Pedagogical approaches for Metaverse-based engineering education

Veselina NEDEVA, Zlatoeli DUCHEVA

Trakia University – Stara Zagora, Faculty of Technics and Technologies,
"Graf Ignatiev" Str. 38, Yambol, Bulgaria

veselina.nedeva@trakia-uni.bg, zlatoeli.ducheva@trakia-uni.bg

Abstract: *This paper describes pedagogical approaches in metaverse engineering education, with a focus on the application of Metaverse technologies. The research methods employed include data collection, a keyword-based search strategy, data extraction, and various forms of analysis: bibliometric, visualization, and interpretation. The results are presented in tables and charts. Key characteristics and major types of Metaverse technologies are identified according to the authors of the reviewed publications, including Augmented Reality and Virtual Reality, Artificial Intelligence, Simulation, Blockchain, Cryptocurrencies, and the Internet of Things. Additionally, Avatar-based and Second Life Systems, Learning Management Systems, and Social Media are discussed. According to the authors, these systems are not merely components of the Metaverse but are also significantly influenced and enhanced by Metaverse technologies. This influence is demonstrated in how these systems leverage virtual and augmented reality, immersive simulations, and artificial intelligence to create more interactive and engaging user experiences. The authors provide a critical perspective by not only listing the technologies but also discussing how certain systems are shaped by the advancement of Metaverse technologies, reflecting a depth of analysis that goes beyond mere description. The paper also highlights the analysis of various pedagogical approaches, such as constructivist, collaborative, integrative learning, reflective, inquiry-based learning, and continuous assessment and feedback, offering practical insights into how these technologies can be applied in educational settings.*

Keywords: engineering education, Metaverse technologies, pedagogical approaches.

1. Introduction

Integrating digital technologies within the Metaverse has transformed education, offering innovative pedagogical strategies and immersive learning experiences that complement traditional teaching methods (Wong et al., 2023; Ghoulam & Bouikhalene, 2024). Digital technologies in the Metaverse provide opportunities and pedagogical strategies that enhance students' learning outcomes (Ng, 2022; Marques et al., 2024). Metaverse-based learning transcends spatial and temporal limitations, enabling the sharing of high-quality educational resources, particularly in higher education, where it plays a crucial role in improving the quality of teaching and learning for sustainable development (Gao et al., 2024).

https://doi.org/10.58503/icvl-v19y202412

Education is one of the fields where the Metaverse is a collective virtual shared environment formed by the confluence of persistent virtual spaces and augmented physical reality is increasingly being recognized as a revolutionary platform. It offers immersive, dynamic, and hands-on learning environments that have the potential to significantly improve academic outcomes. The Metaverse provides unique opportunities for engineering education by simulating real-world engineering problems, promoting collaborative learning, and engaging students in ways that conventional approaches may not (Lee et al., 2021).

The objective of this research is to explore and identify effective pedagogical approaches for incorporating the Metaverse into engineering education. By leveraging the immersive and interactive features of the Metaverse, educators can address current challenges in education, enhance student engagement, and improve learning outcomes. This study is important because it contributes to the ongoing discourse on educational innovation and reform by offering a model for the integration of Metaverse-based learning environments in engineering education.

2. Research methods

To review the pedagogical approaches for engineering education in the metaverse the research of the sources databases was made. This study uses quantitative and qualitative synthesis methodologies. Before doing any research, the traditional systematic review is a crucial step, but a manual review can induce bias in reporting and result interpretation is often subjective (He at al. 2017). Consequently, to determine a topic's knowledge base and evolution scientifically, a systematic review utilizing mixed methods - bibliometric analysis combined with content analysis (Tlili at al. 2022).

2.1 Data collection

(1) Database Selection: The Web of Science Core Collection (WoSCC) and Google Scholar databases were used for scientific research on the topic.

