17-10-2024

Editor: PhD. Yailen Martínez Jiménez

Corresponding Author: Víctor Hugo González Torres

ABSTRACT

This study aims to conduct a critical analysis of the impact of the metaverse on higher education. To achieve this, it addresses both the pedagogical effectiveness and implementation gaps of this technology. The authors performed a systematic review of recent literature (2020-2025), identifying that immersive environments like virtual and augmented reality enhance knowledge retention in practical disciplines (medicine, engineering), particularly through surgical simulations or 3D prototyping. However, it must be noted that these benefits depend on intentional pedagogical designs and well-structured curricula, moving beyond reductionist approaches focused solely on technological novelty. While tools like AI enable personalized learning pathways, their integration raises ethical dilemmas, with the literature highlighting key concerns such as biometric data privacy and algorithmic biases. Implementation gaps reveal profound inequalities: universities in developed economies adopt advanced metaverse solutions, while institutions in peripheral regions face technical and training limitations. Furthermore, the STEM-focused approach marginalizes humanities and social sciences, where in-person interaction remains crucial. Sustainability also emerges as a challenge, with little discussion on the environmental or economic costs of infrastructure like 5G or blockchain. From this, we conclude that the metaverse is not a universal solution but rather a resource whose value depends on inclusive policies, faculty training, and robust ethical frameworks. We urge prioritizing hybrid models that balance innovation with equity.

Keywords: Metaverse; Immersive Learning; Higher Education; Digital Divides; Pedagogical Effectiveness.

RESUMEN

Esta investigación se propone llevar a cabo un análisis crítico del impacto del metaverso en la educación superior. Para ello, se plantea la necesidad de abordar su efectividad pedagógica y las brechas de implementación de esta tecnología. Los autores realizaron una revisión sistemática de literatura reciente (2020-2025) en la que se identificó que entornos inmersivos como la realidad virtual y aumentada mejoran la retención de conocimientos en disciplinas prácticas (medicina, ingeniería), especialmente mediante simulaciones quirúrgicas o prototipados 3D. Aun así, no se puede dejar de mencionar que estos beneficios dependen de diseños pedagógicos intencionales y currículos bien estructurados, por lo que se debe obviar el reduccionismo centrado solo en la novedad tecnológica. Aunque herramientas como IA personalizan rutas de aprendizaje, su integración plantea dilemas éticos, donde los principales señalados en la literatura son la privacidad de datos biométricos o sesgos algorítmicos. Las brechas de implementación revelan desigualdades profundas: universidades en economías desarrolladas adoptan metaversos avanzados, en contraste con instituciones en regiones periféricas que enfrentan limitaciones técnicas y formativas. Además, el enfoque en STEM margina a humanidades y ciencias sociales, donde la interacción presencial sigue siendo crucial. La sostenibilidad también se invoca como un desafío, con poca discusión sobre costos ambientales o económicos de infraestructuras como 5G o blockchain. A partir de esto, concluimos que el metaverso trasciende una solución universal, por lo que debe verse como un recurso cuyo valor depende de políticas inclusivas, formación docente y marcos éticos robustos. Se urge a priorizar modelos híbridos que equilibren innovación con equidad.

Palabras clave: Metaverso; Aprendizaje Inmersivo; Educación Superior; Brechas Digitales; Efectividad Pedagógica.

INTRODUCTION

According to Shi et al.[1] the impact of the metaverse on higher education is evident, as it has a substantial influence on education by impacting learning methods, outcomes, and positive dispositions of students.[2] According to Neveda et al.[3] metaverse technologies significantly influence and improve pedagogical approaches in education by enhancing interactive and engaging user experiences.

The metaverse presents opportunities for a more relevant and practical teaching process, requiring both the implementation and monitoring of research studies in the follow-up of education in the metaverse environment, according to Sá et al.[4]. Kaddoura et al.[5] warn that using the metaverse in education presents points of attention that must be addressed to avoid cracks related to its educational uses and enabling technologies such as extended reality and the internet.

Previous research indicates that 3D technology, which, according to Alhonkoski et al.[6] includes environments, images, holograms, and prints, has positively impacted student learning. About this, Mcnaughtan et al.[7] demonstrated that 3D models created with custom printing technology can increase students' retention of abstract concepts. However, the use of the metaverse in education has been associated with weaker social connections, a possible violation of privacy, and a possible poor adaptation to the real world for students whose identity has not been established.[8]

The current debate oscillates between two narratives about the challenges and opportunities for integrating it into educational practices.[9,10] On the one hand, advocates such as Schott et al.[11] argue that immersive virtual environments can provide participants with a holistic experience of real-world environments that would otherwise be too expensive, impractical, or unethical. On the other hand, critics such as Camilleri[12] point out that while the metaverse in education can improve students' knowledge, skills, and abilities, it can also lead to privacy violations, security risks, and potential addiction.

The relevance of this research lies in its dual approach, as existing literature addresses the study of the metaverse from isolated perspectives (i.e., technological, pedagogical, or ethical)[8,13] without delving into the combination of educational effectiveness and the real conditions in which it is implemented. Therefore, this article stems from the urgent need to chart a critical course. The authors do not seek to condemn or idealize the metaverse but rather to identify the circumstances under which it enhances learning, the obstacles that hinder its equitable adoption, and how universities can navigate this uncertain territory without losing sight of their core mission: to train professionals capable of transforming, not just inhabiting, the world they inherit.

METHOD

Research approach

A mixed sequential approach was adopted, structured in two complementary phases. The authors designed these phases to ensure rigor and depth in the analysis, as indicated by methodological experience.[14]

Phase 1. Exploratory bibliometric analysis

In the first phase, an exploratory scope was adopted through a search strategy in Scopus and Web of Science using the chain TITLE-ABS-KEY (metaverse) AND TITLE-ABS-KEY (higher AND education) AND PUBYEAR > 2020 AND PUBYEAR < 2025. Peer-reviewed articles in English and Spanish were included, while duplicates, book chapters, and studies without empirical evidence were excluded. The preliminary results were analyzed using the bibliometric tool VOSviewer,[15,16] focusing on keywords' co-occurrence and the publications' geographical distribution.

