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Metaverse Applications in Education 4.0: A Decade of Systematic Literature Review

Khalid Ghoulam[1]*, Belaid Bouikhalene[2]
[1]University of Sultan Moulay Slimane, Beni Mellal, Morocco
[2]Director of the Digitalization Division, University of Sultan Moulay Slimane, Beni Mellal, Morocco
*Corresponding Author: khalid.ghoulam@gmail.com

ABSTRACT
The advent of Education 4.0, which aligns with the fourth industrial revolution, has been significantly influenced by advancements in digital technologies. Central to this evolution is the metaverse, a virtual shared space that merges augmented reality, virtual reality, and physical reality. This paper delves into the metaverse's applications within Education 4.0, highlighting its potential to revolutionize learning experiences, enhance collaboration, and improve access to quality education. By reviewing current literature and case studies, we identify the primary benefits, such as increased engagement, personalized learning, and broader accessibility. Additionally, we address the challenges associated with metaverse integration, including technical limitations, privacy concerns, and the need for new pedagogical approaches. Through a mixed-methods research approach, combining qualitative and quantitative data along with expert interviews, this paper provides a comprehensive overview of the metaverse's role in future education. The findings suggest that while significant hurdles remain, the metaverse offers a promising avenue for transforming educational practices to meet the demands of the digital age, ultimately fostering more dynamic, inclusive, and effective learning environments. Future research should focus on evaluating long-term impacts and developing standards for metaverse applications in education.

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INTRODUCTION

The landscape of education is undergoing a profound transformation driven by the advent of Education 4.0, a paradigm that aligns educational practices with the technological advancements of the fourth industrial revolution. This shift emphasizes the integration of cutting-edge technologies such as artificial intelligence (AI), the Internet of Things (IoT), big data, and cloud computing to create more personalized, adaptive, and student-centered learning experiences. Education 4.0 aims to equip students with the skills and knowledge necessary to thrive in a rapidly evolving digital world, emphasizing competencies like critical thinking, creativity, collaboration, and digital literacy.

One of the most promising developments within this new educational framework is the concept of the metaverse. Coined by Neal Stephenson in his 1992 novel "Snow Crash," the metaverse refers to a collective virtual shared space, created by the convergence of virtually enhanced physical reality and persistent virtual reality. It is a fully immersive digital environment where users can interact with each other and with digital

content in real-time through avatars. The metaverse integrates various technologies, including augmented reality (AR), virtual reality (VR), and blockchain, to provide rich, interactive experiences that can mimic real-world interactions and environments.

The purpose of this paper is to explore how the metaverse can be effectively leveraged within the framework of Education 4.0 to create more engaging, inclusive, and effective learning environments. By examining current applications, potential benefits, and associated challenges, this study seeks to provide a comprehensive overview of the metaverse's role in the future of education. Through a detailed review of current literature and case studies, coupled with insights from interviews with educators and technology experts, this paper aims to identify the transformative potential of metaverse technologies in enhancing educational experiences.

LITERATURE REVIEW

The Evolution of Education 4.0

Education 4.0 represents a significant transformation in educational practices, driven by the integration of advanced technologies and the need to equip students with skills relevant to the 21st century. This evolution is characterized by several key developments:

a. Technological Advancements: The integration of technologies such as AI, IoT, big data, cloud computing, and blockchain has revolutionized educational environments. These technologies facilitate the creation of smart learning ecosystems where data-driven insights enable personalized learning experiences (Hussin, 2018). For instance, AI can provide real-time feedback and adapt instructional methods to individual student needs, enhancing learning outcomes (Luckin et al., 2016).
b. Shift in Educational Focus: Traditional education models focused on rote memorization and standardized testing are being replaced by approaches that prioritize critical thinking, creativity, problem-solving, collaboration, and digital literacy (Redecker, 2017). This shift aligns educational objectives with the requirements of a knowledge-based economy, preparing students for dynamic and complex job markets.
c. Personalized Learning: Personalized learning is a cornerstone of Education 4.0, where educational content and pacing are tailored to individual learners. AI and machine learning algorithms analyze vast amounts of student data to customize learning pathways, ensuring that each student progresses according to their own pace and learning style (Hwang, 2020).
d. Blended Learning Environments: The combination of physical and virtual learning environments defines the blended learning model. This approach supports flexible and accessible education, allowing students to engage with learning materials anytime and anywhere. Blended learning enhances student engagement and accommodates diverse learning preferences (Graham, 2013).
e. Lifelong Learning: Education 4.0 emphasizes the importance of lifelong learning to keep pace with technological advancements and changing job markets. Educational institutions are offering a range of courses and programs designed to support continuous professional development and upskilling (Koper, 2014).
f. Collaborative Learning: Digital platforms facilitate collaborative learning, enabling students to work together on projects, share knowledge, and solve problems collectively. This mirrors the collaborative nature of modern workplaces and fosters essential teamwork skills (Dillenbourg, 1999).
g. Assessment and Feedback: Continuous, formative assessments are becoming integral to Education 4.0. Technologies like learning analytics provide real-time insights into student performance, allowing educators to adjust their teaching strategies to better meet students' needs (Siemens, 2013).

The Concept of the Metaverse

The metaverse is a persistent, shared, virtual space that represents the convergence of augmented reality (AR), virtual reality (VR), and blockchain technologies to create fully immersive digital environments. It

is characterized by its ability to host a continuous, collective virtual experience, which persists regardless of whether individual users are logged in or not. This persistent nature distinguishes the metaverse from traditional virtual environments that are session-based and temporary.