(2) Search Strategy: The search strategy was based on keywords determined according to the authors' experience in the field, preliminary information on the topic, and the goals of the scientific publication. The search was conducted using the following keywords: METAVERSE AND ENGINEERING EDUCATION AND (EXTENDED REALITY OR XR OR MIXED REALITY OR EXTENDED REALITY TECHNOLOGY OR ARTIFICIAL INTELIGENCE). As a result, a list of 9,768 publications was compiled. Data from 2024 are not comparable to data from other years because it only covers up to June 2024. However, it is included as it shows a clear trend of increasing publications in the area outlined by these keywords.

During the analysis, it was necessary to search for sources under additional criteria to confirm or reject statements where there were disagreements. This search was conducted in WoSCC using the keywords: PEDAGOGICAL APPROACHES,

BLOCKCHAIN, CRYPTOCURRENCIES, INTERNET OF THINGS**.** As a result, an additional 17 sources were identified, some of which were manually scanned and analyzed.

(3) Inclusion and Exclusion Criteria: Publications were screened based on parameters such as language (only English), document type (articles, conference papers; open access), and publication year (from 2013 to June 2024); research areas (engineering education and research). After applying these criteria, 3,157 records from WoSCC remained.

(4) Data Extraction: The extracted data served as the basis for additional analysis. Pertinent bibliometric data, such as publication years, record counts, and citation counts, were collected.

2.2 Steps and processes

Preprocessing: The data were cleaned and preprocessed to ensure consistency and accuracy. This included removing duplicates, standardizing term variations, and ensuring that all records were complete.

Bibliometric Analysis: Quantitative analysis was conducted to examine publication trends, citation patterns, and the distribution of research output over time.

Visualization and Interpretation: The processed data were visualized using VOSviewer to identify key research areas, influential studies, and emerging trends. The visualizations were interpreted to provide insights into the state and evolution of research on the given topic.

Completion of the List of Scientific Publications: The list of scientific publications from Google Scholar was completed according to the terms obtained from VOSviewer. The Google Scholar database search was performed using Publish or Perish software (Harzing, 2010).

Data Compilation: The data from WoSCC and Google Scholar were compiled into a unified dataset for analysis by merging publications from both sources.

Manual Screening: Publications were manually screened for research relevance based on the abstract, keywords, and title. After this analysis, approximately 50 studies were included for full-text review, of which 25 were analyzed in the report.

3. Results

3.1 Analysis of citations and publications

The data spans from 2013 to June 2024, capturing the number of citations and publications per year (Table 1). Below is the detailed analysis including absolute numbers and percentages for both citations and publications.

The emerging trends are evident. All years have seen an increase in publications and citations, with the rapid dissemination of published results leading to faster growth in citations compared to publications. The largest increase in citations was observed in 2023: this included 9,893 citations, representing 28.37% of their total number. Similar results are also seen in the publications – 616 publications, which is 18.91% of their total number for the period. The following year 2024, for which there is data until June 2024, shows and continues this trend. In 2024, although the data is only until June, there is already a substantial number of citations (5,863) and publications (346), which signifies continued relevance and impact. The constant growth of publications and citations in 2021, 2022 and 2023. In 2023 is shown a significant increase in both citations and publications. These years alone account for 59.61% of the total citations and 45.41% of the total publications.

Table 1. Number of publications and citations by year according to WoSCC

Year	Citations	Publications	Citations (%)	Publications (%)
2013	13	78	0.04%	2.39%
2014	97	75	0.28%	2.30%
2015	173	64	0.50%	1.96%
2016	339	135	0.97%	4.14%
2017	627	149	1.80%	4.57%
2018	1008	265	2.89%	8.14%
2019	1698	365	4.87%	11.21%
2020	2871	301	8.23%	9.24%
2021	5005	379	14.35%	11.64%
2022	7282	484	20.88%	14.86%
2023	9893	616	28.37%	18.91%
Jume 2024	5863	346	16.81%	10.62%

These results are also contained in the attached diagram (Figure 1), which reflects the results, both in absolute values and as percentages of the total number.

