

Metaverse in Education for AI-Enhanced Lifelong Learning and SDG Advancement in the Context of an Aging Society: A Systematic Review

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Abstract

The rapid advancement of immersive technologies and Artificial Intelligence (AI) has reshaped digital education and introduced new possibilities for lifelong learning in aging societies. This study presents a systematic review of research published between 2020 and 2026 examining the integration of AI within Metaverse-based educational environments. Guided by the PRISMA framework, 18 peer-reviewed studies were identified and synthesized to analyze emerging research trends, pedagogical applications, and alignment with the Sustainable Development Goals (SDGs). Findings indicate a shift from technological infrastructure integration toward pedagogically focused applications, including intelligent tutoring systems, adaptive learning models, generative AI, and immersive simulations. AI enhances personalized learning pathways, real-time feedback, and experiential skill development within interactive virtual environments, supporting flexibility, self-directed learning, and continuous reskilling. The review further demonstrates strong alignment with SDG4 (Quality Education), SDG9 (Industry, Innovation, and Infrastructure), and SDG10 (Reduced Inequalities), highlighting the structural role of AI-enhanced Metaverse systems in promoting inclusive and sustainable educational ecosystems. Within the context of an aging society, immersive AI-driven environments show potential to mitigate mobility constraints, reduce social isolation, and foster cognitive engagement among older adults. AI-integrated Metaverse education represents an emerging paradigm capable of supporting inclusive, adaptive, and sustainable lifelong learning infrastructures in response to demographic transformation and global sustainability agendas.

Keywords: Metaverse in Education; Artificial Intelligence, Lifelong Learning, Aging Society

Introduction

The transition to the digital era has fundamentally transformed educational systems worldwide. Technological advancements in education have emerged extensively across diverse contexts, reshaping instructional practices and learning experiences into new forms that promote greater sustainability in digital learning environments. Furthermore, the COVID-19 pandemic significantly accelerated technological transformation in education, driving a rapid shift from traditional classroom-based instruction to online and distance learning (Illi & Elhassouny, 2025; Kaddoura & Al Husseiny, 2023). However, current two-dimensional online learning (2D e-learning) environments present several limitations, including decreased learner engagement, reduced motivation, and emotional isolation (Chua & Yu, 2024; X. Zhang et al., 2022). Advancements in communication and computing technologies have consequently led to the emergence of a new platform known as the “Metaverse,” a three-dimensional virtual world that integrates the physical and digital realms, thereby overcoming spatial and temporal constraints (Chua & Yu, 2024; Samala et al., 2023).

The application of the Metaverse in education (Edu-Metaverse) represents a transformative shift in instructional design, utilizing Extended Reality (XR) technologies such as Virtual Reality (VR) and Augmented Reality (AR), in conjunction with the Internet of Everything (IoE), to create immersive and highly interactive learning environments (Illi & Elhassouny, 2025; Jagatheesaperumal et al., 2022; Tlili et al., 2022). Within these virtual spaces, learners and instructors can communicate and engage in collaborative activities through avatars. Educational Metaverse environments enable users to interact, communicate, and participate in simulated real-world experiences via avatars, effectively reducing barriers related to time and location (Illi & Elhassouny, 2025; X. Zhang et al., 2022).

At the same time, Artificial Intelligence (AI) has emerged as a significant driving force in reshaping educational practices. AI-driven systems facilitate adaptive learning pathways, intelligent tutoring systems, automated assessment, and predictive analytics through machine learning algorithms. These capabilities enhance learning efficiency and substantially transform digital learning experiences. The integration of the Metaverse with AI thus introduces a novel digital ecosystem (Lin et al., 2022; Odeh & Yousef, 2025; Yu,

2023) that extends beyond entertainment, serving instead as a platform that creates new opportunities for education and lifelong learning with greater flexibility and effectiveness (Chen et al., 2024; Saneinia et al., 2024; Yu, 2023).

Beyond general learner populations, this mode of learning demonstrates considerable potential for older adults, as it enables access to education, skills training, and social interaction without the need for long-distance travel, aligning with the concept of enhancing quality of life within home or community settings (Jagatheesaperumal et al., 2022; Owusu et al., 2023). Meanwhile, many countries are experiencing significant demographic shifts characterized by a steadily increasing proportion of older adults, marking the transition to aging societies. This social phenomenon, in which the elderly population continues to grow globally, has become increasingly prominent. The United Nations projects that one in six people worldwide will be aged 65 or older by 2050 (Mahmood & Dhakal, 2023). This demographic transformation not only challenges existing institutional systems and policy frameworks but also underscores the importance of promoting healthy aging and supporting older adults in maintaining quality lives within their homes or communities (Mahmood & Dhakal, 2023; Owusu et al., 2023).