In the metaverse, users interact with each other and with digital content through customizable avatars. These avatars serve as digital representations of users, enabling them to engage in a variety of activities that mimic real-world interactions and experiences. This includes attending virtual events, participating in simulations, collaborating on projects, and socializing in virtual spaces. The avatars can move freely within these spaces, perform tasks, and communicate, making the interactions within the metaverse rich and multifaceted (Mystakidis, 2022).

Augmented reality (AR) enhances physical environments by overlaying digital information and objects onto the real world, visible through devices such as smartphones, tablets, or AR glasses. Virtual reality (VR), on the other hand, immerses users entirely in a computer-generated environment, experienced through VR headsets. The integration of blockchain technology adds a layer of security and trust, enabling the creation of decentralized, transparent systems for identity verification, asset ownership, and transaction management within the metaverse.

The potential of the metaverse to revolutionize various sectors, including education, is increasingly recognized. In education, the metaverse can create dynamic, interactive learning environments that go beyond the capabilities of traditional classrooms (Hong Lin, et al., 2022). For instance, it can facilitate virtual classrooms where students and teachers interact in 3D spaces, enhancing the sense of presence and engagement. Furthermore, the metaverse can host simulation-based learning experiences, allowing students to practice and develop skills in a risk-free, controlled environment (Khaldi et al., 2023).

These environments are not limited by physical constraints, thus offering unprecedented opportunities for collaborative projects among students from different geographical locations. This global collaboration fosters a diverse learning experience and prepares students for the interconnected world of the future. The immersive nature of the metaverse can also enhance experiential learning, where students engage with content in a hands-on manner, deepening their understanding and retention of information.

Moreover, the metaverse supports the development of social and emotional skills by providing platforms for social interaction and teamwork in virtual settings (Bailenson J., 2018). This can be particularly beneficial in areas such as language learning, where students can practice speaking and listening in realistic scenarios. The ability to replicate cultural environments also aids in cultural studies, offering students immersive experiences that traditional methods cannot match.

As the technology continues to evolve, the metaverse is poised to become a central component of Education 4.0, driving innovation and transforming how education is delivered and experienced.

The Integration of the Metaverse in Education 4.0

The Metaverse has become a significant topic in education, largely fueled by Facebook's rebranding to Meta. This shift emphasizes creating a comprehensive virtual ecosystem designed for socializing, collaboration, and immersive learning experiences. Meta aims to integrate technologies like augmented reality (AR) and virtual reality (VR) into everyday interactions, offering new ways for users to connect and learn within these digital environments (Andrew Bosworth, 2022; Meta, 2022).

The Metaverse represents the evolution from an internet of hyperlinks to virtual reality environments, merging physical and digital spaces for interaction and information exchange (Collins, 2008; Hackl, 2021). In Education 4.0, the concept of the Metaverse extends beyond virtual reality glasses and avatars to meet the needs of Industry 4.0 by promoting cooperation, knowledge management, and complex thinking. This broader view encompasses various advanced technologies, such as artificial intelligence, augmented reality, and data analytics, aiming to create personalized and collaborative learning experiences. These technologies are used to foster essential skills required for the future workforce, enhancing students' abilities to think

critically and solve complex problems (George-Reyes et al., 2023; González-Pérez LI and Ramírez-Montoya, 2022; Patiño et al., 2023).

The overlap between the Metaverse and Education 4.0 indeed fosters innovative digital pedagogy and hybrid learning experiences. This integration leverages various advanced technologies to create immersive, interactive educational environments that blend virtual and real-world elements. Such environments support active learning, gamification, and the development of digital competencies crucial for the modern workforce (Zhang X et al., 2022; Said, G.R.E., 2023).

Figure 1 illustrates the technologies and tools of Metaverse in education 4.0 implication.