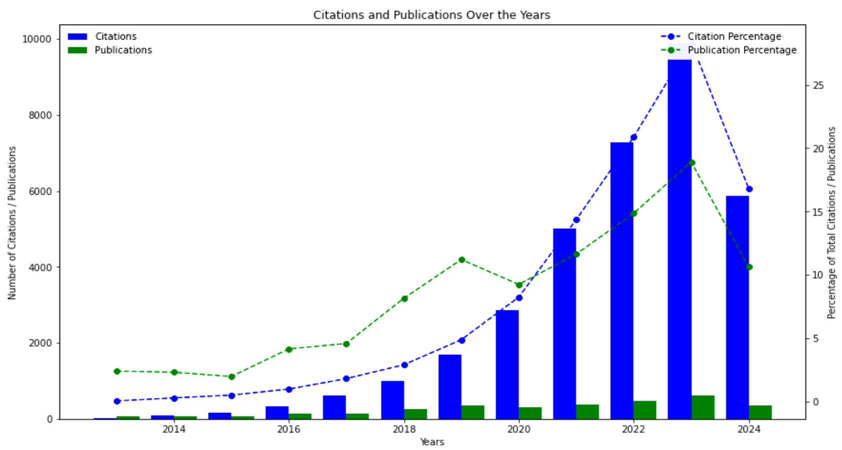

Figure 1. Citation and publications over the years

3.2 Visualization and interpretation by VOSviewer

VOSviewer is a software application designed for creating and visualizing bibliometric networks, which can be constructed based on citation, bibliographic coupling, co-citation, or co-authorship interactions (Van Eck & Waltman, 2010). These networks can involve journals, researchers, or individual articles, providing a comprehensive view of the research landscape. The tool allows for detailed analysis and visualization of the relationships between various terms and concepts within the gathered data.

The visualization capabilities of VOSviewer enable users to see how different terms co-occur and their relevance to the study's focus. By examining these relationships, researchers can gain insights into the connections between various study subjects. The software's clustering feature is particularly useful for identifying significant themes and trends in the data, which are then displayed in a network map. This visual representation makes it easier to understand the importance and interconnections of different topics within a discipline.