Phase 2. Qualitative systematic review

The second phase planned was a systematic review,[17] to broaden the scope of the previous stage with a refined strategy: TITLE-ABS-KEY (metaverse) AND PUBYEAR > 2020 AND PUBYEAR < 2025, combined with filters for specific terms (E-learning, Artificial Intelligence, Immersive, among others). This stage prioritized quantitative, qualitative, and mixed studies that evaluated pedagogical effectiveness or implementation gaps.

The selected studies were analyzed using the thematic synthesis technique through Atlas.Ti[18] to code recurring patterns in three categories: (1) impact on learning (motivation, retention, technical skills), (2) technical and ethical challenges (accessibility, data privacy), and (3) institutional sustainability (costs, teacher training). As a validation measure, the results of both phases were cross-referenced to identify convergences or contradictions. In addition, a critical analysis of recurring limitations in the literature was conducted.

Study limitations

Among the study's limitations, it is recognized that the exclusion of gray literature and studies in other languages may have omitted relevant experiences in non-English-speaking contexts. Likewise, the heterogeneity of effectiveness indicators among the articles reviewed complicated the direct comparison of results, requiring a contextualized and cautious interpretation. Nevertheless, combining bibliometric, systematic, and critical techniques was a strength of this research in discussing advances and contradictions in the field.[19]

RESULTS AND DISCUSSION

The analysis focused on the context of higher education revealed particular elements regarding adopting the metaverse as an educational resource (figure 1). First, a study conducted by Wu et al.[20] found that virtual simulation is an effective educational strategy in undergraduate medical training, with the potential for broader integration and improved student motivation and engagement. Furthermore, according to Campos et al.[21] simulation-based education enhances teaching and learning processes in engineering, science, and management, promoting international cooperation and collaboration between universities. However, comparative studies warn that although immersive virtual reality simulations can increase students' interest and self-efficacy in science, they do not seem to improve their professional aspirations,[22] satisfaction, self-efficacy, or commitment to education.[23]

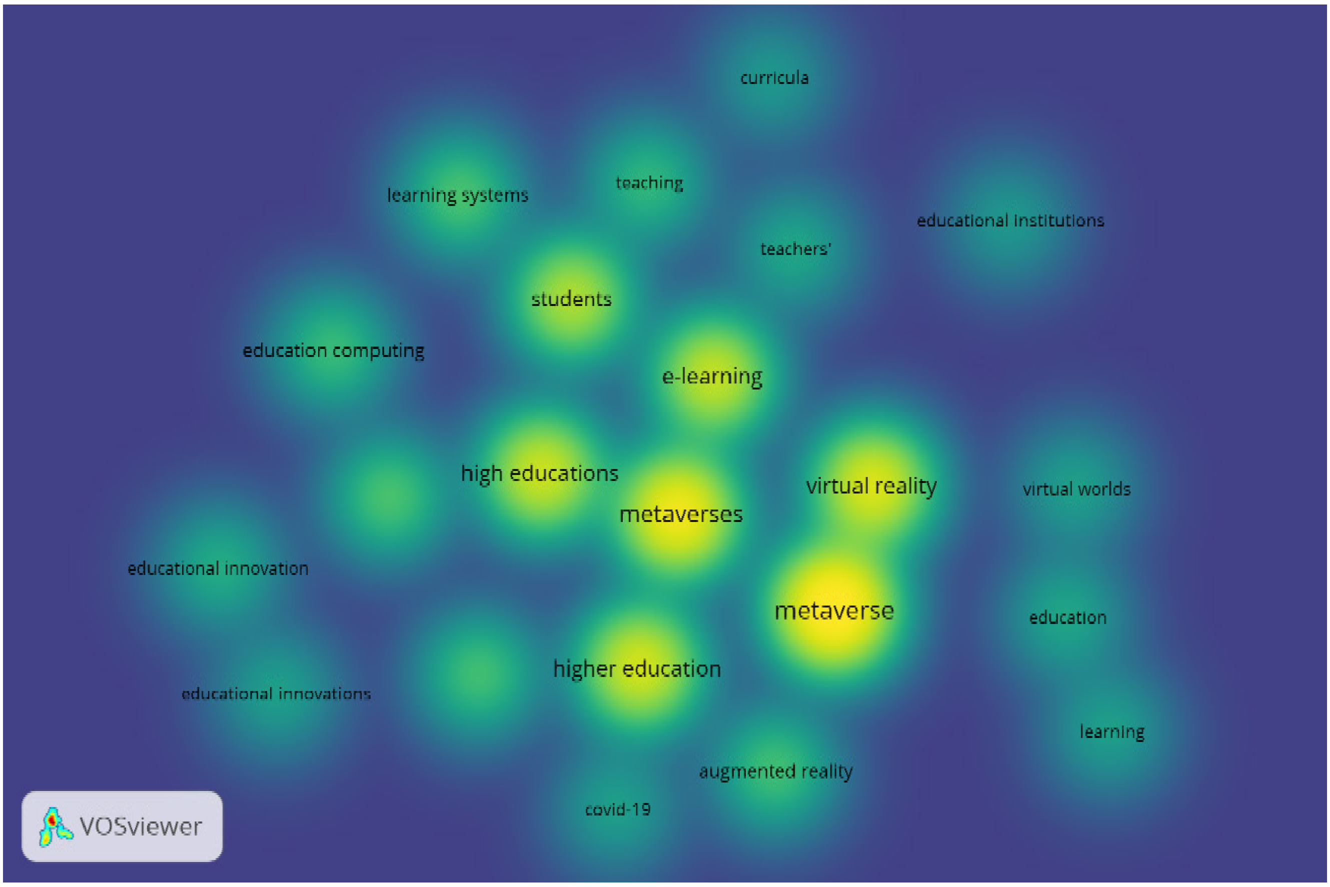

Figure 1. Exploratory analysis of keywords

https://doi.org/10.56294/mr2024.97

A second finding was the growing use of multidisciplinary collaborative environments. In this regard, Li et al.[24] emphasize that Edu-Metaverse platforms, such as AltSpace and Gather, increase participation and the sense of co-presence in collaborative learning activities for university students. Following this line of thinking, Chen et al.[25] report that Edu-Metaverse research reveals that the main applications of this technology in education have ranged from physical education, medical education, health, art appreciation, STEM education, language development, and communication in autism.

