Metaverse: A Paradigm Shift in STEM Education for Science Learning Beyond the Review

Hanandita V., Binar K., Eko, Marianus

Abstract. The integration of the Metaverse into innovative education has the potential to transform traditional teaching methods, offering new opportunities for both in-person and remote learning, ultimately making education more engaging and effective. This research aims to provide a cutting-edge assessment of how the Metaverse is integrated into education specific to science learning in the context of future employment. This article highlights its contemporary relevance and novel insights.

This qualitative descriptive study uses data-gathering procedures based on the library research method. Metaverse platforms offer immersive and interactive experiences that enhance students' understanding of scientific concepts. Metaverse-based science learning is not confined by geographic limitations, enabling a broader audience to access quality educational content. Researchers are increasingly interested in investigating the effectiveness of metaverse-based science learning, and industry support and investment drive innovation in this field. However, this study is limited in its reliance on Scopus as the sole source of articles. Nevertheless, this research is a valuable resource for educators seeking to integrate the Metaverse into science education. Researchers recommend that future researchers conduct more targeted literature reviews focusing on specific learning models, subjects, educational levels, and curriculum variations.

1 Introduction

The idea of a digital learning environment (DLE) can align with various targets and indicators linked to Goal 4 SDGs. This emerging technology reshapes how students learn, interact, and collaborate, providing fresh avenues for engaging and dynamic learning experiences.[1–4]. It encompasses a range of technologies, including augmented reality (AR), virtual reality (VR), and 3D simulations, allowing students to explore intricate subjects and concepts in innovative ways,[5,6]. However, since its initial emergence, the Metaverse has introduced a virtual world or virtual environment accessible to users through their avatars. The concept of the Metaverse was first introduced in the science fiction novel “Snow Crash” by Neal Stephenson in 1992.[7,8]. In other words, the Metaverse is a framework that blends the principles of augmented reality (AR), virtual reality (VR), and 3D simulation. Innovative education, in contrast to traditional classroom teaching,*Corresponding author: binarprahani@unesa.ac.id
methodologies, is an interactive and graphically focused paradigm that employs cutting-edge AI technology to accomplish educational objectives. The incorporation of the Metaverse into creative education offers an opportunity to alter traditional teaching techniques, providing new options for both in-person and distant learning and, as a result, creating learning fascinating and successful [9–11].

The power of the Metaverse to modify and enrich the educational environment enhances science learning tremendously. Students in traditional scientific education sometimes struggle with complex and complicated ideas such as physics, chemistry, and biology [12–14]. Through AR and VR technologies, students can enter virtual laboratories, simulate experiments, and interact with three-dimensional models of molecules, ecosystems, or celestial bodies [15–17]. This hands-on and experiential approach not only makes science learning more captivating but also helps students grasp complex scientific principles more effectively.

However, aside from integrating AR, VR, and 3D, the use of the Metaverse in education is still in the developmental stage, so the implementation of the Metaverse itself is infrequent. Previous research found that most students had no prior experience with Metaverse, yet they expressed a desire to incorporate the Metaverse environment into the classroom [18]. Within the contemporary educational metaverse landscape, numerous emerging challenges and prospects have captured significant interest [19]. Additionally, previous research suggests that given the rapid growth in the volume of research articles related to AR, VR, and It is expected that the number of publications concerning the use of the Metaverse to learning will increase in the future years in valued technology for education magazines. Potential study pathways for investigating the Metaverse's function in education have been identified to assist scholars who wish to participate in this emerging topic [20–22], the investigation of how metaverse-based educational environments impact learners' performance and perceptions [23], the utilization of the Metaverse as an assessment tool [24,25], the alignment of the Metaverse with established pedagogical theories [26,27], the proposition of metaverse-based learning strategies, the examination of learner performance and perceptions within metaverse-based contexts, the analysis of behavioral and interactive patterns among learners with varying achievement levels in the Metaverse [28], the creation of metaverse training programs that are challenging to replicate in real-world settings [29], the development of ethical guidelines for metaverse use in educational settings, as well as the investigation of new possibilities for AI in metaverse-based learning environments.

Furthermore, previous research tends to conduct the systematical review based on the advantages and disadvantages of virtual educational spaces in Metaverse [30], the role of the Metaverse as a tool for education in any subject of learning [31–34], software engineering education [35], and so on. By providing a cutting-edge assessment of how the Metaverse is integrated into education, specifically science learning in the context of future employment, this article highlights its contemporary relevance and novel insights. Consequently, future research is well-informed about utilizing the Metaverse in science education, including its strengths, weaknesses, areas for improvement, and suggested enhancements. This study has condensed multiple literature reviews that outline the benefits, real-world applications, limitations, and potential avenues for leveraging the Metaverse in science learning.