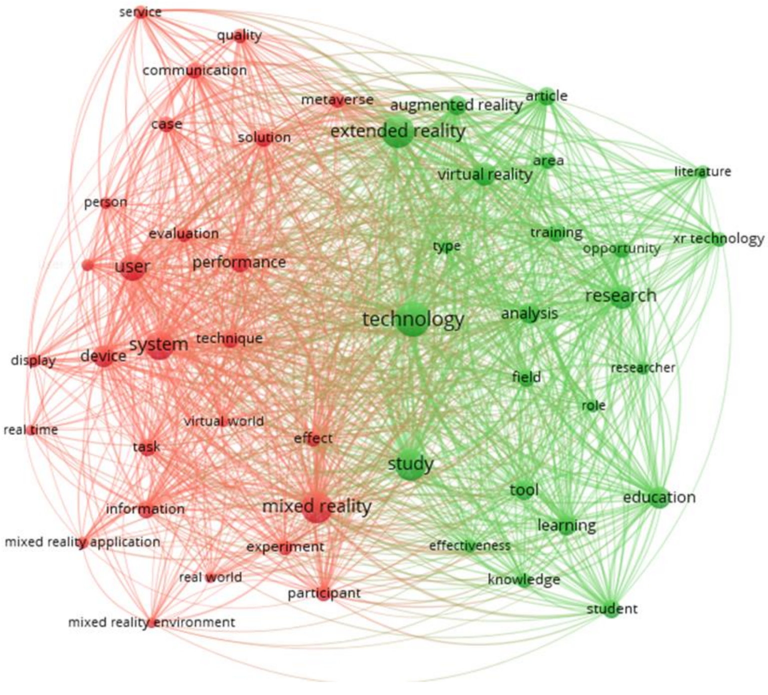

Figure 2. Terms and clusters from VOSviewer

In a specific analysis of the first 1000 records out of 3157 from the WoSCC data, VOSviewer was used to focus on terms that appeared at least 45 times. This approach aimed to concentrate on the main terms within the analyzed area, resulting in the selection of 49 terms divided into two clusters for graphical presentation. Key metrics like occurrences and relevance scores provided additional insights, highlighting terms such as "technology," "extended reality," "study," and "mixed reality" for their high frequency and importance.

The first cluster (Figure 2), depicted in green, focuses on academic and research-oriented topics, particularly the study and implementation of various reality technologies (augmented, virtual, extended reality) in educational and training contexts. Core terms like "research," "technology," "study," and "education" reflect a strong emphasis on scientific analysis and knowledge dissemination. Notable terms in this cluster include "augmented reality," "virtual reality," "xr technology," and "training."

The second cluster (Figure 2), shown in red, centers on the practical and user-oriented aspects of these technologies. Terms such as "user," "system," and "device" emphasize the focus on implementation and user interaction. This cluster also highlights performance and evaluation metrics, as well as real-time applications, with core terms including "user," "system," "device," and "performance." Notable terms here are "quality," "real-time," "mixed reality application," and "user experience."

This graphical and term analysis facilitated the identification of key themes and trends, allowing researchers to limit the number of scientific articles and papers to those meeting specific criteria based on the most common terms. As a result, they were identified 18 scientific publications on which our analysis is based.

4. Disscussion

4.1 Metaverse technologies and their role in pedagogical approaches to Engineering Education according to various authors

The paper provides a more detailed introduction to the technologies to better reflect their transformative role in pedagogical approaches. The Metaverse unites fragmented virtual worlds into a persistent digital realm. It encompasses all virtual and augmented reality experiences, including IoT, AI, and machine learning interactions between virtual environments and the real world. Nowadays, various teaching methods and approaches are widely accepted (Harte, 2024). Educators employ diverse and highly creative methods, incorporating specific strategies and tools (Terzieva et al., 2021).

Key characteristics of engineering education in the Metaverse include:

- Immersion and Simulation: Creating realistic simulations and environments that offer experiential learning;
- Collaboration and Social Interaction: Facilitating teamwork and peer interaction in virtual spaces;
- Personalization: Adapting learning paths to individual needs using AI and other technologies;

- Engagement through Gamification: Using game-based elements to make learning more engaging;
- Experiential Learning: Offering hands-on activities in virtual labs and augmented reality scenarios.

The study shows that existing pedagogical approaches are evolving to a new level due to the technological components of the Metaverse. Ng (2022) suggests that the Metaverse is a combinatorial technological innovation that integrates existing technologies to create exponential gains in educational value and applications. His study proposes four key components of the Metaverse: immersion, advanced computing, socialization, and decentralization, and identifies five major types of technologies associated with these components.

Augmented reality (AR) and Virtual reality (VR): Research shows their effectiveness in increasing students' motivation, knowledge, and skills acquisition. These technologies combine digital and physical objects, creating immersive learning environments where learners can develop practical skills (Noh, 2022) and processing skills (e.g., communication, critical thinking, problem-solving) (Potkonjak et al., 2016).

Simulation: Simulation is a technology that effectively improves students' knowledge, skills, and behaviors, allowing them to participate in authentic scenarios that replicate real-world practice (O'Regan et al., 2016; Rooney & Nyström, 2018), including engineering practices.

Artificial Intelligence (AI): AI is transforming various industries, including education, by improving user experience, work efficiency, and job opportunities. Researchers are integrating AI into virtual worlds, such as through data mining and autonomous tutors, enabling learners to interact with smart devices, enhancing online learning, and increasing the acceptance of technology and motivation. Future metaverses could incorporate AI elements for a more immersive learning experience.