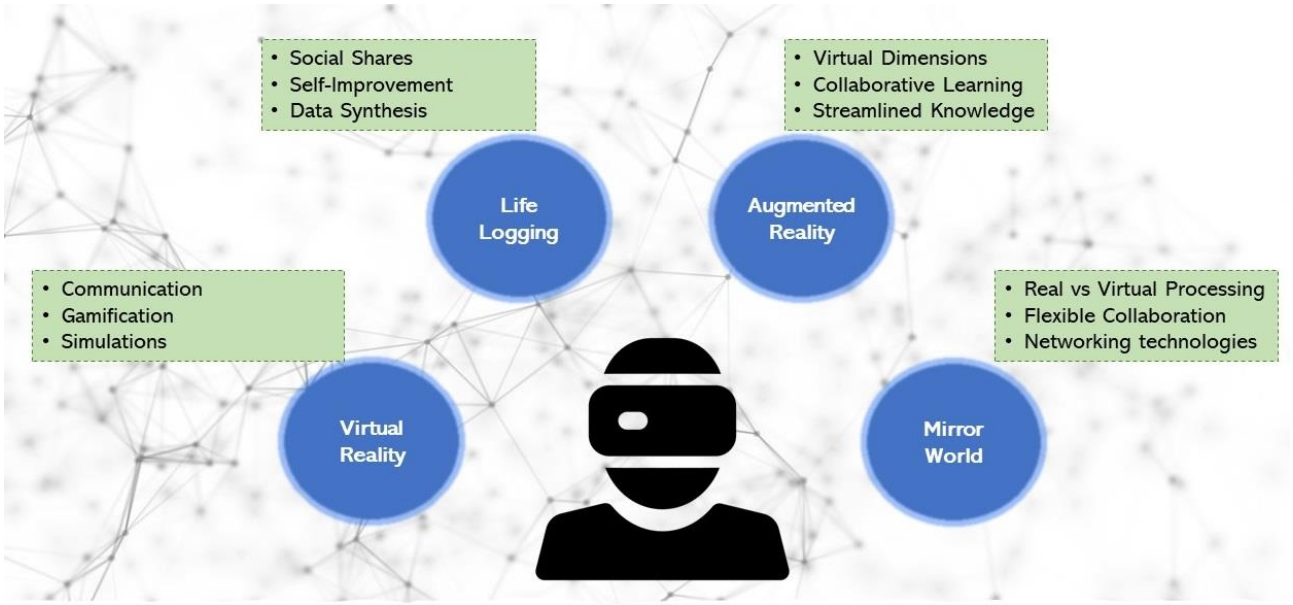

Figure 1. Elements of Metaverse in Education 4.0

METHODOLOGY

This study conducts a systematic literature review to investigate the use of the Metaverse in education 4.0. A systematic literature review is a methodical, transparent, and reproducible process for identifying, evaluating, and synthesizing existing research. This research adhered to the PRISMA 2020 checklist (Page et al., 2020), which provides guidelines for systematically compiling, reviewing, and analyzing studies in international literature.

Data Sources

Relevant databases in the field of education were examined to explore the Metaverse. Existing literature was reviewed to determine appropriate keywords. The primary keyword "Metaverse" was combined with "education 4.0" and "3D learning" for the search.

The databases Web of Science (WoS), Scopus, Google Scholar, known for their high impact factors, were searched using these keywords. Given the increasing use of the Metaverse in education, the study focused on the last decade. Full texts of the retrieved studies were assessed and included in the review based on predefined inclusion and exclusion criteria, as well as their quality and relevance.

To search for scientific literature, we used "metaverse" (MV) as a keyword, with "Education 4.0" (E4.0) and "3D Learning" (3DL) as contextual terms. These terms were also searched in English to ensure their inclusion in the databases. The first step in this stage involved searching for the selected keywords, as listed in Table 1.

Table 1. Descriptors for the search in databases

Database	Descriptor
Scopus	("Metaverse") AND ("Education 4.0") AND ("3D learning").
Web of Science	("Metaverse") AND ("Education 4.0") AND ("3D learning").
Google Scholar	("Metaverse") AND ("Education 4.0") AND ("3D learning")

The search yielded 775 articles. These documents were then filtered using the following inclusion and exclusion criteria.

Table 2. Databases Inclusion and Exclusion criteria

Database	Descriptor
Research articles, scientific dissemination papers, systematic reviews of literature, methodological papers, and meta-analyses.	Editorials, errata, and documents not closely related to the study subject.
Publications with titles, abstracts, or keywords containing the terms MV, E4.0, or 3DL.	Publications without a title, abstract, or keywords.

To meet the quality criteria, articles needed to be published between 2014 and 2024, have full-text access, be written in English, and focus on the Metaverse with topics related to any components of Education 4.0.

Analysis method

The PRISMA method (Page et al., 2020) was chosen for the analysis. This method involves identifying and selecting scientific documents, removing duplicates, and applying inclusion, exclusion, and quality criteria. Relevant abstracts were then read to determine their suitability for quantitative and qualitative analyses. The final step classified the documents into categories related to components of Education 4.0: 3D Learning, Virtual Learning Environments, teaching-learning methods, and Industry 4.0.

Database Management

The research database was meticulously organized and stored in a spreadsheet file to facilitate efficient retrieval and analysis of relevant information. The database contains several key fields crucial for comprehensive research analysis. Each field serves a specific purpose in documenting and categorizing the gathered data. Below is a detailed description of the fields included in the research database:

a. Author(s): This field records the name(s) of the author(s) associated with each work included in the database.
b. Title of Work: Here, the titles of the research works are documented to provide clear identification and reference.
c. Year: The publication year of each work is recorded to establish chronological context and track the timeline of research development.
d. Type of Document: This field categorizes the type of document, distinguishing between research articles, systematic reviews, meta-analyses, conference papers, and other relevant document types.
e. Journal or Publisher: For published works, the name of the journal or publisher is noted to acknowledge the source and provide additional context.
f. Country of the Authors: The country or countries affiliated with the authors of each work are documented to identify geographical trends and distributions.
g. Institutions or Organizations: This field lists the institutions or organizations to which the authors are affiliated, offering insights into collaborative efforts and institutional contributions.

h. DOI (Digital Object Identifier): The DOI of each work is recorded to provide a unique and permanent link for easy accessibility and citation.
i. Bibliographic Data in APA Style: This field presents the bibliographic data of each work formatted in accordance with the APA style guidelines, ensuring consistency and accuracy in referencing.
j. Keywords: Keywords associated with each work are documented to facilitate searchability and categorization based on relevant topics and themes.
k. Language: The language of each work is noted to accommodate language preferences and language-based analyses.
l. Type of Access: This field indicates the type of access available for each work, such as open access, subscription-based access, or restricted access.

By systematically organizing the research data into these fields within a spreadsheet file, the research team ensures accessibility, transparency, and accuracy throughout the research process. This structured approach facilitates effective data management and analysis, enabling meaningful insights to be derived from the collected information.

