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Technological Trends in Metaverse-Based Learning Environments: A Bibliometric Analysis

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Abstract. The metaverse, powered by immersive technologies such as virtual, augmented, and mixed reality, has emerged as a promising tool to enhance online education by creating interactive and engaging learning environments. Despite its growing relevance, few bibliometric studies have systematically explored its development in education, which has left gaps in understanding research trends and priorities. This study conducted a bibliometric analysis of 838 publications from the Scopus database (2010–2025) using VOSviewer to examine publication trends, subject areas, influential countries, journals, and highly cited works. The results revealed a sharp increase in publications after 2020, with computer science and social sciences leading contributions, followed by engineering and medicine. The United States and China dominate outputs, while *IEEE Access* is the most productive journal. The five emerging research areas identified were applications and evaluation, immersive technologies, instructional design, secure platforms, and intelligent systems. This study offers valuable insights and guidance for

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researchers, educators, and policymakers to promote sustainable adoption of the metaverse in education.

Keywords: Bibliometric analysis; metaverse technologies; extended reality

1. Introduction

The term "metaverse" can encompass a variety of definitions. It generally refers to a parallel virtual reality universe in which individuals can interact with others, engage in work, and play within an immersive and shared environment. Immersive technologies, such as extended reality, enable users to seamlessly navigate and interact with these virtual spaces as if they were physically present. Extended reality encompasses a range of technologies, including virtual, augmented and mixed reality (Kaddoura & Al Husseiny, 2023; Suh & Ahn, 2022).

Virtual reality immerses users in a computer-generated digital environment to interact with digital elements and experiences. Augmented reality overlays the digital aspects of a virtual world onto the physical world. Mixed reality combines physical and virtual elements to facilitate seamless interaction between the two worlds. By harnessing these advanced technologies, the metaverse has the potential to enhance users' online experiences by creating immersive digital spaces that enable real-time collaborative activities with others, represented by avatars, from any location and at any time.

The metaverse can help address online learning systems' lack of social interaction in education. Current systems have limitations in replicating cognitive and emotional experiences in face-to-face learning environments, such as body language, gestures, co-presence, and social interaction (Sinha, 2023). Students, confined to their computers, often miss out on the benefits of in-person interactions with their peers and instructors. By creating immersive virtual environments that simulate real-world interactions, the metaverse can revolutionize online learning, making it more engaging, interactive, and effective (Kaddoura & Al Husseiny, 2023).

However, there are inadequate bibliometric studies on the metaverse in education. This could lead to incomplete insights and uninformed decisions, potentially affecting the support for educational initiatives related to the metaverse. Therefore, this study aimed to provide a thorough bibliometric analysis of the metaverse in online education, covering the publication period from 2010 to 2025. The following were the research questions that guided our study:

- What is the current research trend in the field of metaverse in education?
- What are the most influential countries, journals, publishers, authors and articles in the field of metaverse in education?
- What is the key concept, technologies, and potential research area in the field of metaverse in education?

Our analysis adhered to the research guidelines for bibliometric analysis (Donthu et al., 2021a; Mukherjee et al., 2022). We aimed to investigate publication patterns; top-performing countries; noteworthy journals based on publications and citations; the ten most cited publications; the most prolific research areas by subjects; potential research areas; and potential challenges. By doing so, we aimed to offer valuable insights into the current state of metaverse research in education. The remainder of this paper has been organized as follows: Section 2 presents the research background, followed by the methods used to conduct this bibliometric analysis study in Section 3. Section 4 reports the analysis results, which are then discussed in Section 5, followed by conclusions in Section 6.

2. Research Background

The metaverse has proven to be a beneficial tool in education (Almarzouqi et al., 2022; Hwang et al., 2023; Lee & Jo, 2023). The embodiment of the Internet and immersive technologies enables students and teachers from remote locations to convene in a shared virtual space, much like a physical classroom (Chen et al., 2023). In these virtual classrooms, students and teachers can interact in real time, engage collaboratively with the learning materials and learning activities and collaborate with their peers. Moreover, the metaverse provides educational settings beyond time and space constraints, allowing a unique opportunity for students to engage in explorative learning activities through immersive technologies (Almarzouqi et al., 2022).

Research has demonstrated that the metaverse, a virtual reality space allowing users to interact with a computer-generated environment and other users, can be a highly efficient and engaging educational tool (Lee & Jo, 2023). Gamified real-world projects and immersive environments using Metaverse technologies also can significantly improve engagement, understanding, and the teaching of computational thinking (Jaaffar & Adnan, 2025). Compared to traditional in-person teaching and remote instruction via video conferencing, the metaverse has the potential to enhance learning outcomes by providing learners with more immersive, interactive and personalized experiences which cater to their unique needs and preferences (Duan et al., 2021; Jovanović & Milosavljević, 2022; Lee & Jo, 2023).

Unlike traditional online communication methods, such as instant messaging or online chatting, the metaverse offers users virtual face-to-face communication, allowing users to create new content, just like in the real world (Chen et al., 2023). Hussain et al., (2024) emphasized the metaverse's potential to enhance education through immersive learning, while noting challenges of accessibility, equity, cost, and technology. By leveraging the latest advancements in technology and digital media, educators can leverage the metaverse to create dynamic and engaging learning environments that help students acquire new knowledge and skills more effectively and enjoyably, making the metaverse an ideal platform for online education.

Hwang and Chien (2022) presented several reasons why adopting the metaverse benefits education. First, it provides students with a secure environment to

practice cognitive skills or engage in activities that may be too risky in real life. Second, it allows students to explore and learn from contexts that might otherwise be inaccessible to them. Third, it enables students to learn and engage in long-term involvement and practice, which can be challenging to achieve in real-life situations. Fourth, it encourages students to be creative and explore ideas that may not be feasible in real life due to practical limitations, such as cost or lack of resources. Fifth, it offers students diverse perspectives and experiences that may expand their career or life opportunities.

Sixth, and finally, the metaverse can help learners to perceive, experience, or observe things from different perspectives or roles. Learning in the metaverse allows students to have hands-on and immersive experience of the learning content and process and real-time interactions with other students in the virtual classroom (Chen et al., 2023). An example of metaverse applications in education is the metaverse campus prototype to provide a mixed environment that synchronously reflects student actions in both real and virtual worlds (Duan et al., 2021).

Chen et al. (2023) observed that virtual worlds, avatars and interactive features are commonly integrated into metaverse frameworks. Ibrahim et al. (2025) also showed that the metaverse could enhance education through immersive learning and evaluates its effectiveness using the SCORE model to guide sustainable adoption. Rahaman et al., (2022) highlighted how the metaverse can transform education through immersive and personalized learning while also addressing challenges like technology, accessibility, and ethics. However, the specific design elements, components, and technological advancements required to create a successful educational metaverse are still being established and refined.