2 Methods

Data gathering techniques in this qualitative descriptive study were carried out using library research methods. Initially, a thorough library search on Scopus yielded 115 papers about Metaverse in scientific learning. Following that, the list was filtered to reveal the leading 15...
most frequently referenced papers related to Metaverse in scientific education. Following the technique advocated by Miles and Huberman, the study entailed doing descriptive analyses and constructing a series of written phrases, the stages of analysis for qualitative research are generally depicted in Figure 1.

Fig. 1. Stages of Qualitative Data Analysis in General.

Qualitative data analysis involves four key stages. First, data collection entails gathering information from reliable sources to fulfill the research objectives. Second, data reduction involves organizing and condensing relevant information to align with the research objectives, typically accomplished by filtering based on specific titles or keywords, with the authors manually selecting the most pertinent papers. Third, data presentation encompasses sharing research findings, often through concise descriptions, charts, and elucidating relationships among subjects, which is particularly applicable to qualitative research. Finally, the fourth stage, conclusion and verification, entails summarizing the ultimate results derived from the preceding processes and unveiling new insights that serve the study's purpose.

3 Results and Discussion

Table 1 assesses the top 15 most frequently referenced publications recognized for their significant impact on the intersection of the metaverse and science education. For each of these articles, a thorough analysis was conducted, considering their citation counts, Scimago Journal and Country Rank (SJR) data obtained from www.scimagojr.com, and CiteScore data retrieved from www.scopus.com as of October 2023. This analysis encompasses a comprehensive examination of the results and guidance in each of these publications.
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<th>Author(s)</th>
<th>Year</th>
<th>SJR</th>
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<tr>
<td>Moro [44]</td>
<td>2023</td>
<td>Q1 (1.46)</td>
<td>9.80</td>
<td>The Metaverse will introduce a variety of innovative and distinctive methods for education. In many instances, it will expand upon existing practices, such as using live video for remote instruction, virtual dissections, or incorporating gamification. However, it may also bring about certain risks that require careful consideration. Nevertheless, the Metaverse's enhanced accessibility, connectivity, authenticity, and immersive qualities may make it appealing for educators in the anatomical sciences to contemplate transitioning some of their curricula into this virtual environment.</td>
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<td>Mik &amp; Raisa [45]</td>
<td>2023</td>
<td>Q2 (0.56)</td>
<td>5.20</td>
<td>In post-program assessments, many students preferred the social learning aspects within the Metaverse during the week-long program. Instructors who conducted the lessons noted that the poster presentations delivered by students reflected a strong understanding of HSAB theory. This lesson is valuable for educators looking to teach HSAB theory concepts within a metaverse environment, such as Gather. Town.</td>
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<td>Pang et al. [46]</td>
<td>2023</td>
<td>Q2 (0.56)</td>
<td>5.20</td>
<td>Incorporating avatars is the pivotal feature differentiating it from conventional video conferencing platforms. While Gather. Researchers have examined the town in various domains to enhance online learning by facilitating better student interaction, but its application in chemistry education has yet to be thoroughly explored. Empirical data supports that students concur with the idea that the designed Gather. The town has amplified social interaction during online learning.</td>
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<td>Jafari [47]</td>
<td>2023</td>
<td>Q2 (0.53)</td>
<td>5.20</td>
<td>The characteristics of novice &quot;digital natives&quot; align well with the Metaverse, and this demographic exhibits a relatively high level of confidence in utilizing the Metaverse for educational purposes. Generating innovative concepts in this context demands expertise that pre-service teachers typically need to gain. Nevertheless, this knowledge gap can be bridged with experienced educators leveraging their know-how to guide inexperienced teachers in integrating such tools into their teaching practices, especially in science classes.</td>
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<td>Rodriquez et al. [48]</td>
<td>2023</td>
<td>Q2 (0.42)</td>
<td>5.20</td>
<td>In 2020, they introduced moleculARweb (<a href="https://molecularweb.epfl.ch">https://molecularweb.epfl.ch</a>), a website providing interactive educational content for chemistry and structural biology. This content is accessible through web-based augmented reality (AR) technology, compatible with standard consumer devices such as smartphones, tablets, and laptops. It serves as a reference to the metaverse environment.</td>
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| Solanes et al. [49] | 2023 | Q2 (0.49) | 4.50 | The fusion of VR technology with the development of educational metaverses has shown considerable
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<td>Damaševičiūs &amp; Sidekerskienė</td>
<td>2023</td>
<td>-</td>
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<td>In a case study focusing on Metaverse escape rooms deployed within Studio Gometa as a smartphone application for mathematics education, we emphasize the educational achievements and the obstacles encountered during the planning and execution phases.</td>
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<td>Ho et al.</td>