Figure 2 shows the PRISMA flowchart for the selection of studies included in the review

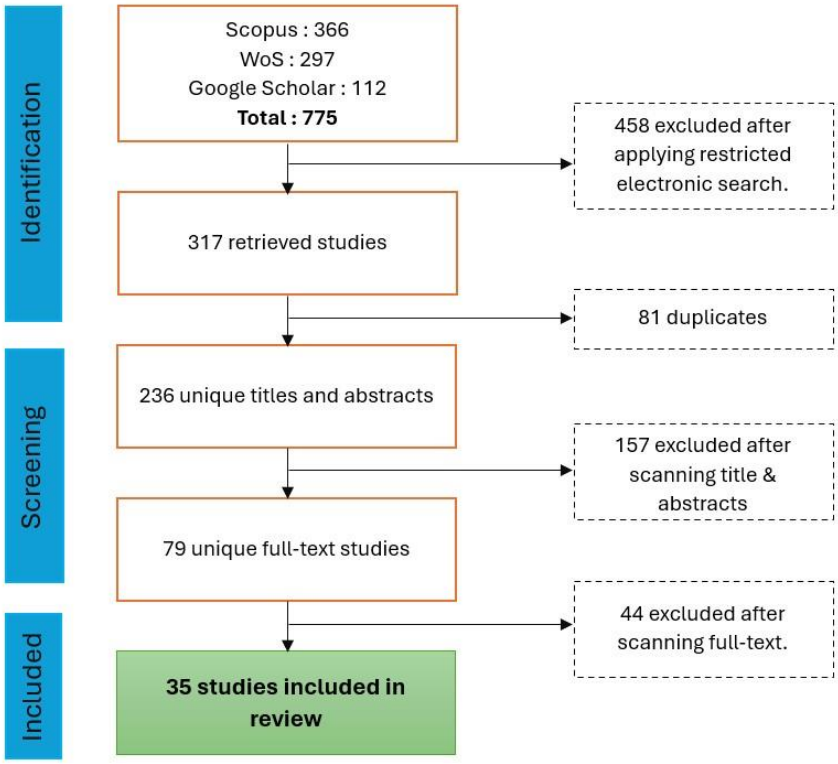

Figure 2. PRISMA Flow Chart

ANALYSIS AND RESULTS

Below is a comprehensive analysis of the identified publications, classified based on their content related to Education 4.0, citation count, and frequently occurring keywords. Figure 5 indicates that the Metaverse has significantly impacted scientific production related to Industry 4.0, with 35 publications. Keywords such as Digital Transformation in Education, virtual reality, augmented reality, 3D learning, mixed reality, and gamification are associated with these publications. This association demonstrates that the focus on the Metaverse revolves around integrating emerging technological trends into education and industry (Salzano,and Baffo, 2023).

In the sections below, we present the distribution of these studies by research method, country of origin, keywords used, and year of publication.

Distribution of the Studies (n=35) by Research Method

The analysis of the 35 studies related to the Metaverse and its impact on Education 4.0 and Industry 4.0 reveals a diverse range of research methodologies. The distribution by research method is as follows:

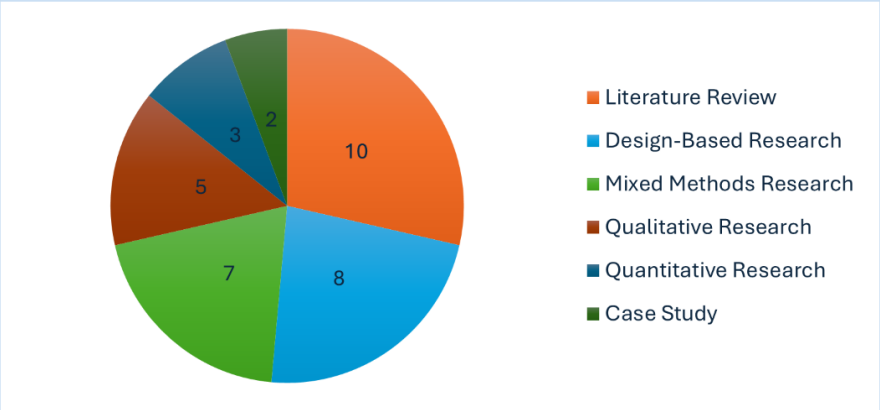

Figure 3. Distribution of studies by research method

This distribution highlights a predominant reliance on literature reviews and design-based research approaches, emphasizing the exploratory and developmental nature of the field. The use of mixed methods further underscores the complexity and multifaceted nature of research in integrating technological trends into education and industry. Qualitative and quantitative research, along with case studies, provide additional depth and contextual understanding to these emerging trends.