Past studies show strong support for the metaverse as an emerging platform for interactive and experiential learning. However, critical synthesis reveals that the field still lacks clear theoretical frameworks and unified models for designing effective metaverse-based learning environments. These gaps point to the need for future studies that link immersive technologies with educational theories and explore how they can be used sustainably and equitably. This study aimed to address these gaps by investigating current research trends and identifying guiding directions for the continued development of the educational metaverse.

3. Method

To conduct thorough research on the subject, a structured search of journal papers was performed using bibliometric analysis of data collected from the Scopus database. The search criteria were carefully set to both quantify and qualify the research written on the topic. This approach offered a quantitative means of evaluating the data obtained, while also allowing for a detailed description of how the examined elements interact or behave during specific periods. This study divided the process into two steps: procedural analysis and bibliometric analysis.

3.1 Procedure Analysis

The Scopus database was selected in this study, because it provides a more comprehensive and diverse collection of literature for this research field, enabling a focused assessment of the global research landscape (Burnham, 2006). About 838 publications were retrieved from 2010 to 2025.

Various sources were used to extract data for the study, including publication trends, primary subject research areas, the most influential countries, journals related to the metaverse in education-related research articles with citations, analysis of authors' keywords, and index keywords analysis. To ensure accuracy, the screening of papers involved independent assessments by the authors, focusing on titles and abstracts. The keywords used in this analysis were determined through a literature review of the publications' titles and verified among the authors.

To get the overall concept of metaverse research in the education domain, we decided to use general terms for keyword search, which were (metaverse OR extended reality) AND (education or learning). The keyword 'extended reality' was included in the search string because it comprises interactive technologies necessary for a metaverse. Therefore, any application with extended reality features could be a virtual world of a metaverse.

The inclusion criteria encompassed all document types written solely in English, including journal articles, proceedings, book chapters and books. Review articles were excluded as they typically summarize and synthesize existing literature, which could lead to inconsistency in the data and difficulty in analyzing trends across various variables. The truncation or wildcard operator (*) was included in search queries to expand the results. Our preliminary analysis found that all the retrieved publications appeared relevant, with no duplicate entries. Hence, there is no removal of publications. The flow diagram of this bibliometric analysis was indicated by a modified version of the preferred reporting items for systematic review and meta-analyses (PRISMA) guideline, as shown in Figure 1.

3.2 Bibliometric Analysis

Our bibliometric data analysis used the statistical processing software VOSViewer (van Eck & Waltman, 2010). The two methods are used in this analysis were performance analysis and science mapping. In terms of performance analysis, this research provides a descriptive analysis of performance and contributions of various aspects pertaining to annual publication and citation trends, most prolific research areas by subject, scientific production across countries globally, highly cited journals, and the top ten highly cited articles. To gauge the significance of individual publications in the context of the metaverse in education, Harzing's "publish or perish" and Microsoft Excel were utilized.

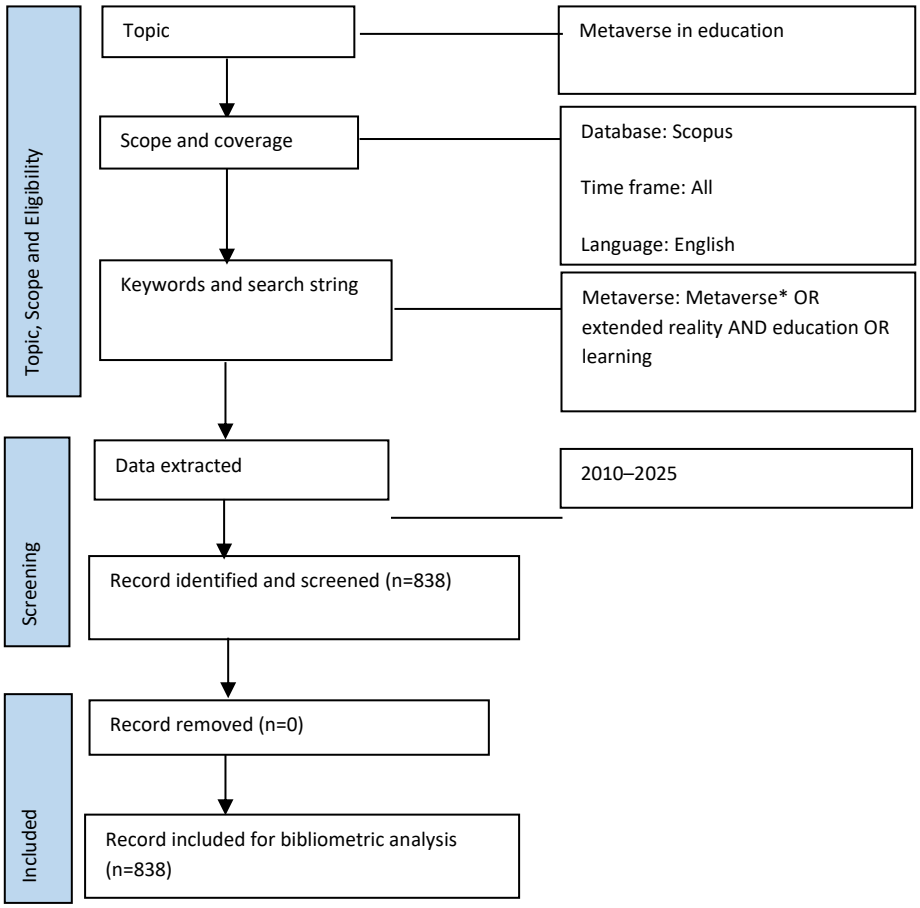

Figure 1: The modified PRISMA guidelines for metaverse in education

Figure 1 shows the modified PRISMA guidelines for metaverse in education. Science mapping was employed to analyze the strength and relationships between research items (Donthu et al., 2021b). This method involved two techniques: bibliographic coupling of countries and content analysis of the author's keywords and index keywords. Using these techniques, the relationships between research items can be determined and future research interests can be anticipated and described.

4. Results

A total of 838 publications from 2010 to 2025 were used for analysis. The 16-year time frame was selected because the idea of the metaverse and extended reality has been around since the early 2000s, even though the terms have only recently become popular. From 2009 onwards, extended reality gained momentum due to the availability of technologies and devices that support its applications, such as the Oculus Rift virtual reality headset in 2010 and the Microsoft HoloLens in 2016.

In 2018, Facebook's founder made headlines by expressing his enthusiastic support for a new generation of immersive internet. This led to a surge of interest and excitement surrounding the metaverse concept. The idea of a metaverse has since captured the imaginations of many and is seen by some as the next big thing in the evolution of the internet. In this study, the data obtained from analyzing the publications indexed in Scopus within the stipulated timeframe are

categorized accordingly based on the following criteria indicated by the subheadings in this section.