Thirdly, artificial intelligence is taking on a crucial role in developing the metaverse by enhancing the immersive experience. Based on this, Yang et al.[26] point out that blockchain and AI can be merged to create an exciting metaverse that integrates real and virtual worlds and fosters collaboration between academia and industry for a fair and rational future. In addition, AI-based methods can improve immersive experiences and human-like intelligence in virtual worlds, enhancing applications in healthcare, manufacturing, education, smart cities, and gaming.[27,28,29,30]

As a fourth trend, inequalities in access to metaverse resources by students and their universities were confirmed. Such is the case in the research by De Matías Batalla et al.[31], who concluded that the metaverse in higher education promotes learning and immersion. Still, teachers lack the knowledge to use it effectively as a teaching resource. In addition, students with unequal access to learning resources, such as Wi-Fi, high-speed 4G mobile internet, and mobile internet slower than 4G, were found to experience different cognitive outcomes after using a metaverse integrated into a learning management system.[32] Wang et al.[33] conclude that a new framework for designing metaverse learning environments, focused on infrastructure, communication, access to technology, equity, and user rights, can guide future research and development in education.

Finally, questions remain about how to measure the metaverse's real impact on employability and academic research. According to Al-Kfairy et al.[34], the metaverse's success will depend on usability, social influence, and interoperability, the latter being a key challenge. Furthermore, applying the metaverse in education offers unique opportunities and challenges, so future research should address ethical issues and potential threats to improving learning and teaching experiences.[5,35,36]

Analysis of pedagogical effectiveness

The data from the keyword co-occurrence analysis (figure 2) reveal that the metaverse (60 occurrences, 212 links) and virtual reality (37 occurrences, 170 links) are at the forefront of topics on educational innovation in practical areas such as engineering education (12, 74) and e-learning (31, 181). In the authors' interpretation and line with Simon et al.[37,38], this suggests that the combination of haptic and visual modalities is the most appropriate for improving student performance and enhancing the user experience in immersive learning environments (learning systems: 13, 76). However, terms such as educational innovation (8, 53) and educational innovations (6, 49) are moderate, suggesting that solid evidence of their cross-cutting impact on non-STEM disciplines is still lacking.[39]

The high frequency of students (27, 155) and teaching (10, 58) indicates, at first glance, the importance of user experience. However, the lack of mention of curricula (5, 30) cannot be overlooked, which inevitably shows that pedagogical integration into curricula is still in its infancy. This, in turn, draws attention to a paradox about the interpretation of the texts by Pellas et al.[40,41]. While the tools are promising, their adoption is not always aligned with robust instructional designs.

Analysis of Implementation Gaps

Disparities are evident when contrasting terms such as "high education" (33, 190) and "higher education" (35, 156), which highlight the relevance of the issue at the institutional level, compared to the scant attention given to "educational institutions" (5, 23). In the opinion of Galdos et al.[42], this reflects a disconnect between innovative rhetoric and the actual capabilities of universities, especially in resource-constrained contexts. Furthermore, the technology gap is widening when comparing metaverse (60) with augmented reality (12, 52), indicating a preference for complex solutions over more accessible technologies. This could exclude institutions without state-of-the-art infrastructure. Furthermore, computer-aided instruction (13, 83) and education computing (11, 71) show that digital accessibility in higher education is uneven, creating a digital divide and higher costs for some students.[43] Finally, the near absence of virtual worlds (6, 29) and the limited discussion of teachers (7, 47) reveal that teacher training in digital accessibility is essential for inclusive education. Still, objective data and assessment tools are needed for objective evaluation.[44]