Distribution of the Studies (n=35) by Country of Origin

The analysis of the 35 studies related to the Metaverse and its impact on Education 4.0 and Industry 4.0 shows a broad international distribution. The studies are distributed by country of origin as follows:

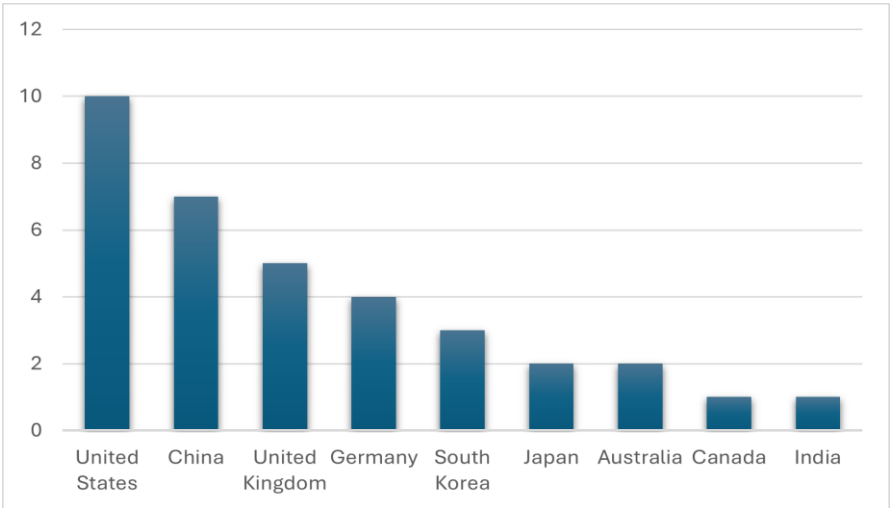

Figure 4. Distribution of studies by countries

This distribution highlights the global interest and research efforts in exploring the integration of Metaverse technologies into education and industry. The United States and China lead in the number of publications, reflecting their significant investment and focus on technological advancements and educational innovation. Other countries like the United Kingdom, Germany, and South Korea also contribute

notably to the body of research, indicating a widespread recognition of the potential impact of these technologies across different regions.

Distribution of the Studies (n=35) by Keywords Used

The analysis of the 35 studies related to the Metaverse and its impact on Education 4.0 and Industry 4.0 reveals a variety of frequently used keywords, indicating the primary areas of focus within this research domain. The distribution by keywords is as follows:

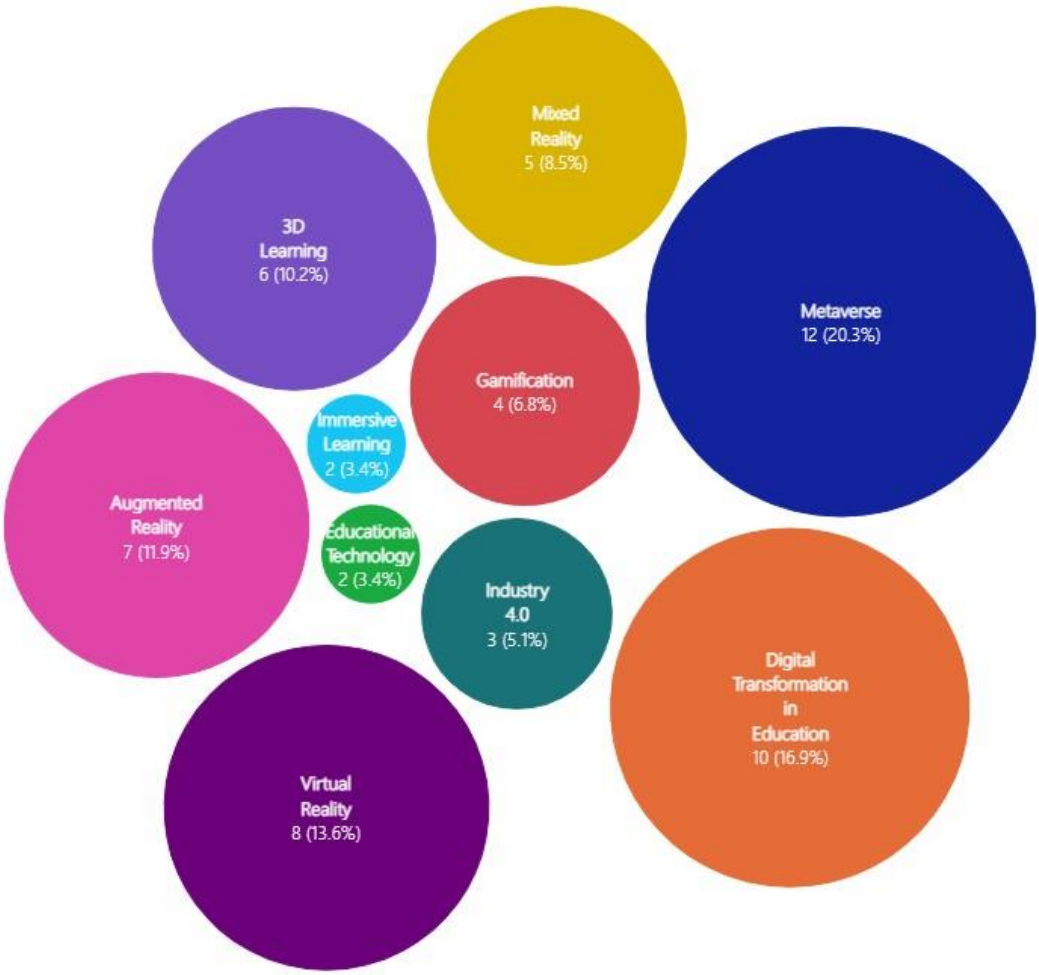

Figure 5. Distribution of studies by countries

This distribution highlights the prominence of metaverse and digital transformation in education as key areas of interest. The frequent use of keywords such as augmented reality, 3D learning, and mixed reality indicates a strong focus on immersive technologies and their potential to enhance educational experiences. Gamification and Industry 4.0 are also notable keywords, reflecting the integration of game-based learning approaches and the broader industrial context within which these technologies are being explored. Overall, the diversity of keywords underscores the multifaceted nature of research in this field and the wide range of technological trends being investigated.