4.1 Current Research Trend in Metaverse Education

4.1.1 Trend of Total Publication

Figure 2 indicates the trend of total publications over 16 years. The analysis indicates that in 2020, only 15 related publications were found in the Scopus database. However, since then, there has been a remarkable and quick increase in the number of publications. In 2022, the number of publications rose to 95. In 2023, there were 194 publications, followed by 270 in 2024. In 2025, the number of publications has shown a slight drop to 196, which can be attributed to the fact that the year is still ongoing when this paper was written, and the number is expected to rise by the end of the year. This significant increase over a short period indicates a surge in interest among researchers and highlights the urgent need for research in this area.

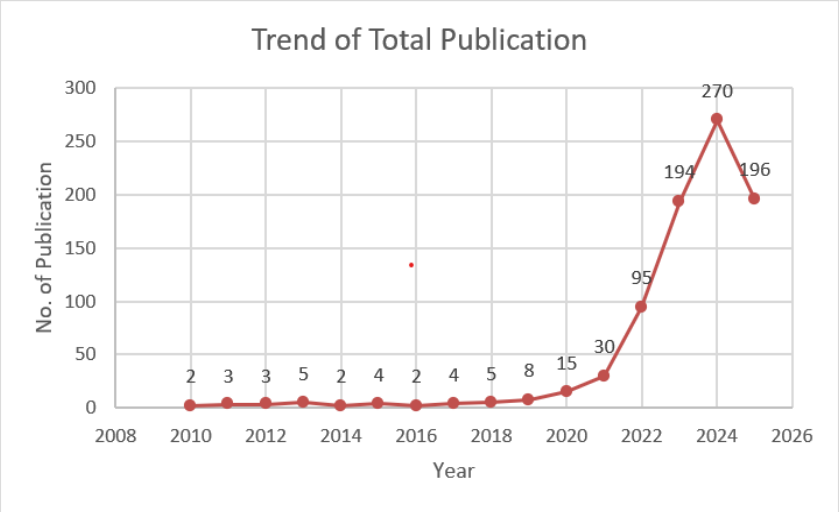

Figure 2: The trend of total publication

Figure 3 shows the trend of total citations over 16 years. The analysis indicates that in 2020, publications on the topic received 890 citations in the Scopus database. Since then, there has been a substantial increase. In 2021, citations rose to 1,337, followed by a remarkable increase to 5,314 in 2022. Although the numbers slightly decreased to 3,137 in 2023 and 2,195 in 2024, in 2025 citations have already reached 3,640. The apparent fluctuations in recent years may be due to the year still being ongoing at the time of writing, with the number of citations expected to continue rising. This rapid increase shows that the topic is highly sought-after and likely to remain a significant research focus in the coming years.

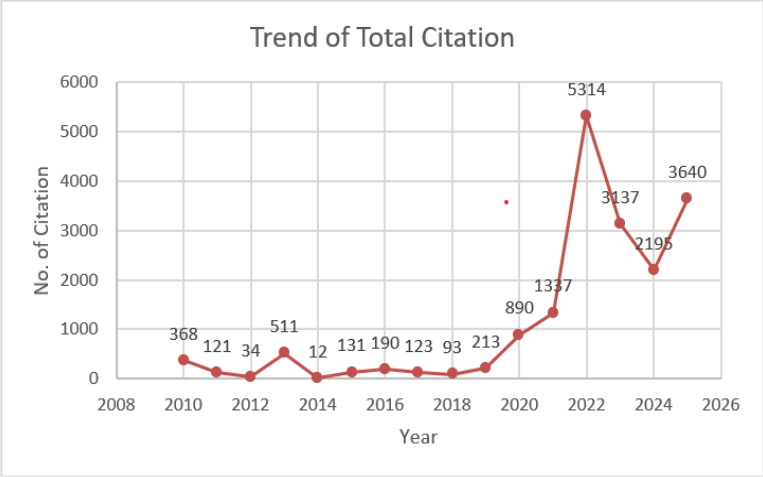

Figure 3: The trend of total citation

4.1.2 Trend on Research Areas by Subject

After conducting a comprehensive analysis of the research area, it was discovered that the use of metaverse technology in education is a multifaceted and diverse area that involves various research areas, as illustrated in Table 1. Table 1 shows that computer science (49.0%) provides the requisite technology, infrastructure, and applications to support learning and teaching in the metaverse. The social sciences (35.2%) also play a major role, as researchers in this field explore the development of educational metaverse applications and bear a crucial responsibility to ensure that these applications are designed to engage students and capture their interest.

Engineering (28.3%) further contributes by advancing the technical integration of metaverse tools in educational contexts. Additionally, the medical field (17.5%) explores the potential to train students in handling critical or intricate procedures via simulation in the metaverse. Other subject areas such as material science (7.8%), mathematics (5.7%), psychology (5.1%), business, management and accounting (5.0%), neuroscience (4.4%), and arts and humanities (4.3%) also demonstrate significant contributions, highlighting the broad interdisciplinary interest in this field.

Table 1: The most active research areas by subject on metaverse educational research

No	Research Area	Number of articles	Percentage of 838
1	Computer Science	411	49.0%
2	Social Sciences	295	35.2%
3	Engineering	237	28.3%
4	Medicine	147	17.5%
5	Material Science	65	7.8%
6	Mathematics	48	5.7%
7	Psychology	43	5.1%
8	Business, Management and Accounting	42	5.0%
9	Neuroscience	37	4.4%
10	Arts and Humanities	36	4.3%

4.3 The Most Influential Countries in Metaverse Education

Our study found that 79 countries investigated the metaverse and education-related studies. The top 10 countries actively researching and implementing metaverse-related studies in education were analyzed (see Table 2). These countries have been ranked based on the number of publications they have produced on the topic. The list shows that research on metaverse in education has garnered significant attention from researchers and scholars across Asia, Europe, and North America. The interest in this topic from these regions is balanced, indicating its relevance and importance in the global academic community.

It is worth highlighting that the United States (21.4%) and China (12.5%) lead the list, followed by South Korea (8.7%) and India (7.4%). European countries such as the United Kingdom (6.7%), Italy (5.5%), Germany (5.1%), and Spain (4.9%) also demonstrate strong contributions. Meanwhile, Australia (5.0%) and Canada (4.9%) reflect the growing interest in other regions. This trend highlights the growing importance of these cutting-edge technologies in shaping the future of education and underscores the need for continued investment and innovation in this field.

Table 2: The most active publication in education metaverse-related studies by countries

No	Country	Number of Publications	% of 838
1	United States	180	21.4%
2	China	105	12.5%
3	South Korea	73	8.7%
4	India	62	7.4%
5	United Kingdom	56	6.7%
6	Italy	46	5.5%
7	Germany	43	5.1%
8	Australia	42	5.0%
9	Spain	41	4.9%
10	Canada	41	4.9%

This study highlights that a coupling approach was used to analyze network correlation among different countries. The analysis generated a visual representation of the network using VOSviewer, as illustrated in Figure 4.