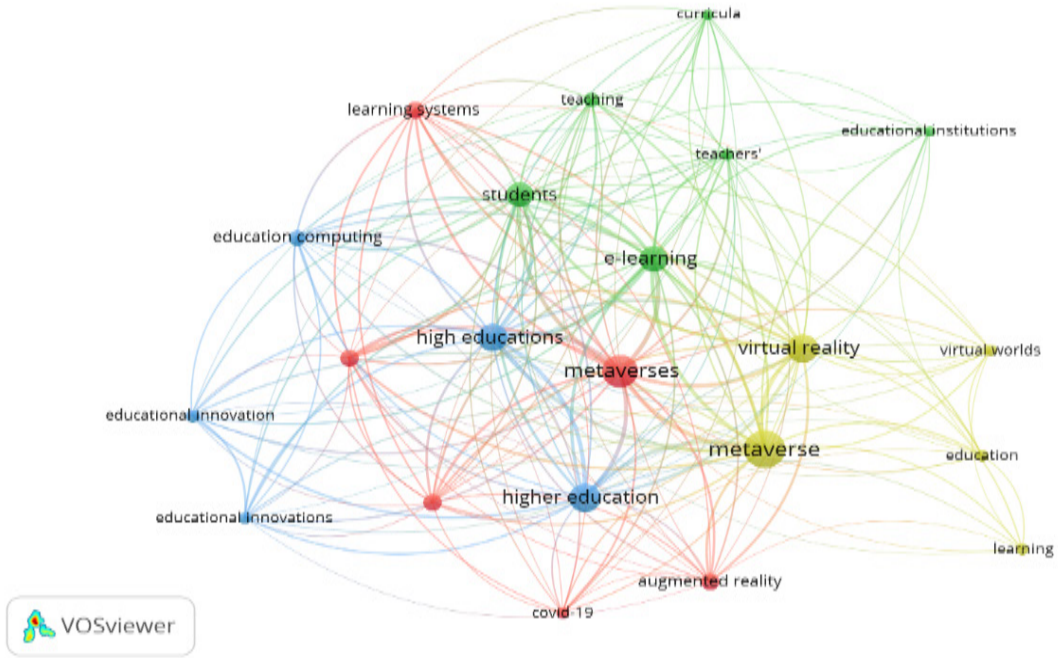

Figure 2. Analysis of keyword co-occurrence

Systematic review

Keyword analysis

Keyword analysis reveals a polarized research ecosystem (figure 3), where the fascination with technology overshadows urgent pedagogical and social debates. Immersive technologies (metaverse: 666, virtual reality: 526, augmented reality: 247) dominate the discourse, with applications concentrated in engineering (engineering education: 85) and medicine (medical education: 38). These areas prioritize practical simulations (e.g., 3D modeling: 7, surgical training: 6), supported by advanced infrastructures (5G mobile communication systems: 34, edge computing: 22). However, the scarce mention of curricula (29) or educational innovation (9) is in line with what Zhang et al.[45] suggest, namely that technological innovation does not always translate into transformative pedagogical designs, but rather into tools attached to traditional models.

The personalization of learning emerges as a key sub-theme linked to artificial intelligence (298) and machine learning (69). Adaptive systems (learning systems: 95, reinforcement learning: 24) promise to optimize educational pathways, but terms such as ethics (11) or data privacy (21) appear only marginally. According to Magee et al.[46], this indicates an ethical gap: while biometric data (avatars: 39, user interaction: 6) is collected to adjust algorithms, few studies question who controls this data or how it affects student autonomy.

In contrast, structural gaps are evident in significant absences. Concepts such as accessibility (7), cost, or equity are conspicuous by their rarity despite the frequent use of higher education (33) and higher education (25). The required infrastructure (blockchain: 108, internet of things: 68) is not discussed about low-income regions, reinforcing an elite narrative. Even in privileged disciplines, there are biases: medical students (6) have low visibility compared to surgical training (6) as if technology were valued more than human experience in clinical training.[47]

The social dimension of the metaverse also shows contradictions. Although social interactions (17) and collaborative learning (9) suggest an interest in group dynamics, terms such as cultural heritages (5) or arts computing (6) are almost anecdotal. This reflects a disciplinary hierarchy: the humanities and social sciences are relegated to the background in favor of STEM, perpetuating the idea that "immersive" is only relevant in technical contexts. Furthermore, the sporadic mention of teachers (32) compared to students (108) reveals a learner-centered vision that ignores the need to train teachers in these technologies (personnel training: 15).

Finally, sustainability stands out for its ambiguity. While digital transformation (43) and emerging technologies (19) are celebrated, sustainability (13) and sustainable development (23) lack depth. There is no dialogue between innovation and its environmental (e.g., the energy required for real-time rendering: 5) or economic (mixed reality costs: 92) impacts. As Bina et al.[48], the literature navigates in a techno-utopian presence without projecting how these tools will scale or who will bear their externalities.

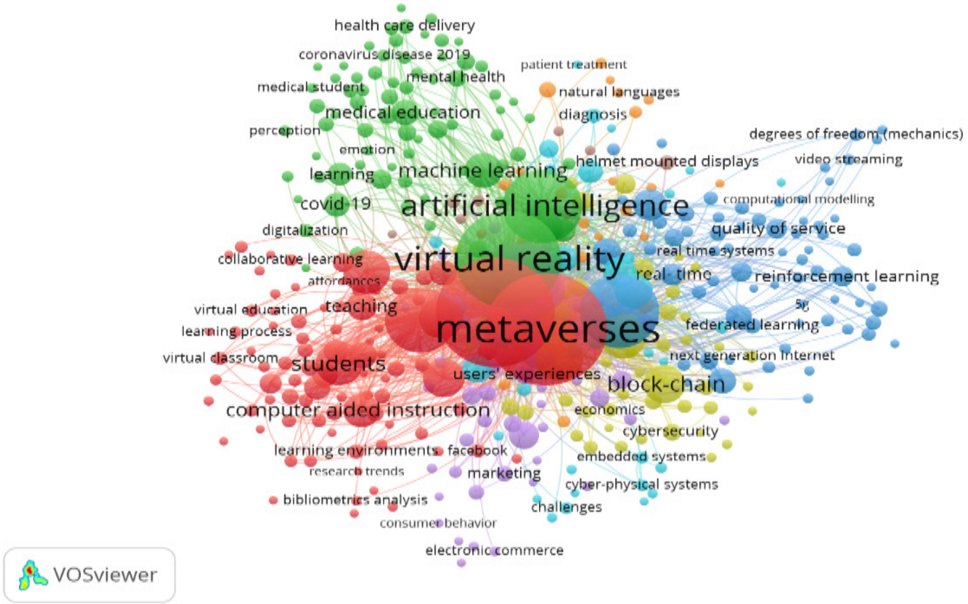

Figure 3. Keyword analysis

Analysis of Pedagogical Effectiveness

The data shows an overwhelming dominance of immersive technologies in the literature, with metaverse (666 occurrences) and virtual reality (526) as pillars. These tools are closely linked to engineering education (85) and medical education (38), suggesting perceived effectiveness in practical disciplines where simulation is critical, such as virtual surgery or 3D prototyping. However, terms such as immersive learning (21) and learning systems (95) focus on structured systems. At the same time, educational innovation (9) and curricula (29) have a low presence, indicating that pedagogical integration in instructional designs remains superficial. The high frequency of students (108) contrasts with the moderate mention of teachers (32), pointing to an asymmetry noted by Hab et al.[49]: the student experience is prioritized, but the role of teachers in adapting these technologies is underestimated. In addition, artificial intelligence (298) and machine learning (69) highlight the personalization of learning, although the scarcity of terms such as ethics (11) or data privacy (21) raises questions about how algorithmic biases or privacy are managed in these environments.