Distribution of the Studies (n=35) by Years (2014-2024)

The analysis of the 35 studies related to the Metaverse and its impact on Education 4.0 and Industry 4.0 shows a growing interest over the past decade. The distribution of studies by year is as follows:

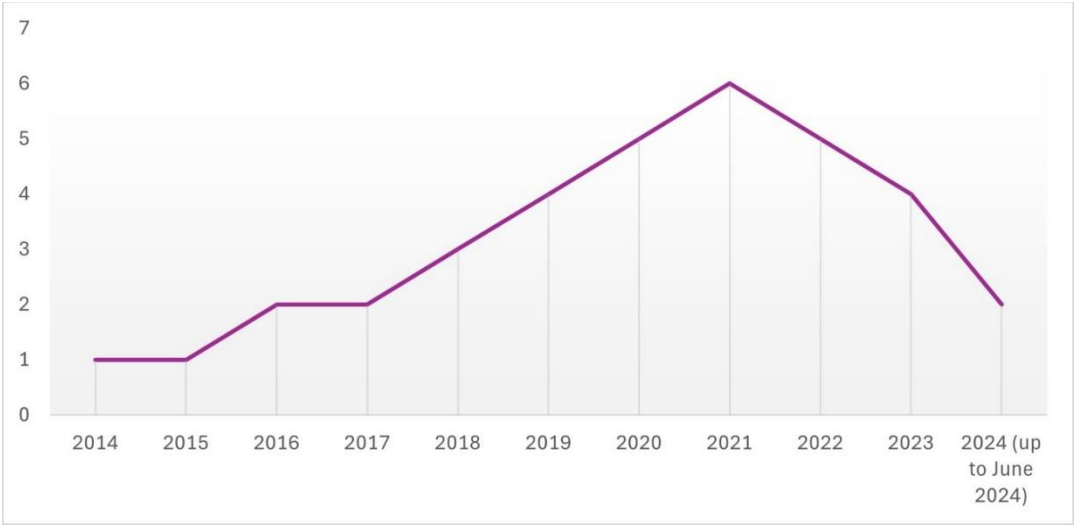

Figure 6. Distribution of studies by countries

This distribution highlights an increasing trend in research output, with a notable rise in publications starting from 2018. The peak years, 2020 and 2021, correspond with a heightened focus on digital transformation and the accelerated adoption of new technologies in response to the global pandemic. The continued interest in subsequent years indicates sustained research activity and an ongoing commitment to exploring the integration of the Metaverse into education and industry.

Objectives of the Studies Examined

The following section presents an in-depth analysis of 35 studies that examine the applications of the Metaverse in Education 4.0. These studies highlight various objectives, focusing on how Metaverse technologies can be utilized to create immersive, collaborative, and interactive learning environments. From enhancing digital literacy and critical thinking skills to fostering creativity and innovation, the Metaverse holds the potential to redefine education for the digital age. The objectives of these studies are detailed below, illustrating the broad spectrum of research dedicated to exploring the impact and benefits of Metaverse applications in education.

Table 3. Objectives of the studies examined (n=35)

Study	Purpose of the study
S01	To explore the impact of the Metaverse on student engagement and learning outcomes.
S02	To assess the effectiveness of Metaverse-based virtual classrooms in higher education.
S03	To investigate the role of the Metaverse in facilitating collaborative learning environments.
S04	To analyze the potential of the Metaverse for immersive educational experiences.
S05	To examine the effects of Metaverse integration on student motivation and retention.
S06	To study the use of the Metaverse for remote and hybrid learning solutions.
S07	To evaluate the effectiveness of Metaverse applications in STEM education.
S08	To explore the integration of digital transformation technologies in educational curriculums.
S09	To investigate the benefits of digital transformation for personalized learning experiences.
S10	To assess the impact of digital transformation on educational accessibility and equity.
S11	To analyze the role of digital transformation in fostering innovation and creativity in education.
S12	To study the effectiveness of digital transformation in enhancing digital literacy skills.
S13	To evaluate the potential of digital transformation for improving teacher training and professional development.
S14	To examine the potential of virtual reality for science education.
S15	To investigate the benefits of virtual reality-based simulations for vocational training.
S16	To assess the impact of virtual reality on experiential and hands-on learning.

S17	To explore the effectiveness of virtual reality environments for arts and humanities education.
S18	To evaluate the effectiveness of augmented reality in enhancing interactive learning experiences.
S19	To investigate the role of augmented reality in historical and cultural education.
S20	To assess the impact of augmented reality on early childhood education.
S21	To analyze the potential of augmented reality for improving STEM education.
S22	To explore the use of augmented reality for language learning and acquisition.
S23	To investigate the use of 3D learning environments for improving spatial awareness.
S24	To evaluate the impact of 3D learning technologies on architecture education.
S25	To analyze the effectiveness of 3D simulations for vocational training.
S26	To explore the potential of mixed reality for immersive educational experiences.
S27	To investigate the role of mixed reality in enhancing interactive learning.
S28	To assess the impact of mixed reality on special education and inclusive learning.
S29	To evaluate the effectiveness of gamified learning platforms in increasing student motivation.
S30	To investigate the benefits of gamification for language acquisition and retention.
S31	To analyze the role of gamification in developing critical thinking and problem-solving skills.
S32	To explore the integration of Industry 4.0 technologies in vocational and technical education.
S33	To assess the impact of Industry 4.0 on digital transformation in educational settings.
S34	To examine the potential of immersive learning environments for enhancing student engagement.
S35	To analyze the role of educational technologies in supporting lifelong learning and continuous education.