AI-powered tools facilitate real-time problem-solving and decision-making scenarios, allowing students to apply theoretical knowledge in practical, virtual environments. This hands-on experience is crucial for developing the critical thinking and technical skills essential for engineering practice (Johnson et al., 2015). Additionally, AI enhances collaborative learning by forming intelligent virtual teams, promoting communication and teamwork among students, regardless of their physical location. Overall, AI in the Metaverse prepares engineering students for future challenges by offering interactive, adaptive, and collaborative learning experiences.

Ng (2022) also includes "Avatar-based and Second Life Systems" and "Learning Management Systems (LMS) and Social Media" as technologies associated with the Metaverse. We argue that these systems are not only part of the Metaverse but are also significantly influenced and enhanced by it. This is evident in how these systems leverage virtual and augmented reality, immersive simulations, and AI to create more interactive and engaging user experiences. While Ng (2022) categorizes these technologies as part of the Metaverse, we emphasize their dynamic relationship and the reciprocal impact of Metaverse advancements on their evolution and functionality.

Avatar-based and Second Life Systems: These systems provide students with social and cognitive support, allowing them to gain knowledge by visualizing concepts and participating in hands-on experiences in a virtual environment (Ng, 2022).

Learning Management Systems and Social Media: These platforms enable learners to discuss and communicate using visual identities for learning objectives. LMS and social networking systems (SNS) can incorporate Metaverse technologies, allowing learners to socialize in an authentic and lifelogging world, as well as record, share, and accumulate their daily activities (e.g., using AR in Facebook) (Tlili et al., 2022).

We supplement the technologies proposed by Ng (2022) with additional ones not covered in his study:

Blockchain: Blockchain technology offers several benefits for engineering education in the Metaverse by providing secure, transparent, and decentralized systems for managing academic records and credentials. Educational institutions can issue tamper-proof digital diplomas and certificates using blockchain, ensuring that students' achievements are verifiable and recognized globally (Zheng et al., 2018). This enhances the credibility and portability of qualifications, making it easier for students to present their credentials to potential employers or other institutions.

Cryptocurrencies: The use of cryptocurrencies in the Metaverse can provide incentives for student engagement and participation. For instance, students can earn cryptocurrency rewards for completing assignments, contributing to discussions, or collaborating on projects. These incentives can motivate students to become more active participants in their education while also teaching them about the real-world value and potential uses of digital currencies. Integrating cryptocurrency technology into engineering education in the Metaverse fosters practical financial literacy and engagement, equipping students with valuable skills for the digital economy (Tapscott & Tapscott, 2016).

Internet of Things (IoT): IoT in engineering education within the Metaverse offers significant benefits by creating highly interactive and interconnected learning environments. IoT enables the simulation of real-world systems and devices, allowing students to interact with and control virtual representations of physical objects. This hands-on experience helps students understand the complexities of IoT systems, including data collection, communication, and processing, in a risk-free and immersive setting (Gubbi et al., 2013).

Various authors have highlighted how these advancements can lead to more effective and inclusive educational experiences, preparing students for the complexities of modern engineering challenges. As the Metaverse continues to grow, its transformative impact on education paves the way for innovative teaching methodologies and a new era of learning.

4.2. Key pedagogical approaches for Engineering Education in the Metaverse

The term "pedagogical strategies for the Metaverse" encompasses a broad range of teaching and learning approaches specifically designed to leverage the unique characteristics of the Metaverse. It focuses on how educators can utilize the immersive, interactive, and collaborative features of the Metaverse to enhance learning experiences. Following a detailed description of our research methods and the identification of relevant scientific literature, we have analyzed and identified several key pedagogical approaches that are particularly effective in the context of Metaverse-based engineering education. These approaches, derived from our comprehensive analysis, are as follows: Constructivist Approach, Collaborative Approach, Integrative Learning Approach, Reflective Approach, Inquiry-Based Learning Approach, and Continuous Assessment and Feedback. These approaches form the foundation of our analysis, offering practical insights into how Metaverse technologies can be effectively applied in educational settings.