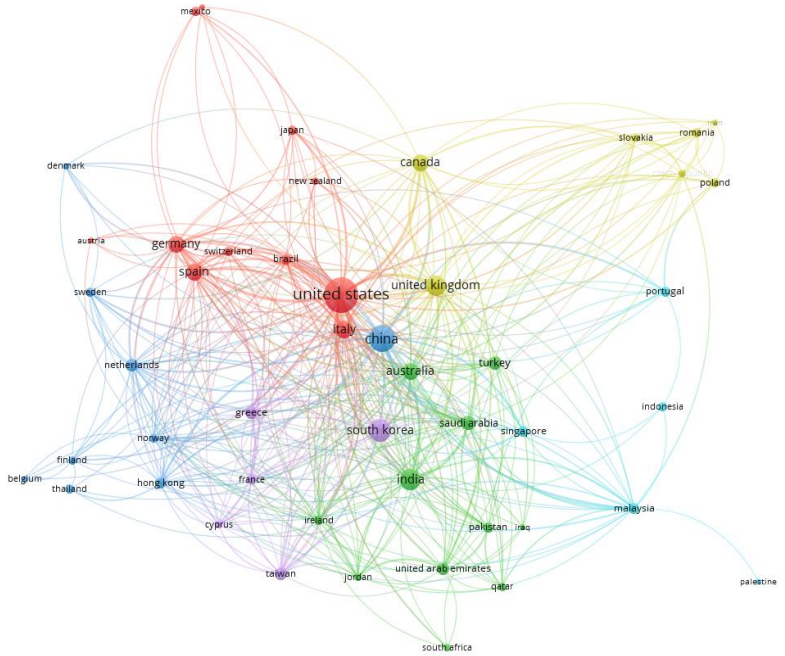

Figure 4: Bibliographic coupling of countries

This network mapping assists in identifying the relationship of citation connections between two or more countries on the same document (Kessler, 1963). The distance between the nodes on the map denotes the correlation intensity, while the node's size indicates the number of articles published for the study period. The graph reveals that the United States and China occupy central positions, reflecting their dominance in the field. The United States shows strong connections with European countries such as the United Kingdom, Germany, Italy, and Spain, while China demonstrates frequent collaborations with Australia, South Korea, and India. Additionally, close regional collaborations can be observed between Malaysia, Indonesia, and Middle Eastern countries, highlighting the global spread and interconnectedness of research on the metaverse in education.

4.4 The Most Productive Journals

Table 3 provides valuable insights into the research landscape of metaverse in education. The data reveals that *IEEE Access* has published the most publications (43) on the topic and has also received the highest number of citations (2,230). Other notable contributors include *IEEE Transactions on Learning Technologies* with 17 publications and 529 citations and *Applied Sciences (Switzerland)* with 14 publications and 338 citations. It is noteworthy that most of these journals, such as *Frontiers in Education*, *Electronics (Switzerland)*, *Virtual Reality*, and the *Journal of Metaverse*, are open access, which has made them more accessible to researchers and has contributed to their citation impact.

The list also shows the presence of high-impact journals, such as the *IEEE Journal on Selected Areas in Communications* with an impact factor of 17.2, demonstrating that metaverse research is being published not only in education-focused journals

but also in top-tier technical outlets. Overall, the listed information about the top publishers in this field would be useful for researchers and scholars interested in exploring the latest developments in the metaverse in education.

Table 3: Journal with the highest publication in education metaverse related studies

No	Journals	Publisher	TP	TC	IF	Open access
1	*IEEE Access*	Institute of Electrical and Electronics Engineers Inc.	43	2230	3.6	Yes
2	*IEEE Transactions on Learning Technologies*	Institute of Electrical and Electronics Engineers Inc.	17	529	4.9	Yes
3	*Applied Sciences (Switzerland)*	MDPI	14	338	2.5	Yes
4	*Frontiers in Education*	Frontiers Media S.A.	11	45	1.9	Yes
5	*Electronics (Switzerland)*	MDPI	11	486	2.6	Yes
6	*Virtual Reality*	Springer Science and Business Media Deutschland GmbH	10	192	5.0	Yes
7	*Journal of Metaverse*	Izmir Academy Association	10	477	N/A	Yes
8	*IEEE Journal on Selected Areas in Communications*	Institute of Electrical and Electronics Engineers Inc.	9	299	17.2	Yes
9	*Plos One*	Public Library of Science	8	44	2.6	Yes
10	*Frontiers on Virtual Reality*	Frontiers Media S.A.	8	35	3.6	Yes
TP = total publication, TC = total citations, IF = impact factor based on Journal Citation Report (JCR) 2022, N/A = not applicable						

4.5 The Most Influential Publishers, Authors and Articles

Table 4 lists the top 10 research works that have been highly cited in the field of metaverse in education. These research papers are the most influential and informative in this study area. It is worth noting that all the publications listed have recently been published, with seven published in 2022 and one in 2020, 2021, and 2023. This indicates that the field of metaverse in education is rapidly evolving and these research works are at the forefront of this development.

The first highest cited paper is by Dwivedi et al. (2022) titled *Metaverse Beyond the Hype: Multidisciplinary Perspectives on Emerging Challenges, Opportunities, And Agenda for Research, Practice and Policy*. Published in the *International Journal of Information Management* by Elsevier, it has 1823 citations. This study highlights how the metaverse is growing quickly and why research must address not just the technology, but also social, economic, and policy issues. It provides a full agenda for future work and remains the most influential paper in the metaverse field (Dwivedi et al., 2022).

The second highest cited paper is by S. Park and Kim (2022) titled *A Metaverse: Taxonomy, Components, Applications, and Open Challenges*. Published in *IEEE Access*, it has 1271 citations. This paper creates a taxonomy of the metaverse, dividing it into key components and application areas such as education, healthcare, and entertainment. It also explains the big challenges in areas such as scalability, ethics, and security. This paper has become a foundation for researchers and practitioners to build and test metaverse systems (S. Park & Kim, 2022).

The third highest cited paper is by Hwang and Chien (2022) titled *Definition, Roles, And Potential Research Issues of the Metaverse in Education: An Artificial Intelligence Perspective*. Published in *Computers and Education: Artificial Intelligence*, it has 536 citations. The authors explain how AI can help create smart metaverse learning systems that improve engagement and adapt to student needs. They also raise issues about ethics, digital gaps, and technical limits. This paper is a strong guide for future studies on AI in metaverse education (Hwang & Chien, 2022).

The fourth highest cited paper is by Xi et al., (2023) titled *The Challenges of Entering the Metaverse: An Experiment on the Effect of Extended Reality on Workload*. Published in *Information Systems Frontiers*, it has 281 citations. This study tests how extended reality affects users' workload. Results show that while extended reality increases immersion, it also increases mental and physical load, which may cause problems. The paper stresses that designers must balance immersion with user comfort and safety (Xi et al., 2023).

The fifth highest cited paper is by Jovanović and Milosavljević (2022) titled *VoRtex Metaverse Platform for Gamified Collaborative Learning*. Published in *Electronics (Switzerland)*, it has 234 citations. The study presents a platform that uses gamification and avatars to improve teamwork and learning in the metaverse. It shows how interactive learning can motivate students and strengthen collaboration. The authors also stress that cross-platform access is needed for wider use (Jovanović & Milosavljević, 2022).