<td>2023</td>
<td>-</td>
<td>-</td>
<td>The AI notes generator module is used in the metaverse adventure to create personalized lecture notes by combining diverse technologies such as visual character recognition, automated speech recognition, natural language processing, and text-to-speech. We discuss current and future efforts to build an AI-supported metaverse for performing proof-of-concept trials in computer science education.</td>
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<td>Angelos</td>
<td>2022</td>
<td>Q2</td>
<td>4.00</td>
<td>The findings suggest that students prefer AR quizzes, substantiating their preference concerning the educational benefits and immersive experiences provided. It was emphasized that AR contributes significantly by establishing an engaging and immersive learning environment in science education. The results endorse students' positive attitudes towards the amalgamation of AR and formative self-assessment and underscore the role of immersion facilitated by AR technologies. Moreover, considering the extended implementation duration, the findings raise questions regarding the potential impact of the novelty effect on students' favorable perceptions of AR.</td>
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<td>Marini et al.</td>
<td>2022</td>
<td>Q3</td>
<td>4.20</td>
<td>The utilization of metaverse applications has a positive impact on students' educational achievements. By employing the Metaverse app, students can achieve improved learning outcomes and engagement and facilitate their comprehension and exploration of new knowledge. Furthermore, students find the learning experience more enjoyable when using the Metaverse app, a mobile AR tool. It offers valuable insights to elementary school educators on how to enhance student performance. It is essential to conduct additional global research to gain a comprehensive understanding of the influence of mobile augmented</td>
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<td>Arif &amp; Nurhayati [54]</td>
<td>2022</td>
<td>Q3 (0.30)</td>
<td>2.50</td>
<td>In this research, a metaverse-based mathematics pedagogy media (MMPM) is introduced, incorporating a learning material selection (LMS) feature that dynamically tailors content to match students' knowledge levels. The test outcomes demonstrate the adequate performance of the LMS system in its role of intelligently selecting subject matter scenarios for students based on their pre-test results.</td>
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<td>Kung &amp; Wong [55]</td>
<td>2022</td>
<td>-</td>
<td>-</td>
<td>Utilizing the Metaverse alongside a C3-based platform incorporating educational gaming strategies and question types derived from Mason, Walsh, Satter, Sahin, and Kulm enhances students' ability to broaden their social network and develop problem-solving and mathematical thinking skills. The C3 platform within the avatar-based Metaverse, employing the IREFFo pattern, is structured to foster more accessible interactions among users and their peers, emphasizing the mutual benefits they offer to one another.</td>
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<td>Reyes [56]</td>
<td>2020</td>
<td>Q2 (0.63)</td>
<td>5.60</td>
<td>Enhancements were made to the school approval rating, showing a growing inclination to incorporate augmented reality in the classroom. Furthermore, there is a positive perception regarding the impact of utilizing strategies facilitated by these tools on learning. As a result, implementing metaverse AR in mathematics instruction substantially benefits student achievement.</td>
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<td>Estudante &amp; Dietrich [57]</td>
<td>2020</td>
<td>Q2 (0.56)</td>
<td>5.20</td>
<td>Metaverse opens new AR learning scenarios accessible on smartphones and tablets, transcending location and participant constraints. This interactive tool encourages student engagement with chemistry concepts, offers insights into chemists and engineering principles, and can be used independently. It accommodates up to 3 simultaneous students, requires minimal resources, and may involve students in creating content, enhancing education.</td>
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<td>Schaf et al. [58]</td>
<td>2012</td>
<td>-</td>
<td>-</td>
<td>To explore the practical application of this research field, a prototype named 3DAutoSysLab was created. In this prototype, a metaverse serves as a collaborative social interface, actual or simulated experiments are integrated with virtual objects, learning materials are presented as interactive media, and guidance/feedback is facilitated through an autonomous tutoring system that relies on data mining of user interactions. While this prototype is currently undergoing testing, initial results suggest a high level of acceptance and increased student motivation.</td>
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Based on Table 1, there has been various research on Metaverse in science education throughout the years. The integration of metaverse applications has a positive impact on students' academic achievements, fostering improved learning outcomes, increased engagement, and enhanced understanding of complex concepts of science learning. In line with Chen et al. [59], in the context of blended teaching in the Metaverse, learners expressed higher satisfaction levels regarding program accessibility, stability, and immersion during sessions. They found the sessions straightforward, faced challenges positively, and appreciated the interaction, innovation, participation opportunities, and diverse learning formats. The innovative pedagogy also had a beneficial influence on learners' self-assurance in clinical reflection, creativity, collaborative learning, and communication skills [60,61]. However, the advantages of integration metaverse to science learning are likely in Figure 2.