Implementation Gap Analysis

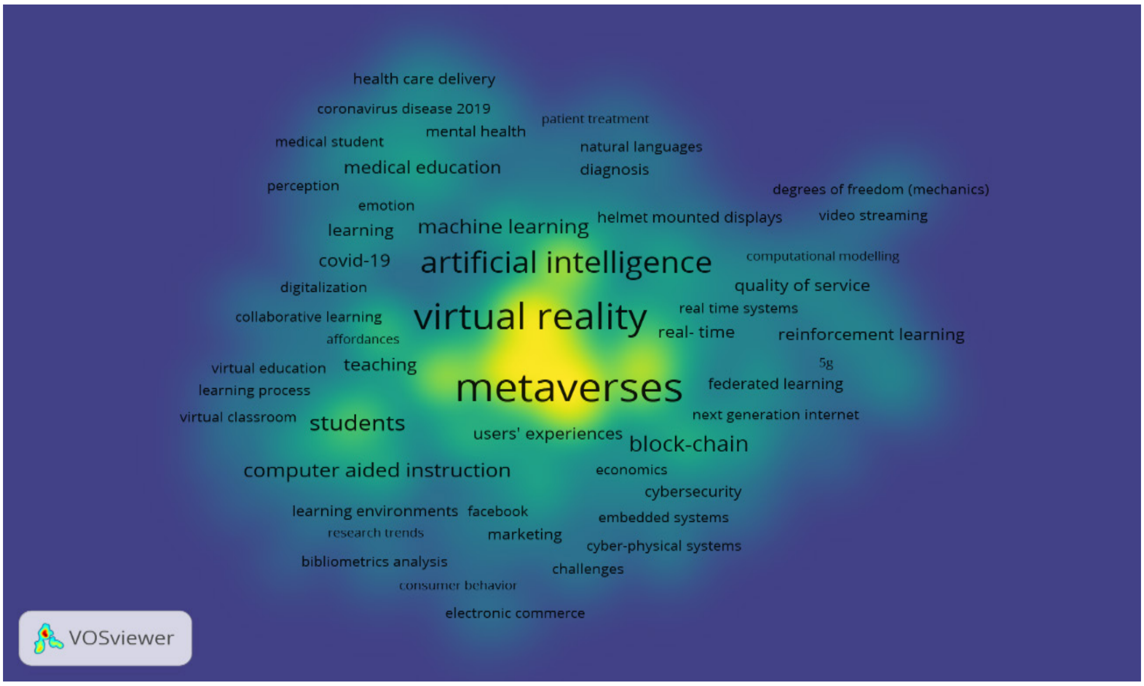

Figure 4. Keyword density analysis

Technological disparities are evident in the density analysis shown in figure 4. While augmented reality (247) and extended reality (135) have high visibility, concepts such as accessibility (7) and educational institutions (10) are marginal. This reflects a gap between innovative rhetoric and actual institutional capacities, particularly relevant in regions with limited infrastructure. The mention of 5G mobile communication systems (34) and edge computing (22) underscores the dependence on advanced networks, excluding institutions without access to these technologies.

Another contrast emerges between professional disciplines, such as medical education (38) and engineering education (85), which attract attention, while arts computing (6) and social sciences computing (6) are almost anecdotal. This suggests that the metaverse is being adopted unevenly, favoring areas with funding and clear technical applications. In addition, terms such as digital transformation (43) and blockchain (108) reveal a fascination with complex solutions, but cost or budget are absent, omitting critical discussions about economic sustainability.

Finally, the scarcity of sustainability (13) exposes a gap in assessing long-term impacts. Although systematic reviews (10) and literature reviews (6) appear, technical studies on specific tools predominate, with little exploration of how these technologies affect inclusion or replicate existing hierarchies. The gap is not only technological but also epistemic: innovation occurs in how to teach, but not always in teaching for whom or with what social consequences.[50]

Qualitative analysis assisted by Atlas.ti

The analysis of the research selected for this review allowed the authors to identify relevant analysis points across the three defined categories. The information was processed in Atlas.Ti, where the gaps reported in the literature consulted were contextualized.

1. Impact on learning

Studies agree that environments such as virtual reality (526 occurrences) and the metaverse (666) increase student motivation, especially in practical simulations (surgical training: 6, 3D modeling: 7), according to a study published by Jiang et al.[51] In medical education (38), virtual reality environments have increased motivation, perceived competence, usefulness, and user experience compared to video and text-based learning environments.[52] The acquisition of technical skills was associated with engineering education (85) and learning systems (95). In this regard, Amirbekova et al.[53] point out that immersive technologies have an advantage over traditional programs regarding motivation and skills development.

2. Technical and ethical challenges

Accessibility emerged as a recurring problem (accessibility: 7) since, according to Tang et al.[54], the metaverse requires ubiquitous connectivity, ultra-low latency, ultra-low capacity, and strict security in wireless systems and advanced infrastructures (5G mobile communication systems: 34, edge computing: 22) to achieve seamless connectivity and immersive experiences. In this sense, the metaverse presents significant advances in digital accessibility, but it needs to incorporate assistive technologies and ensure interoperability between different virtual environments.[55]

3. Institutional sustainability

Teacher training (teachers: 32) also showed deficiencies since, according to Mogier et al.[56], the metaverse environment has excellent potential for teacher training. Still, its practical use requires careful consideration of technical, pedagogical, and organizational factors. In addition, environmental sustainability was marginal (sustainability: 13), even though blockchain interoperability (108) and open standards, according to Neulinger et al.[57] can promote a sustainable metaverse ecosystem, promoting the UN Sustainable Development Goals.