The sixth highest cited paper is by Díaz et al., (2020) titled *Virtual World as a Resource for Hybrid Education*. Published in the *International Journal of Emerging Technologies in Learning*, it also has 234 citations. This research shows how virtual worlds can connect physical and online classrooms to create hybrid models. Students benefit from flexibility and interactive learning. The authors also warn of barriers such as infrastructure and teacher training. It is one of the earlier works on metaverse-based hybrid education (Díaz et al., 2020).

The seventh highest cited paper is by Comino and Narasimhan (2022) titled *Healthcare in Metaverse: A Survey on Current Metaverse Applications in Healthcare*. Published in *IEEE Access*, it has 223 citations. This paper reviews how the metaverse is being applied in healthcare, including telemedicine, clinical care, and fitness. It also discusses challenges like data security and hardware issues. The paper offers a roadmap for applying metaverse tools to transform healthcare systems (Comino & Narasimhan, 2022).

The eighth highest cited paper is by Damar (2021) titled *Metaverse Shape of Your Life for Future: A bibliometric snapshot*. Published in the *Journal of Metaverse*, it has 215 citations. The study provides a bibliometric analysis of metaverse research, showing growth trends, popular themes, and leading authors. It finds education, gaming, and healthcare as top fields, but also points out gaps in ethics and sustainability (Damar, 2021).

The ninth highest cited paper is by Lee and Hwang (2022) titled *Technology-Enhanced Education through VR-Making and Metaverse-Linking to Foster Teacher Readiness and Sustainable Learning*. Published in *Sustainability (Switzerland)*, it has 209 citations. This paper shows how teachers can use virtual reality and metaverse tools to improve readiness and create sustainable learning environments. The authors highlight the importance of teacher training in adopting immersive technology (Lee & Hwang, 2022).

Finally, the tenth highest cited paper is by S. M. Park and Kim (2022) titled *Identifying World Types to Deliver Gameful Experiences for Sustainable Learning in the Metaverse*. Published in *Sustainability (Switzerland)*, it has 200 citations. This paper categorizes different world types, such as cooperative and competitive, to see how they support learning. It finds that game-like designs can improve student motivation and support long-term sustainable learning (S. M. Park & Kim, 2022).

Table 4: The most highly cited articles of the metaverse in education-related studies

No	Title or article	Publisher	Publication	TC	Authors/ Reference
1	Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy	Elsevier	*International Journal of Information Management*	1823	Dwivedi et al. (2022)
2	A Metaverse: Taxonomy, Components, Applications, and Open Challenges	Institute of Electrical and Electronics Engineers Inc.	*IEEE Access*	1271	S. Park and Kim (2022)
3	Definition, roles, and potential research issues of the metaverse in education: An artificial intelligence perspective	Elsevier	*Computers and Education: Artificial Intelligence*	536	Hwang and Chien (2022)
4	The challenges of entering the metaverse: An experiment on the effect of extended reality on workload	Springer	*Information Systems Frontiers*	281	Xi et al. (2023)
5	VoRtex Metaverse Platform for Gamified Collaborative Learning	MDPI	*Electronics (Switzerland)*	234	Jovanović and Milosavljević (2022)
6	Virtual world as a resource for hybrid education	Kassel University Press GmbH	*International Journal of Emerging Technologies in Learning*	234	Díaz et al. (2020)
7	Healthcare in Metaverse: A Survey on Current Metaverse Applications in Healthcare	Institute of Electrical and Electronics Engineers Inc.	*IEEE Access*	223	Comino and Narasimhan (2022)
8	Metaverse Shape of Your Life for Future: A bibliometric snapshot	Izmir Academy Association	*Journal of Metaverse*	215	Damar (2021)
9	Technology-Enhanced Education through VR-Making and Metaverse-Linking to Foster Teacher Readiness and Sustainable Learning	MDPI	*Sustainability (Switzerland)*	209	Lee and Hwang (2022)
10	Identifying World Types to Deliver Gameful Experiences for Sustainable Learning in the Metaverse	MDPI	*Sustainability (Switzerland)*	200	S. M. Park and Kim, (2022)
Tc = total citation					

4.6 Analysis of Authors' Keywords

An analysis of the keywords used was carried out to comprehend the primary information of the articles. In this section, we performed an analysis of the authors' keywords. Authors' keywords are determined by their opinion of three to five words that they believe are the most essential keywords to represent the content of their articles. We conducted a bibliometric author keywords analysis of articles published in the Scopus database using VOSviewer and 5,699 keywords were extracted. After setting a minimum occurrence threshold of 20, keywords that occurred less than 20 times were removed, leaving only 59 potential keywords. We then meticulously analyzed these remaining keywords, filtering out irrelevant and redundant keywords, resulting in 30, as listed in Table 5.

Table 5: The most mentioned authors' keywords of metaverse in education-related studies

Rank	Keywords Term	Occurrence	Total Link Strength
1	Virtual reality	483	2656
2	Metaverse	411	1604
3	Extended reality	303	1180
4	Augmented reality	234	1288
5	Education	187	1135
6	Learning	123	776
7	Mixed reality	91	563
8	E-learning	90	584
9	Artificial intelligence	77	462
10	Medical education	64	575
11	Deep learning	55	277
12	Teaching	51	362
13	Immersive	51	296
14	Machine learning	50	336
15	Simulation	48	384
16	Engineering education	44	284
17	Learning systems	43	253
18	Virtual environments	36	205
19	Digital twin	33	205
20	Blockchain	31	201
21	Reinforcement learning	29	161
22	Computer aided instruction	28	190
23	Machine-learning	28	183
24	Computer simulation	25	240
25	Immersive learning	25	122
26	Educational technology	22	131
27	Immersive technology	22	103
28	Psychology	21	217
29	Internet of things	21	148
30	Personnel training	20	113

The importance of interactive technologies in metaverse-based education is underscored by the first five keywords: virtual reality, metaverse, extended reality, augmented reality, and education. Extended reality is a term that encompasses virtual reality, augmented reality, and mixed reality, and plays a

significant role in establishing learning resources and activities in a metaverse environment. Among the three, mixed reality is the most recent interactive technology, which justifies its relatively lower number of occurrences (91) in document collections. This suggests that there is much to be explored regarding understanding the concept and application of mixed reality in educational technology.

Upon conducting an in-depth analysis of Table 5, a noteworthy trend surfaced in metaverse education. The utilization of artificial intelligence (77 occurrences) in metaverse-based education is steadily gaining momentum, as evidenced by the keyword analysis. Additionally, the implementation of machine learning (50 occurrences) and deep learning (55 occurrences) is crucial to ensure seamless and adaptive user interactions when learning in a virtual environment such as the metaverse.