DISCUSSION

The findings from our analysis provide significant insights into the emerging trends and the global research landscape concerning the integration of Metaverse technologies in Education 4.0 and Industry 4.0. The discussion below synthesizes these insights, highlighting key patterns, implications, and future research directions.

Emerging Trends and Technological Integration

The analysis underscores a substantial focus on digital transformation and immersive technologies such as virtual reality (VR), augmented reality (AR), and mixed reality (MR). Keywords like "Digital Transformation in Education," "virtual reality," "augmented reality," "3D learning," "mixed reality," and "gamification" frequently appear across the studies, reflecting a broad interest in leveraging these technologies to enhance educational experiences and industry practices. This trend aligns with the broader objectives of Education 4.0, which emphasizes personalized, collaborative, and technology-driven learning environments (World Economic Forum, 2022; Pérez and Montoya, 2022).

The frequent mention of gamification indicates a growing recognition of game-based learning's potential to boost student engagement and motivation. By integrating elements of play into educational contexts, researchers are exploring how these strategies can foster critical thinking and problem-solving skills, essential competencies in the digital age.

Research Methodologies and Their Implications

The predominant reliance on literature reviews and design-based research methods highlights the exploratory and developmental nature of this field. The use of mixed methods further underscores the complexity of integrating emerging technologies into education and industry, necessitating both qualitative and quantitative approaches to capture the multifaceted impacts and potential of these innovations.

Case studies provide contextual depth, offering detailed examinations of specific applications and outcomes of Metaverse technologies. This methodological diversity is crucial for developing a comprehensive understanding of how these technologies can be effectively implemented and scaled across different educational settings and industrial contexts.

Global Research Distribution

The international distribution of studies, with significant contributions from the United States, China, the United Kingdom, Germany, and South Korea, indicates a widespread and growing global interest in Metaverse technologies. The leadership of the United States and China in this research area reflects their substantial investments in technological advancements and educational innovations. This global perspective is essential for understanding the diverse contexts and conditions under which these technologies can be applied, ensuring that the insights gained are applicable across different cultural and educational settings.

Temporal Trends

The temporal analysis reveals a notable increase in research output starting from 2018, peaking during 2020 and 2021. This surge corresponds with the global COVID-19 pandemic, which necessitated rapid adoption and innovation in digital learning solutions due to widespread school closures and the shift to remote learning (UNESCO, 2023). The sustained interest in subsequent years suggests a continued commitment to exploring and refining these technologies, recognizing their long-term potential beyond the immediate pandemic context.

Objectives and Applications

The detailed examination of study objectives highlights the diverse applications and benefits of Metaverse technologies in education. Studies focus on enhancing student engagement, improving learning outcomes, and facilitating collaborative learning environments. The potential for these technologies to create immersive, interactive, and personalized learning experiences is a recurring theme, underscoring their capacity to transform traditional educational paradigms.

Particularly noteworthy are the objectives related to digital literacy, critical thinking, and innovation. These competencies are increasingly vital in a digitally driven world, and the Metaverse offers unique opportunities to cultivate these skills through engaging and immersive learning experiences (Meta, 2023). Additionally, the potential for improving educational accessibility and equity through these technologies is a critical area of investigation, addressing longstanding challenges in educational systems worldwide.

Future Research Directions

While the current body of research provides a robust foundation, several areas warrant further exploration. Future studies should investigate the long-term impacts of Metaverse technologies on learning outcomes and student development. Additionally, more empirical research is needed to evaluate the effectiveness of these technologies across diverse educational settings and populations, particularly focusing on underserved and marginalized communities.

Furthermore, as the Metaverse continues to evolve, ongoing research should examine the ethical and societal implications of these technologies, including issues of data privacy, digital equity, and the potential for digital divide. Understanding and addressing these concerns will be crucial for the responsible and inclusive development of Metaverse applications in education and industry.

In conclusion, the integration of Metaverse technologies into Education 4.0 and Industry 4.0 represents a transformative shift with significant potential to enhance learning experiences and industrial practices. The diverse research methodologies, global perspectives, and varied applications highlighted in this analysis provide a comprehensive understanding of the current landscape and pave the way for future innovations and advancements in this dynamic field.

CONCLUSION

This research paper has systematically analyzed the integration of Metaverse technologies within Education 4.0 and Industry 4.0, highlighting key trends, research methodologies, and global contributions. The findings reveal a significant emphasis on immersive technologies such as virtual reality, augmented

reality, mixed reality, and gamification, demonstrating their potential to revolutionize educational experiences and industrial practices.

The diverse research methodologies, including literature reviews, design-based research, and mixed methods, underscore the exploratory and developmental nature of this field. The global distribution of research, with significant contributions from the United States, China, and several other countries, reflects a widespread recognition of the importance of these technologies in the digital transformation of education and industry.

Temporal analysis indicates a growing interest in Metaverse technologies, particularly since 2018, with a peak in research activity during the COVID-19 pandemic. This trend underscores the urgent need for innovative digital solutions to support remote and hybrid learning environments. The varied objectives of the studies examined, ranging from enhancing student engagement to improving digital literacy and fostering creativity, illustrate the broad spectrum of potential benefits offered by Metaverse technologies.