CONCLUSIONS

The conclusions of this study paint a dual picture of the potential and limitations of the metaverse in higher education. On the one hand, it confirms that immersive environments—such as virtual reality, augmented reality, and collaborative platforms—have proven effective in practical contexts and STEM disciplines. However, these advances depend on intentional pedagogical designs: when tools complement a well-structured curriculum, they enhance motivation and knowledge retention. In addition, the research presented in this text exposes little-explored ethical and operational dilemmas. One worrying aspect in this regard is that mass collecting biometric data to adjust educational algorithms raises risks of surveillance and bias. Equally important, the dependence on costly infrastructure (5G, blockchain) unequivocally calls into question these models' environmental and economic sustainability. In addition, several pilot experiences show short-term benefits, yet doubts remain about scalability and its impact on employability or cognitive development from a long-term analysis. An essential aspect that the authors highlight in this section is that the metaverse is not a universal solution but a set of tools whose value depends on how, where, and for whom they are implemented. In this regard, future research should delve deeper into hybrid models that balance innovation with equity. It is also imperative to begin creating ethical frameworks that regulate the use of data and algorithms in educational environments. Institutions, for their part, require clear policies, from investments in inclusive infrastructure to teacher training programs that prevent the digital divide. Only then can the promise of higher education that is not only immersive but also fair and transformative be fulfilled.

BIBLIOGRAPHIC REFERENCES

1. Shi C, Park J. A systematic review of the Metaverse in formal education. Journal of Applied Research in Higher Education. 2024. https://doi.org/10.1108/jarhe-04-2024-0162

2. Waquar A S, Kareem S, Yasmeen N, Hussain S. From traditional to virtual classrooms: unravelling themes and shaping the future of metaverse education. Interactive Technology and Smart Education. 2024. https://doi.org/10.1108/itse-02-2024-0032

3. Nedeva V, Ducheva Z. Pedagogical approaches for Metaverse-based engineering education. Proceedings of the International Conference on Virtual Learning - VIRTUAL LEARNING - VIRTUAL REALITY (19th edition). 2024. https://doi.org/10.58503/icvl-v19y202412

4. Sá M, Serpa S. Metaverse as a Learning Environment: Some Considerations. Sustainability. 2023;15(3):2186. https://doi.org/10.3390/su15032186

5. Kaddoura S, Husseiny F. The rising trend of Metaverse in education: challenges, opportunities, and ethical considerations. PeerJ Computer Science. 2023;9. https://doi.org/10.7717/peerj-cs.1252

6. Alhonkoski M, Salminen L, Pakarinen A, Veermans M. 3D technology to support teaching and learning in health care education – A scoping review. International Journal of Educational Research. 2021;105:101699. https://doi.org/10.1016/j.ijer.2020.101699

7. Mcnaughtan J, Litsey R, Morelock N. Fabricating concepts: using custom 3D models to teach abstract concepts. Journal of Applied Research in Higher Education. 2020. https://doi.org/10.1108/jarhe-06-2020-0172

8. Kye B, Han N, Kim E, Park Y, Jo S. Educational applications of metaverse: possibilities and limitations. Journal of Educational Evaluation for Health Professions. 2021;18. https://doi.org/10.3352/jeehp.2021.18.32

9. Fan S, Yecies B, Zhou Z, Shen J. Challenges and Opportunities for the Web 3.0 Metaverse Turn in Education. IEEE Transactions on Learning Technologies. 2024;17:1989-2004. https://doi.org/10.1109/TLT.2024.3385505

10. Bracho-Fuenmayor PL. Ética y moral en la Educación Superior. Una revisión bibliométrica. Revista De Ciencias Sociales. 2024;30(3):553-568. https://doi.org/10.31876/rcs.v30i3.42695

11. Schott C, Marshall S. Virtual Reality and Situated Experiential Education A conceptualization and exploratory trial. Journal Contribution. 2020. https://doi.org/10.26686/wgtn.12744659.v1

12. Camilleri M. Metaverse applications in education: a systematic review and a cost-benefit analysis. Interactive Technology and Smart Education. 2023;21:245-269. https://doi.org/10.2139/ssrn.4490787

13. Salloum S, Marzouqi A, Alderbashi K, Shwedeh F, Aburayya A, Saidat M, et al. Sustainability Model for the Continuous Intention to Use Metaverse Technology in Higher Education: A Case Study from Oman. Sustainability. 2023;15(6):5257. https://doi.org/10.3390/su15065257

14. Stern C, Lizarondo L, Carrier J, Godfrey C, Rieger K, Salmond S, et al. Methodological guidance for the conduct of mixed methods systematic reviews. JBI Evidence Synthesis. 2020;18:2108-2118. https://doi.org/10.11124/JBISRIR-D-19-00169

15. Arruda H, Silva É, Lessa M, Proença D, Bartholo R. VOSviewer and Bibliometrix. Journal of the Medical Library Association: JMLA. 2022;110:392-395. https://doi.org/10.5195/jmla.2022.1434

16. Orduña-Malea E, Costas R. Link-based approach to study scientific software usage: the case of VOSviewer. Scientometrics. 2021;126:8153-8186. https://doi.org/10.1007/s11192-021-04082-y

17. Shaffril H, Samsuddin S, Samah A. The ABC of systematic literature review: the basic methodological guidance for beginners. Quality & Quantity. 2020;55:1319-1346. https://doi.org/10.1007/s11135-020-01059-6

18. Zhang H, Hejblum B, Weber G, Palmer N, Churchill S, Szolovits P, et al. ATLAS: An automated association test using probabilistically linked health records with application to genetic studies. Journal of the American Medical Informatics Association: JAMIA. 2021. https://doi.org/10.1101/2021.05.02.21256490

19. Bracho-Fuenmayor PL. Estado fallido. Un análisis desde la perspectiva de Rotberg. Encuentros. Revista De Ciencias Humanas, Teoría Social Y Pensamiento Crítico. 2025;(23):228–244. https://doi.org/10.5281/zenodo.14268859