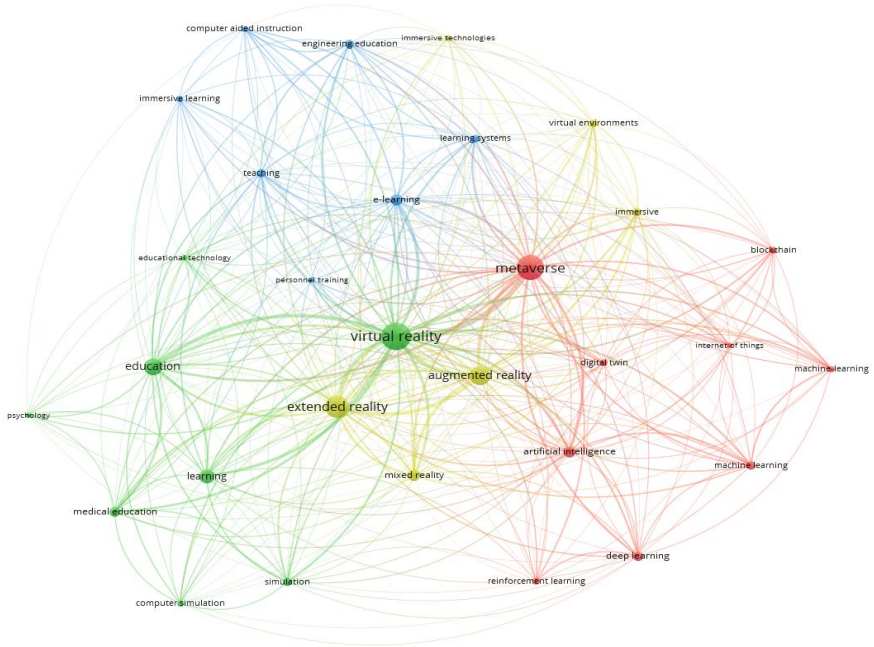

Figure 5: Co-occurrence network of high-frequency author's keywords using VOSviewer

Figure 5 shows a graph of network visualization of authors' keywords in which the size of a node indicates the weight of a keyword's occurrence in a collection of 838 articles. The node labeled virtual reality appears the largest, indicating it is the most frequently occurring keyword, followed by education, extended reality, and metaverse. The line between two nodes represents the relationship between the associated keywords.

For example, the virtual reality node is directly linked to education, extended reality, augmented reality, and metaverse. These relationships suggest that, for effective educational experiences in virtual environments, technologies such as augmented reality and extended reality play a significant role, enhancing interactivity and immersion. Moreover, the direct link from the virtual reality node to medical education and simulation indicates that virtual reality is

instrumental in simulating real-world scenarios for practical training, particularly in complex domains such as healthcare.

Additionally, there are direct links from extended reality to mixed reality, augmented reality, and virtual reality nodes, implying a close correlation among these interactive technologies. While the interconnecting lines between the nodes in a graph represent the relationship between them, the distance between these nodes can be used to determine the strength and significance of their relationship. The shorter the distance between two nodes, the stronger their correlation. For example, virtual reality, education, extended reality, learning, and simulation nodes are situated near each other, indicating a strong connection between them.

This could be interpreted as immersive technologies significantly impacting educational processes. Another example is the short distance between the metaverse and augmented reality nodes, which implies the key role of augmented reality in developing metaverse-based educational applications. Similarly, artificial intelligence and machine learning nodes are situated close together, suggesting these technologies are crucial to implementing intelligent and adaptive learning systems in immersive environments.

4.7 Analysis of Index Keywords

By utilizing the authors' chosen keywords, we gained insights into the article's overall content from the authors' perspective, as well as their research interests and focus. Alternatively, index keywords analysis, commonly known as keyword plus, is generated via computer algorithms that consider the frequency of the keywords' appearance in the articles' content (Zhang et al., 2016). This approach is founded on the notion that the more frequently a keyword appears in the content, the more significant it is. It can serve as a representation of the knowledge structure underlying the reported research. The bibliometric analysis of co-occurrence keywords was visualized using VOSviewer.

About 4,207 keywords were extracted from this keyword-plus approach and only 47 had a frequency of more than 20. We carefully analyzed all 47 keywords, filtering out irrelevant and redundant keywords, eliminating keywords that occurred less than 20 times, and ultimately keeping only the top 26 most relevant ones on the field of metaverse in education. For each of the 26 keywords, the total number of keyword occurrences and the strength of the co-occurrence links with other keywords were calculated, as displayed in Table 6.

Table 6: Summary of index keywords based on their occurrence and total link strength

Research Areas	Keyword Term	Occurrence
Cluster 1 (application and evaluation)	Computer simulation	24
	Education	98
	Learning	98
	Medical education	54
	Psychology	20
	Simulation	32
	Virtual reality	312
Cluster 2 (immersive & interactive technologies)	Augmented reality	151
	Extended reality	128
	Human-computer interaction	21
	Immersive	46
	Mixed reality	52
	Virtual environments	35
Cluster 3 (instructional design & e-learning development)	Computer aided instruction	28
	E-learning	80
	Engineering education	42
	Personnel training	20
	Teaching	47
Cluster 4 (smart & secure online virtual learning	Artificial intelligence	42
	Avatar	23
	Blockchain	25
	Machine learning	28
	Metaverses	2638
Cluster 5 (emerging intelligent technologies)	Decision making	24
	Deep learning	49
	Reinforcement learning	29

The visualization of the network graph using VOSviewer in Figure 6 illustrates that the 26 keywords formed five distinct clusters.

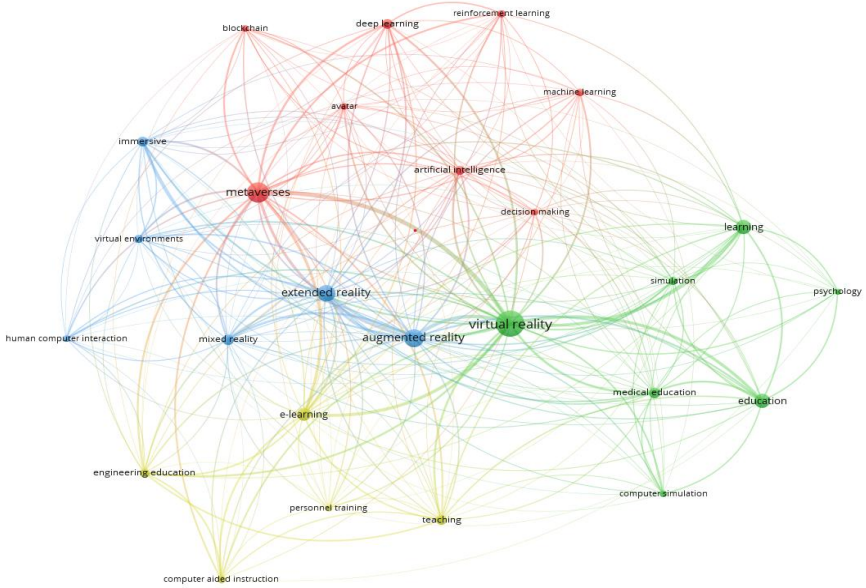

Figure 6: Network visualization of articles by Index keywords using co-occurrence analysis

The circles belonging to the same color cluster represent publications with similar research areas. Each cluster represents a subfield within the larger metaverse field for education, providing a more detailed understanding of the research areas. Analyzing these clusters provided insights into the knowledge structure of metaverse research in education. Additionally, Figure 7 includes cluster information according to yearly research trends. The following discussion section provides a detailed discussion of these clusters.