4.2.1 Constructivist approach - constructivism in Edu-Metaverse

The Constructivist Approach emphasizes active learning, where students construct knowledge through experiences and interactions. The foundation of this approach is the idea that learning is not a passive process of absorbing knowledge but an active process of constructing knowledge internally. According to constructivist learning theory, students build their knowledge through experiences and reflection. The Metaverse fosters constructivist learning by offering students a dynamic and interactive environment in which they can explore and manipulate virtual objects and environments. Experiential learning is essential for engineering education. In the Metaverse, students can apply their theoretical knowledge to real-world scenarios through practical exercises and simulations.

4.2.2 Collaborative approach

The Collaborative Approach emphasizes teamwork and collective problem-solving to enhance learning outcomes. It involves groups of learners working together to solve problems or complete tasks, encouraging participation, interaction, and the exchange of ideas. This approach promotes critical thinking, the development of problem-solving skills, and the co-construction of knowledge, making it particularly suitable for engineering education.

Within the Metaverse, students can form virtual teams, collaborating seamlessly regardless of their physical locations. This digital environment fosters cooperation, dialogue, and the problem-solving skills essential for engineering practice. Through virtual teams, students can jointly work on design projects, analyze data from virtual experiments, and present their findings at virtual conferences, all within an immersive, interactive space.

4.2.3 Integrative Learning Approach

The Integrative Learning Approach encourages the integration of knowledge across different subjects and real-world applications. It refers to the process of combining various areas of knowledge and skills to develop a comprehensive understanding of a subject. By synthesizing information from multiple sources, students can apply it to real-world situations.

Integrative learning fosters students' ability to make connections between different disciplines, concepts, and practical applications, resulting in a more holistic educational experience. By integrating knowledge from various fields, students can better understand the relationships between concepts, enhancing their ability to apply what they have learned in diverse situations (McDaniel et al., 2018).

4.2.4 Reflective Approach

The Reflective Approach fosters self-assessment and reflection to promote deeper understanding and personal growth. By emphasizing critical thinking and self-evaluation, this approach encourages students to regularly reflect on their learning experiences, assess their understanding, and evaluate their progress, ultimately enhancing their problem-solving abilities and academic development.

Techniques such as reflective journaling, self-assessment, and peer feedback are integral to this approach. Students may keep journals to document what they have learned, how they have applied their knowledge, and where improvements are needed. Peer feedback sessions further enrich the learning process by offering diverse perspectives and fostering collaborative learning. Educators can support this process by modeling reflective practices, sharing their experiences, and encouraging students to critique and refine their approaches (Ryan & Ryan, 2013).

4.2.5 Inquiry-Based Learning Approach

The Inquiry-Based Learning Approach promotes curiosity-driven exploration and critical thinking through questioning and investigation. This approach encourages students to take a more active and engaged role in their learning, guided by teacher support (Terzieva et al., 2021). Teachers foster curiosity by prompting students to ask questions, explore problems, and seek solutions.

There are four types of inquiry-based learning (Ng, 2022):

- *Structured Inquiry Approach*: teaches students how to ask questions based on given problem, with the aim to find a solution;
- *Open-Ended Inquiry Approach*: in-depth discussions and debates are important activities within the approach;
- *Problem-Based Inquiry Approach*: extensive research, which entails case studies, documentaries, research papers, etc.;
- *Guided Inquiry Approach*: Students ask questions and find solutions to real-world problems.

4.2.6 Continuous Assessment and Feedback

Continuous Assessment and Feedback involve ongoing evaluation and constructive feedback to support student progress and improvement. The Metaverse enables real-time assessment through interactive simulations and AI-driven analytics. Educators can monitor students' development, provide immediate feedback, and adjust their teaching methods as needed.