**Fig. 2.** The Advantages of Using Metaverse to Science Learning.

Based on Figure 2, incorporating the Metaverse into science education presents many advantages. To begin with, metaverse environments provide immersive learning experiences that enable students to deeply engage with scientific concepts, making the educational journey both captivating and memorable. These environments actively encourage interaction, allowing students to participate in experiments, simulations, and collaborative activities, enhancing their grasp of scientific principles. Notably, the Metaverse's accessibility is a standout feature, transcending geographical constraints and extending its reach to a diverse student population, including those in remote or underserved regions [62]. However, the metaverse framework for education is illustrated by Zhang et al. [31], likely in Figure 3.
Moreover, metaverse platforms facilitate visualization, effectively bringing abstract scientific phenomena to life and instilling a sense of engagement and motivation in science education [63,64]. Metaverse applications excel in simulating real-world scientific scenarios, enabling students to apply their knowledge in practical contexts. Additionally, these platforms offer personalized learning experiences, adapting to the individual needs of students and delivering tailored content and support. Collaboration is another notable advantage, as metaverse environments foster teamwork and enhance communication skills, both crucial for success in scientific fields [65]. Furthermore, they provide access to various digital resources, including simulations, databases, and expert knowledge, enriching the learning process. Metaverse-based science education also supports data analysis and experimentation, empowering students to conduct research and draw informed conclusions [66,67]. Immediate feedback and assessment mechanisms enable students to monitor their progress and refine their scientific skills. Lastly, metaverse-based science learning instills a culture of lifelong learning, motivating individuals of all ages to explore and comprehend the ever-evolving domain of science. In line with this, the trend of metaverse publication in science learning tends to increase, likely in Figure 4.

![Metaverse Framework Diagram](image_url)

**Fig. 3.** Metaverse-education Framework.

**Fig. 4.** Research Trend on Metaverse Publication to Science Learning.
Based on Figure 4, the research trend of a Metaverse in science learning tends to increase. The recent upswing in metaverse-based science learning research can be attributed to several key factors. Technological advancements, particularly in AR and VR, have made metaverse environments more accessible and practical for educational purposes. Furthermore, the COVID-19 pandemic accelerated the adoption of online learning, propelling educators and researchers to explore alternatives, with the Metaverse emerging as a promising solution [68]. These platforms offer immersive and interactive experiences that enhance students’ understanding of scientific concepts. Metaverse-based science learning is not confined by geographic limitations, enabling a broader audience to access quality educational content [69,70]. Researchers are increasingly interested in investigating the effectiveness of metaverse-based science learning, and industry support and investment drive innovation in this field. These factors collectively contribute to the growing research interest in metaverse applications for science education.

Furthermore, based on Table 1, these publications become fundamental for future research, so they have outstanding citations and impact, metaverse in science learning. Based on October 2023, the top relevant publications are listed in the rank journal Quartile 1 (Q1), which has CiteScore 9.80. Journals with quartile rank 2 (Q2) have CiteScore 5.20-4.50. This highlights that the most influential publications are associated with unwavering credibility, primarily due to the reputable publishers behind them. The assessment of the SJR indicator differentiates citation scores based on the significance of the source journal, implying that citations originating from highly regarded journals hold more excellent value [71,72]. Consequently, journals that receive citations from these influential sources gain heightened recognition and prestige.

4 Conclusion

5 Acknowledgement
# References


36. Sugiyono, Metode Penelitian Kuantitatif, Kualitatif, Dan R&D, Alfabeta CV, Bandung, 2017


42. I. Ianoş and A. I. Petrişor, Publications, 8, (2020)


44. C. Moro, Anat. Sci. Educ., 16, 574 (2023)


60. J. D. Ssentamu and V. Chancellor, J. Posit. Sch. Psychol., 7, 1 (2013)


67. J. Han, G. Liu, and Y. Gao, Educ. Sci., 13, (2023)