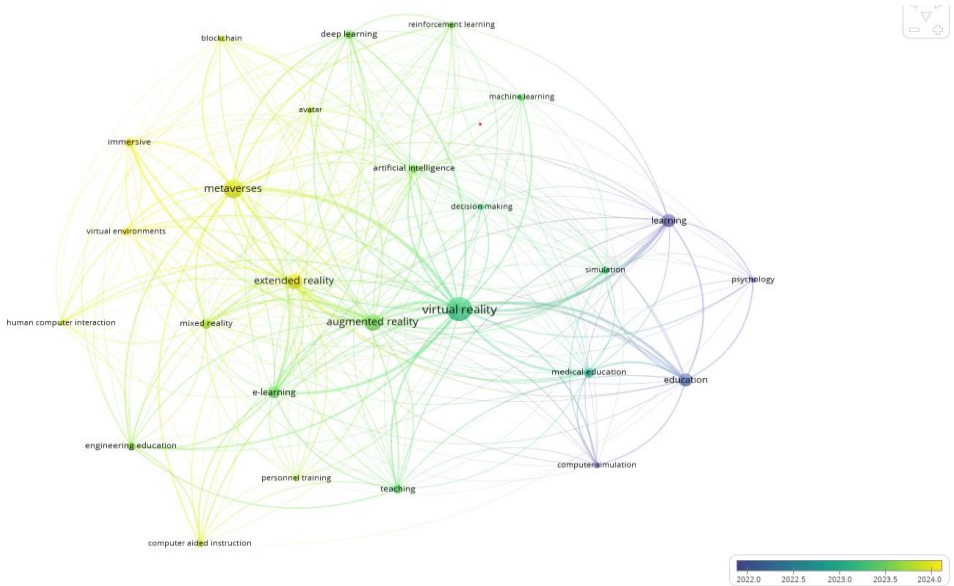

Figure 7: Network visualization of articles by index keywords using co-occurrence and organized based on yearly trends

Figure 7 shows a graphical representation of how the occurrence of keywords related to the metaverse in education has evolved over the years. The graph uses a color-coded format, in which the oldest publications are represented by dark purple and the most recent ones are in yellow. By analyzing the graph, it can be inferred that recent research on the metaverse in education is increasingly oriented towards the integration of intelligent and immersive technologies (such as artificial intelligence, blockchain, deep learning, and reinforcement learning) to enhance security, personalization, and decision-making in educational contexts. The graph also denotes that, in recent times, a growing emphasis is on metaverse platforms and extended reality for creating interactive virtual learning environments, as opposed to solely relying on traditional e-learning or virtual reality platforms.

Metaverse platforms are virtual environments that allow users to interact with each other in a fully immersive and three-dimensional space. This means that students can engage more effectively with the learning content and each other, leading to a more dynamic and collaborative learning experience. The graph also reveals a growing focus in metaverse research in education (shown as circles with yellow color) in comparison to earlier works centered around virtual reality, simulation, and computer-aided instruction (depicted in green and purple), indicating a shift toward more advanced and connected educational ecosystems. Furthermore, the proximity of recent keywords such as avatar, immersive, and virtual environments to the metaverses node suggests that the design of user-centered, engaging, and realistic environments is becoming a key area of interest in current educational research.

5. Discussion

The bibliometric analysis conducted in this study reveals the growth of research examining the use of metaverse in education. Our findings show a steady increase in publications between 2010 and 2025, with a remarkable surge beginning in 2020 (Figure 2). The number of publications rose significantly in 2022, peaking in 2024 with 270 works. A slight decrease in 2025 is due to the year still being in progress, with more outputs expected. Similarly, citations show a rapid rise since 2020, with a dramatic increase in 2022 when publications received more than 5,000 citations (Figure 3). This demonstrates the recognition of metaverse as an important educational field that will likely sustain attention in the future. However, the increase in numbers does not always show the real depth of research, as some works may be driven by trends and not by long-term impact.

Our analysis of the subject areas shows that research on the metaverse in education is inherently multidisciplinary, involving 10 major fields (Table 1). Computer science (49.0%) dominates as the leading discipline, developing technological foundations such as virtual environments, extended reality devices, and artificial intelligence for adaptive learning. The social sciences (35.2%) contribute significantly by exploring pedagogical frameworks, learner engagement, and the cultural acceptance of immersive education. Engineering (28.3%) supports the integration of hardware and system architectures required for large-scale educational applications of the metaverse. Medicine (17.5%) is

another crucial area, using simulation and immersive technologies to train students in complex medical procedures and healthcare delivery. However, despite this variety, little integration exists across these disciplines, which may limit the full potential of the metaverse in education. For example, many projects focus mainly on technical innovation without equally considering learning theories or social impacts. As a result, educational systems may adopt impressive technologies that lack pedagogical depth or cultural adaptability. A stronger collaboration between technologists, educators, and social scientists could lead to more meaningful and inclusive uses of the metaverse in education.

Other subject areas, though smaller in percentage, play unique roles. Material science (7.8%) explores advanced devices and interfaces that make extended reality more efficient and accessible. Mathematics (5.7%) contributes models and simulations for immersive learning environments. Psychology (5.1%) investigates the cognitive and behavioral impacts of immersive technologies, particularly how students perceive and adapt to learning in virtual spaces. Business, management, and accounting (5.0%) examine the potential of the metaverse for professional training, management education, and entrepreneurship learning. Neuroscience (4.4%) studies how brain responses adapt to immersive interactions, offering insights into effective instructional design. Arts and humanities (4.3%) emphasize creativity, culture, and critical reflections on digital identity and representation in the metaverse. However, these smaller areas remain underexplored and often lack strong connections to mainstream studies.

This broad participation highlights that metaverse in education cannot be addressed from a single lens. Instead, it requires cooperation between technical, social, medical, and creative domains to ensure the development of effective, engaging, and ethically sound educational environments. A challenge is that such cooperation is still rare, and many studies stay within their own fields without building wider collaborations. The study further found that research on metaverse in education is globally distributed, with 79 countries producing publications. The United States (21.4%) and China (12.5%) are the top contributors, followed by South Korea, India, and the United Kingdom. European countries, such as Italy, Germany, and Spain, along with Australia and Canada, also show strong participation (Table 2).