This continuous feedback loop ensures timely assistance for students and helps identify areas for growth (Kapp, 2012). In his exploration of gamification in education, Kapp (2012) showed that instantaneous feedback systems can significantly increase student motivation and engagement in classroom environments.

The Metaverse has been successfully incorporated into engineering education, showcasing its potential to revolutionize traditional pedagogical approaches. Educators and experts can design immersive learning environments, interactive simulations, collaborative spaces, personalized learning paths, and continuous assessment models to create effective and engaging learning experiences that prepare students for real-world engineering challenges. While this report outlines pedagogical approaches and their evolution in relation to Metaverse technologies, it is important to note that the analysis is based on existing literature sources.

5. Conclusion

The integration of Metaverse technologies into Engineering Education has the potential to revolutionize traditional pedagogical approaches. By offering immersive and interactive learning environments, these technologies can enhance student engagement, facilitate hands-on experience in a virtual setting, and enable collaboration beyond physical boundaries. For the successful transformation of engineering education, development of pedagogical approaches based on new metaverse technologies is necessary. The report examines their role and the changes they cause in different approaches.

The report examines pedagogical approaches and their transformation and development according to new metaverse technologies. It is based on existing literature sources and does not claim to be comprehensive or exhaustive. By mentioning the potential transformative impact of the metaverse on education and the anticipation of innovative teaching methodologies, the paper positions itself within the forward-looking discourse on educational technology.

It is necessary to continue the research with a detailed analysis of each of the approaches, taking into account the impact of metaverse technologies on them, such as VR and AR, Simulation technology, Artificial Intelligence, Blockchain technology, Cryptocurrency technology, Internet of Things technology and others.

Acknowledgements

The paper is part of a research project: Metaverse Approach for a New Generation of Engineering Education and Collaborative Learning (MAGURA), as the frame of Project No. BG-RRP-2.004-0006-C02 "Development of research and innovation at Trakia University in service of health and sustainable well-being".

REFERENCES

Gao, M., Yunus, M. M., Rafiq, K. R. M. (2024) Using Metaverse-based Learning as a Strategy to Improve Higher Education: A Systematic Review (2019-2023). *International Journal of Academic Research in Progressive Education and Development*. doi:10.6007/ijarped/v13-i1/20856 .

Ghoulam, K. & Bouikhalene, B. (2024) From classrooms to cyberspace: Understanding pedagogical approaches and outcomes in Metaverse learning environments. *Advances in Mobile Learning Educational Research*. 4(1), 983-993. doi:10.25082/AMLER.2024.01.010 .

Gubbi, J., Buyya, R., Marusic, S. & Palaniswami, M. (2013) Internet of Things (IoT): A vision, architectural elements, and future directions. *Future generation computer systems*. 29(7), 1645-1660.

Harte, K. (2024) *Theories and pedagogical strategies for teaching*. https://www.theanimatedteacherblog.com/pedagogical-strategies-for-teaching/. Mar 12, 2024 | Pedagogy.

Harzing, A. W. (2010) *The publish or perish book*. Melbourne, Australia: Tarma Software Research Pty Limited.

He, Q., Wang, G., Luo, L., Shi, Q., Xie, J. & Meng, X. (2017) Mapping the managerial areas of building information modeling (BIM) using scientometric analysis. *International Journal of Project Management*. 35(4), 670–685. doi:10.1016/j. ijpro man. 2016.08.001 .

Johnson, L., Becker, S. A., Cummins, M., Estrada, V., Freeman, A. & Hall, C. (2016) *NMC horizon report: 2016 higher education edition*. pp. 1-50. The New Media Consortium.

Kapp, K. M. (2012) *The gamification of learning and instruction: Game-based methods and strategies for training and education*. John Wiley & Sons.

Lee, Y.-S. & Lee, T.-Y. (2022) Applying the metaverse platform and contents in practical engineering education. *J. Korea Comput. Graph. Soc*. 28(3), 31-43. doi:10.15701/kcgs.2022.28.3.31 .