20. Wu Q, Wang Y, Lu L, Chen Y, Long H, Wang J. Virtual Simulation in Undergraduate Medical Education: A Scoping Review of Recent Practice. Frontiers in Medicine. 2022;9. https://doi.org/10.3389/fmed.2022.855403

21. Campos N, Nogal M, Cáliz C, Juan A. Simulation-based education involving online and on-campus models in different European universities. International Journal of Educational Technology in Higher Education. 2020;17. https://doi.org/10.1186/s41239-020-0181-y

22. Makransky G, Petersen G, Klingenberg S. Can an immersive virtual reality simulation increase students' interest and career aspirations in science? British Journal of Educational Technology. 2020;51:2079-2097. https://doi.org/10.31234/osf.io/2qrs3

23. Ryan G, Callaghan S, Rafferty A, Higgins M, Mangina E, Mcauliffe F. Learning Outcomes of Immersive Technologies in Health Care Student Education: Systematic Review of the Literature. Journal of Medical Internet Research. 2021;24. https://doi.org/10.2196/30082

24. Li C, Jiang Y, Ng P, Dai Y, Cheung F, Chan H, et al. Collaborative Learning in the Edu-Metaverse Era: An Empirical Study on the Enabling Technologies. IEEE Transactions on Learning Technologies. 2024;17:1107-1119. https://doi.org/10.1109/TLT.2024.3352743

25. Chen X, Zou D, Xie H, Wang F. Metaverse in Education: Contributors, Cooperations, and Research Themes. IEEE Transactions on Learning Technologies. 2023;16:1111-1129. https://doi.org/10.1109/TLT.2023.3277952

26. Yang Q, Zhao Y, Huang H, Xiong Z, Kang J, Zheng Z. Fusing Blockchain and AI With Metaverse: A Survey. IEEE Open Journal of the Computer Society. 2022;3:122-136. https://doi.org/10.1109/ojcs.2022.3188249

27. Huynh-The T, Pham V, Pham X, Nguyen T, Han Z, Kim D. Artificial Intelligence for the Metaverse: A Survey. Engineering Applications of Artificial Intelligence. 2022;117:105581. https://doi.org/10.1016/j.engappai.2022.105581

28. Lv Z. Generative Artificial Intelligence in the Metaverse Era. Cognitive Robotics. 2023. https://doi.org/10.1016/j.cogr.2023.06.001

29. Jauhiainen J. The Metaverse: innovations and generative AI. International Journal of Innovation Studies. 2024. https://doi.org/10.1016/j.ijis.2024.04.004

30. Marabelli M, Lirio P. AI and the metaverse in the workplace: DEI opportunities and challenges. Personnel Review. 2024. https://doi.org/10.1108/pr-04-2023-0300

31. De Matías Batalla D, Pedrero A. Metaverse to foster learning in higher education. Metaverse. 2023;4(1). https://doi.org/10.54517/m.v4i1.2184

32. Pigultong M. Cognitive Impacts of Using a Metaverse embedded on Learning Management System for Students with Unequal Access to Learning Resources. 2022 10th International Conference on Information and Education Technology (ICIET). 2022:27-31. https://doi.org/10.1109/ICIET55102.2022.9779045

33. Wang M, Yu H, Bell Z, Chu X. Constructing an Edu-Metaverse Ecosystem: A New and Innovative Framework. IEEE Transactions on Learning Technologies. 2022;15:685-696. https://doi.org/10.1109/TLT.2022.3210828

34. Al-Kfairy M, Alomari A, Al-Bashayreh M, Alfandi O, Tubishat M. Unveiling the Metaverse: A survey of user perceptions and the impact of usability, social influence and interoperability. Heliyon. 2024;10. https://doi.org/10.1016/j.heliyon.2024.e31413

35. Barrera K, Shah D. Marketing in the Metaverse: Conceptual understanding, framework, and research agenda. Journal of Business Research. 2023. https://doi.org/10.1016/j.jbusres.2022.113420

36. Dwivedi Y, Hughes L, Baabdullah A, Ribeiro-Navarrete S, Giannakis M, Al-Debei M, et al. Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. International Journal of Information Management. 2022;66:102542. https://doi.org/10.1016/j.ijinfomgt.2022.102542

37. Simon C, Hacene M, Lebrun F, Otmane S, Chellali A. Impact of Multimodal Instructions for Tool Manipulation Skills on Performance and User Experience in an Immersive Environment. 2024 IEEE Conference Virtual Reality and 3D User Interfaces (VR). 2024:670-680. https://doi.org/10.1109/VR58804.2024.00087

38. Simon C, Hacene M, Otmane S, Chellali A. Study of communication modalities to support teaching tool manipulation skills in a shared immersive environment. Computers & Graphics. 2023;117:31-41. https://doi.org/10.1016/j.cag.2023.09.011

39. Uddin M, Imam T, Mozumdar M. Research interdisciplinarity: STEM versus non-STEM. Scientometrics. 2021. https://doi.org/10.1007/s11192-020-03750-9

40. Pellas N, Mystakidis S, Kazanidis I. Immersive Virtual Reality in K-12 and Higher Education: A systematic review of the last decade scientific literature. Virtual Reality. 2021;25:835-861. https://doi.org/10.1007/s10055-020-00489-9

41. Pellas N, Dengel A, Christopoulos A. A Scoping Review of Immersive Virtual Reality in STEM Education. IEEE Transactions on Learning Technologies. 2020;13:748-761. https://doi.org/10.1109/TLT.2020.3019405

42. Galdos M, Haneef S. The voluntary underdevelopment paradox: revisiting Freeman's ideas on indigenous capabilities for innovation in the global south. Innovation and Development. 2021;12:33-41. https://doi.org/10.1080/2157930X.2021.1930889

43. Najab A, Amrani O. Digital Accessibility and Distance Higher Education in the Context of COVID-19. Policies and Procedures for the Implementation of Safe and Healthy Educational Environments. 2022. https://doi.org/10.4018/978-1-7998-9297-7.ch006