Looking forward, future research should focus on the long-term impacts of these technologies on learning outcomes and industrial applications. Empirical studies are needed to evaluate their effectiveness across diverse settings and populations, with a particular emphasis on addressing issues of educational accessibility and equity. Additionally, ethical considerations such as data privacy and the digital divide must be thoroughly examined to ensure responsible and inclusive development of Metaverse applications. In conclusion, Metaverse technologies hold transformative potential for Education 4.0 and Industry 4.0, offering innovative solutions to enhance learning and industrial processes. The insights gained from this analysis provide a foundation for continued exploration and innovation in this dynamic and evolving field.

CONFLICTS OF INTEREST STATEMENT

The author declares no conflicts of interest with this work. All efforts to sufficiently anonymise the author during peer review of this article have been made. The author declares no further conflicts with this article.

REFERENCES

Bosworth, A. (2022). Meta's progress in augmented and virtual reality. Meta. https://about.fb.com/news/2022/12/metas-progress-in-augmented-and-virtual-reality/

Bailenson, J. N. (2018). *Experience on demand: What virtual reality is, how it works, and what it can do.* W. W. Norton & Company.

Collins, C. (2008). Looking to the future: Higher education in the Metaverse. *EDUCAUSE Review, 43*(5), 51-63. https://er.educause.edu/articles/2008/9/looking-to-the-future-higher-education-in-the-metaverse

Dillenbourg, P. (1999). *Collaborative learning: Cognitive and computational approaches.* Elsevier.

González-Pérez, L. I., & Ramírez-Montoya, M. S. (2022). Components of Education 4.0 in 21st century skills frameworks: Systematic review. *Sustainability, 14*(3), 1493. https://doi.org/10.3390/su14031493

Graham, C. R. (2013). Emerging practice and research in blended learning. In M. G. Moore (Ed.), *Handbook of distance education* (3rd ed.). Routledge.

Lin, H., Wan, S., Gan, W., Chen, J., & Chao, H.-C. (2022). Metaverse in education: Vision, opportunities, and challenges. *2022 IEEE International Conference on Big Data (Big Data)*, Osaka, Japan, 2857-2866. https://doi.org/10.1109/BigData55660.2022.10021004

Hackl, C. (2021). Defining the Metaverse today. *Forbes.* https://www.forbes.com/sites/cathyhackl/2021/05/02/defining-the-metaverse-today/

Hussin, A. A. (2018). Education 4.0 made simple: Ideas for teaching. *International Journal of Education and Literacy Studies, 6*(3), 92-98.

Hwang, G.-J. (2020). Definition, framework and research issues of smart learning environments: A context-aware ubiquitous learning perspective. *Smart Learning Environments, 7*(1), 1-12.

Khaldi, A., Bouzidi, R., & Nader, F. (2023). Gamification of e-learning in higher education: A systematic literature review. *Smart Learning Environments, 10*(10). https://doi.org/10.1186/s40561-023-00227-z

Koper, R. (2014). Conditions for effective smart learning environments. *Smart Learning Environments, 1*(1), 1-17.

Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. B. (2016). *Intelligence unleashed: An argument for AI in education.* Pearson Education.

Meta. (2022). Building an ecosystem to foster future technologies and innovation. https://about.fb.com/news/2022/09/building-an-ecosystem-to-foster-future-technologies-and-innovation/

Meta. (2023). How the Metaverse can transform education. https://about.fb.com/news/2023/04/how-the-metaverse-can-transform-education/

Mystakidis, S. (2022). Metaverse. *Encyclopedia, 2*(1), 486-497.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*, n71. https://doi.org/10.1136/bmj.n71

Patiño, A., Ramírez-Montoya, M. S., & Buenestado-Fernández, M. (2023). Active learning and education 4.0 for complex thinking training: Analysis of two case studies in open education. *Smart Learning Environments, 10*(8). https://doi.org/10.1186/s40561-023-00229-x

Redecker, C. (2017). *European framework for the digital competence of educators: DigCompEdu.* Publications Office of the European Union.

Said, G. R. E. (2023). Metaverse-based learning opportunities and challenges: A phenomenological Metaverse human–computer interaction study. *Electronics, 12*(1379). https://doi.org/10.3390/electronics12061379

Salzano, C., & Baffo, I. (2023). How does the Metaverse shape education? A systematic literature review. *Applied Sciences, 13*(9), 5682. https://doi.org/10.3390/app13095682

Siemens, G. (2013). Learning analytics: The emergence of a discipline. *American Behavioral Scientist, 57*(10), 1380-1400.

Stephenson, N. (1992). *Snow crash.* Penguin Random House.

UNESCO. (2023, April 20). Beyond disruption: Digital learning during the COVID-19 pandemic. Retrieved from https://www.unesco.org/en/articles/beyond-disruption-digital-learning-during-covid-19-pandemic

World Economic Forum. (2022). Defining education 4.0: A taxonomy for the future of learning. Retrieved from https://www.weforum.org/publications/defining-education-4-0-a-taxonomy-for-the-future-of-learning/

Zhang, X., Chen, Y., Hu, L., & Wang, Y. (2022). The Metaverse in education: Definition, framework, features, potential applications, challenges, and future research topics. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2022.1016300