Marques, W. R., Silva, A. C. S., Nascimento, S. P., Costa, F. das C. S., Câmara, D. M. M. & Farias, S. R. A. (2024) Metaverse and Artificial Intelligence: TDIC Trends in Education. *Revista De Gestão Social E Ambiental*. 18(9), e07682. doi:10.24857/rgsa.v18n9-149 .

McDaniel, C., McDaniel, J. & Lawrence, R. (2018) Connecting concepts: Strategies for integrative learning. *Learning and Instruction*. 58, 62-71. doi:10.1016/j.learninstruc.2018.06.001 .

Moon, J. A. (2013) *Reflection and employability: Reflection on learning and reflective practices*. Routledge.

Ng, D. T. K. (2022) What is the metaverse? Definitions, technologies and the community of inquiry. *Australasian Journal of Educational Technology*. 38(4), 190–205. doi:10.14742/ajet.7945.

Noh, M. E., Odenkirk, S. C. & Shionoiri, Y. (2022) GM! Time to wake up and address copyright and other legal issues impacting visual art NFTs. *Columbia Journal of Law & the Arts*. 45(3). https://www.pryorcashman.com/publications/gm-time-to-wake-up-and-address-copyright-and-otherlegal-issues-impacting-visual-art-nfts .

O'Regan, S., Molloy, E., Watterson, L. & Nestel, D. (2016) Observer roles that optimise learning in healthcare simulation education: a systematic review. *Advances in Simulation*. 1(1), 1–10. https://advancesinsimulation.biomedcentral.com/articles/10.1186/s41077-015-0004-8 .

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrovic, V. M. & Jovanovic, K.(2016) Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education*. 95, 309–327. doi:10.1016/j.compedu.2016.02.002 .

Rooney, D. & Nyström, S. (2018) Simulation: A complex pedagogical space. *Australasian Journal of Educational Technology*. 34(6). doi:10.14742/ajet.4470 .

Ryan, M. & Ryan, M. (2013) *Reflective practice for teaching in higher education*. Open University Press.

Soriani, A. & Bonafede, P. (2023) Metaverse and education: which pedagogical perspectives for the school of tomorrow?. *Journal of Inclusive Methodology and Technology in Learning and Teaching*, *3*(1). doi:10.32043/jimtlt.v3i1.54 .

Tapscott, D. & Tapscott, A. (2016) *Blockchain revolution: how the technology behind bitcoin is changing money, business, and the world*. Penguin.

Terzieva, T., Rahneva, O., Dilyanov, V. (2021) Pedagogical strategies for development of cognitive skills in a digital environment. *International Journal of Differential Equations and Applications*. 20(2), 251-261. ISSN (Print): 1311-2872; ISSN (Online): 1314-6084; url: https://www.ijdea.eu.

Tlili, A., Altinay, F., Huang, R., Altinay, Z., Olivier, J., Mishra, S., Jemni, M. & Burgos, D. (2022) Are we there yet? A systematic literature review of open educational resources in Africa: A combined content and bibliometric analysis. *PLoS ONE*. 17(1), e0262615. doi: 10.1371/journal.pone.02626 15 .

Van Eck, N. J. & Waltman, L. (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*. 2(84), 523–538. doi:10.1007/s11192-009-0146-3 .

Wong, P.P.Y. et al. (2023) Virtual to Reality: Understanding the Role of Metaverse as a Pedagogical Strategy. *The Electronic Journal of e-Learning*. 22(3), 90-110. doi:10.34190/ejel.21.6.3219 .

Zheng, Z., Xie, S., Dai, H., Chen, X. & Wang, H. (2018) An overview of blockchain technology: Architecture, consensus, and future trends. In *2017 IEEE International Congress on Big Data (BigData Congress)*. IEEE. pp. 557-564.