Both the United States and China are technology-developing countries, while most other countries are technology users. Because of this, these two countries lead technological trends, including the metaverse. Network mapping reveals strong collaborations between the United States and Europe, and between China and Asian countries such as South Korea and India. Regional partnerships between Malaysia, Indonesia, and Middle Eastern countries also emerged, reflecting the global spread of research in this area. Even so, many developing countries remain underrepresented, which creates a gap in perspectives from less advanced contexts.

Our journal analysis demonstrates that *IEEE Access* is the most influential outlet, with 43 publications and 2,230 citations, followed by *IEEE Transactions on Learning*

Technologies and Applied Sciences (Switzerland). Many productive journals, such as *Electronics (Switzerland)*, *Frontiers in Education*, and *Journal of Metaverse*, are open access, which enhances visibility and citation impact (Table 3). The inclusion of high-impact technical journals such as *IEEE Journal on Selected Areas in Communications* (impact factor 17.2) also shows that educational metaverse research attracts attention beyond pedagogy-focused journals. This accessibility and multidisciplinary reach signal that the field is expanding rapidly into both education and advanced technology domains. Still, high impact journals are often more focused on technical issues, which may not fully reflect educational outcomes.

The citation analysis highlights the most influential works shaping this field. Research by Dwivedi et al. (2022) is the most cited with 1,823 citations, providing a multidisciplinary agenda for metaverse research. S. Park and Kim (2022) follow with 1,271 citations, creating a taxonomy of metaverse applications and challenges. Hwang and Chien (2022) rank third with 536 citations, focusing on artificial intelligence in educational metaverse. Other highly cited works, such as Xi et al. (2023), Jovanović and Milosavljević (2022), and Díaz et al. (2020), highlight extended reality challenges, gamified learning, and hybrid education (Table 4). These works show that the highly cited literature spans technical, educational, and healthcare applications, demonstrating the wide impact of metaverse studies. However, relying only on citation counts may favor early publications and overlook newer but promising studies.

The keyword analysis further underscores that the field is dominated by interactive technologies such as virtual reality, metaverse, extended reality, augmented reality, and education (Table 5). The strong linkages among these keywords show that immersive technologies are central to metaverse-based learning, with artificial intelligence, machine learning, and deep learning becoming increasingly important to personalize and support adaptive learning (Zhang et al., 2016). Medical education, simulation, and e-learning also emerged as significant clusters, pointing to practical applications in training and instructional design. Nonetheless, the focus on technology terms may overshadow critical social, ethical, and cultural issues that also affect the success of metaverse in education.

The index keyword analysis (Table 6) reveals five distinct research areas that represent the future directions for integrating metaverse into education; first, educational applications and evaluation are important. Keywords such as simulation, psychology, and medical education show that the metaverse is being used to create real-world learning situations, especially in training that is hard, risky, or costly in normal settings. For example, immersive simulations allow medical students to practice important procedures safely (Hwang & Chien, 2022). Psychology-related studies also show how learners respond to virtual settings (Xi et al., 2023). In healthcare, metaverse tools are already being used in clinical training and telemedicine (Comino & Narasimhan, 2022). These works show that testing and evaluation are needed to measure how effective these applications are for students.

Second, immersive and interactive technologies such as augmented reality, mixed reality, and extended reality are the base of metaverse learning. These tools make learning more engaging and help students understand complex subjects better. Studies have shown that immersive extended reality systems improve engagement but may also increase mental effort and stress for learners (Xi et al., 2023). Platforms such as the VoRtex system use avatars and group activities to improve teamwork and learning outcomes (Jovanović & Milosavljević, 2022). Virtual worlds are also used to support hybrid education, giving students flexible and interactive learning options (Díaz, Saldaña, & Ávila, 2020).

Third, instructional design and e-learning development focus on how lessons are planned and delivered in the metaverse. Concepts such as computer-aided instruction, e-learning, and training show that lessons are moving from simple content delivery to interactive and engaging systems. For example, teachers can use virtual reality and metaverse tools to prepare for sustainable teaching (Lee & Hwang, 2022). Game based designs have also been studied to show how different world types can improve student motivation and long-term learning (S. M. Park & Kim, 2022). These works show that the way learning is designed is changing to suit immersive education.

Fourth, secure online learning platforms are a growing need. Keywords such as artificial intelligence, blockchain, avatar, and machine learning point to the importance of safe and trustworthy metaverse systems. Artificial intelligence helps provide feedback and adjust learning to fit student needs (Hwang & Chien, 2022). Security challenges and blockchain solutions have been discussed as key issues for adoption (Dwivedi et al., 2022). Avatars are also important in building presence and interaction but bring challenges related to identity and assessment (Damar, 2021). These tools help to make learning more reliable and safer.

Fifth, emerging intelligent technologies such as deep learning and reinforcement learning are shaping the future of metaverse education. These systems can study student actions and adjust the content to give a more personal learning path (S. Park & Kim, 2022). They also improve group learning and make large scale immersive systems possible (Dwivedi et al., 2022). In healthcare, artificial intelligence helps simulations give real-time feedback to improve student performance (Comino & Narasimhan, 2022). These studies show that intelligent systems are becoming important to support effective learning in the metaverse.

Overall, these five areas, which are applications and evaluation, immersive technologies, instructional design, secure platforms, and intelligent systems, form the focus of research on metaverse in education. Earlier studies paid more attention to simulation and virtual reality-based learning (Díaz et al., 2020), while other research is moving towards more intelligent and secure metaverse platforms that support personal and group learning in the long term (Dwivedi et al., 2022; Hwang & Chien, 2022; S. Park & Kim, 2022).

6. Conclusion

The study investigated the research landscape of the metaverse in education. We employed a bibliometric approach to analyze publications from 2010 to 2025, aiming to uncover research trends and landscapes. Our study provides evidence of the rapidly increasing interest in using and implementing the metaverse for education and its potential. Our analysis highlights the top-producing countries, journals, publishers, highly cited articles, and five important research areas that can serve as a solid basis for future exploration in this domain.

Our analysis also reveals that recent research on metaverse education is primarily focused on immersive technologies, secure and reliable platforms, and the utilization of intelligent systems, such as artificial intelligence and machine learning, to support adaptive and personalized learning. This study also offers valuable insights into the current state of research in metaverse education and provides a roadmap for future research directions.

The paper will benefit researchers, instructional designers, educators, and policymakers. The identified research areas can help researchers align their work with ongoing trends and contribute to building a complete ecosystem of the educational metaverse. Educators can benefit from understanding how immersive tools can improve teaching methods and enhance student engagement. Instructional designers can use these insights to develop more interactive and adaptive online learning experiences. Finally, policymakers can use the findings to plan strategies, develop policies, and allocate resources to ensure equitable and sustainable integration of the metaverse into educational systems.

However, this study has a limitation as it only uses the Scopus database for data collection. For a more comprehensive review, future studies should include other databases such as Web of Science (WoS), Dimensions, Lens, and others. For the metaverse to truly transform learning globally, future research must actively address issues of accessibility, digital equity, and culturally responsive pedagogical design.

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