44. Bong W, Chen W. Increasing faculty's competence in digital accessibility for inclusive education: a systematic literature review. International Journal of Inclusive Education. 2021;28:197-213. https://doi.org/10.1080/13603116.2021.1937344

45. Zhang A, Olelewe C, Orji C, Ibezim N, Sunday N, Obichukwu P, et al. Effects of Innovative and Traditional Teaching Methods on Technical College Students' Achievement in Computer Craft Practices. SAGE Open. 2020;10. https://doi.org/10.1177/2158244020982986

46. Magee P, Ienca M, Farahany N. Beyond neural data: Cognitive biometrics and mental privacy. Neuron. 2024;112:3017-3028. https://doi.org/10.1016/j.neuron.2024.09.004

47. Gonzalez-Moreno M, Monfort-Vinuesa C, Piñas-Mesa A, Rincon E. Digital Technologies to Provide Humanization in the Education of the Healthcare Workforce: A Systematic Review. Technologies. 2023. https://doi.org/10.3390/technologies11040088

48. Bina O, Inch A, Pereira L. Beyond techno-utopia and its discontents: On the role of utopianism and speculative fiction in shaping alternatives to the smart city imaginary. Futures. 2020;115:102475. https://doi.org/10.1016/j.futures.2019.102475

49. Hab N, Kruty K, Tolchieva H, Pushkarova T. Modernization of future teachers' professional training: on the role of immersive technologies. Futurity Education. 2022. https://doi.org/10.57125/fed/2022.10.11.22

50. Dogomeo A. Digital Technology to Promote Inclusion and Diversity in Higher Education: A Qualitative Insight. Asia-pacific Journal of Convergent Research Interchange. 2024. https://doi.org/10.47116/apjcri.2024.10.34

51. Jiang J, Fryer L. The effect of virtual reality learning on students' motivation: A scoping review. Journal of Computer Assisted Learning. 2023;40:360-373. https://doi.org/10.1111/jcal.12885

52. Sattar M, Palaniappan S, Lokman A, Shah N, Khalid U, Hasan R. Motivating Medical Students Using Virtual Reality Based Education. International Journal of Emerging Technologies in Learning. 2020;15:160-174. https://doi.org/10.3991/ijet.v15i02.11394

53. Amirbekova E, Shertayeva N, Mironova E. Teaching chemistry in the metaverse: the effectiveness of using virtual and augmented reality for visualization. Frontiers in Education. 2024. https://doi.org/10.3389/feduc.2023.1184768

54. Tang F, Chen X, Zhao M, Kato N. The Roadmap of Communication and Networking in 6G for the Metaverse. IEEE Wireless Communications. 2023;30:72-81. https://doi.org/10.1109/MWC.019.2100721

55. Othman A, Chemnad K, Hassanien A, Tlili A, Zhang C, Al-Thani D, et al. Accessible Metaverse: A Theoretical Framework for Accessibility and Inclusion in the Metaverse. Multimodal Technologies and Interaction. 2024;8:21. https://doi.org/10.3390/mti8030021

56. Mogier G, Khayat G, Elkordy M, Hanafy Y. A Proposed Metaverse Framework Implementing Gamification for Training Teaching Staff. 2023 IEEE Afro-Mediterranean Conference on Artificial Intelligence (AMCAI). 2023:1-7. https://doi.org/10.1109/AMCAI59331.2023.10431501

57. Neulinger A, Sparer L, Dorner V. The Role of Blockchain Interoperability for a Sustainable Metaverse: A Research Agenda. 2024 6th International Conference on Blockchain Computing and Applications (BCCA). 2024:48-56. https://doi.org/10.1109/BCCA62388.2024.10844416

FINANCING

No financing.

CONFLICT OF INTEREST

None.

AUTHORSHIP CONTRIBUTION

Conceptualization: Víctor Hugo González Torres, Pedro Luis Bracho-Fuenmayor, Elisabeth Viviana Lucero Baldevenites, Marco Vinicio Carrillo Guerrero, Roberto David Santander Erazo.

Data curation: Víctor Hugo González Torres, Elisabeth Viviana Lucero Baldevenites, Marco Vinicio Carrillo Guerrero.

Formal analysis: Víctor Hugo González Torres, Elisabeth Viviana Lucero Baldevenites, Marco Vinicio Carrillo Guerrero

Research: Víctor Hugo González Torres, Pedro Luis Bracho-Fuenmayor, Elisabeth Viviana Lucero Baldevenites.

Methodology: Víctor Hugo González Torres, Pedro Luis Bracho-Fuenmayor, Elisabeth Viviana Lucero Baldevenites.

Project management: Víctor Hugo González Torres, Pedro Luis Bracho-Fuenmayor.

Resources: Víctor Hugo González Torres, Pedro Luis Bracho-Fuenmayor, Elisabeth Viviana Lucero Baldevenites, Marco Vinicio Carrillo Guerrero, Roberto David Santander Erazo.

Software: Víctor Hugo González Torres, Pedro Luis Bracho-Fuenmayor, Elisabeth Viviana Lucero Baldevenites.

Supervision: Víctor Hugo González Torres.

Validation: Elisabeth Viviana Lucero Baldevenites, Marco Vinicio Carrillo Guerrero, Roberto David Santander Erazo.

Display: Elisabeth Viviana Lucero Baldevenites, Marco Vinicio Carrillo Guerrero, Roberto David Santander Erazo.

Drafting - original draft: Elisabeth Viviana Lucero Baldevenites, Marco Vinicio Carrillo Guerrero, Roberto David Santander Erazo.

Writing - proofreading and editing: Víctor Hugo González Torres, Pedro Luis Bracho-Fuenmayor, Elisabeth Viviana Lucero Baldevenites, Marco Vinicio Carrillo Guerrero, Roberto David Santander Erazo.