However, older adults often face physical limitations, social isolation, and barriers to accessing new technologies, which may contribute to both physical and psychological decline. Therefore, promoting lifelong learning has become a critical strategy for sustaining cognitive capacity and social engagement among older populations (Lee et al., 2025). The integration of the Metaverse with AI represents an educational innovation that is closely aligned with the United Nations Sustainable Development Goals (SDGs), particularly SDG 4, which emphasizes inclusive and equitable quality education and the promotion of lifelong learning opportunities for all (Chen et al., 2024; Dragunova et al., 2023; Illi & Elhassouny, 2025). Furthermore, this developmental approach contributes to the advancement of innovation and digital infrastructure associated with SDG 9 (Industry, Innovation, and Infrastructure), while also supporting equitable access to digital education under SDG 10 (Reduced Inequalities), thereby fostering social inclusion within aging societies in the future.

From above, the application of the Metaverse within the context of aging populations emerges as an important mechanism for promoting lifelong learning and social participation. The Metaverse has the potential to eliminate physical barriers, enable older adults to connect, acquire new skills, and interact with others without the need for travel (Kaddoura & Al Hussein, 2023; Lee et al., 2025). By overcoming geographical and physical constraints, it allows elderly individuals, vulnerable groups, and persons with physical limitations to access educational resources and engage in social interaction within virtual environments safely and equitably (Dragunova et al., 2023; Saneinia et al., 2024; Y. Zhang et al., 2022). Nevertheless, implementing the Metaverse among older adults presents specific challenges that must be carefully considered. Older individuals frequently encounter psychological barriers, including low self-confidence and perceptions of being too old to learn new technologies. Additional constraints include limited interest, financial barriers, and restricted access to digital technologies or devices (Lee et al., 2025). Consequently, technology design for older users must emphasize user-friendliness, provide step-by-step guidance, and incorporate family support as a key enabling factor in facilitating technology adoption (Lee et al., 2025; Sathyasundari et al., 2025).

Therefore, this study aims to conduct a systematic review of research published between 2020 and 2026 concerning the application of the Metaverse in education integrated with AI technologies. The objective is to analyze the role of these technologies in promoting lifelong learning and advancing the Sustainable Development Goals within the context of an aging society. Importantly, the analysis does not exclusively focus on elderly populations but instead utilizes demographic transformation as an interpretive framework for examining implications for lifelong learning. Specifically, this study addresses the following research questions.

Q1. What are the trends in educational research in the AI-integrated metaverse between 2020 to 2026?

Q2. How is AI being used in metaverse learning environments to promote lifelong learning?

Q3. How do AI-enhanced education systems in a metaverse contribute to achieving the SDGs?

Q4. What implications do these findings hold for learning in the context of an aging society?

By answering these questions, this systematic review aims to provide a comprehensive understanding of the evolving intersection between Metaverse technologies, AI-driven educational innovation, lifelong learning, and sustainable development. Ultimately, the study contributes to ongoing discussions on how emerging digital ecosystems can support inclusive and resilient learning infrastructures capable of responding to the challenges and opportunities presented by aging societies worldwide.

Methodology

Metaverse

The metaverse can be conceptualized as the integration of physical and digital realities into a unified virtual ecosystem, forming a global virtual community. Through the integration of Augmented Reality (AR) and Virtual Reality (VR) technologies, it enables the fusion of physical environments with immersive digital layers, creating seamless and interactive experiences. Supported by digital infrastructures such as the Internet, smart devices, software platforms, and networked applications, the metaverse represents a transformative technological paradigm with significant implications for the future of human interaction and digital engagement.

At present, the development of the metaverse is characterized by strategic competition among major technology corporations seeking to define its infrastructure, standards, and governance frameworks. Many organizations are investing in proprietary hardware and software ecosystems designed to attract users and establish control over platform access. This competitive landscape is further shaped by contrasting philosophies, particularly the tension between closed, commercially controlled systems and open, privacy-oriented architectures. As these competing visions evolve, the metaverse emerges not only as a technological innovation but also as a contested domain shaped by economic, ethical, and ideological considerations.

Importantly, the influence of the metaverse extends to various sectors, including education. Its immersive and interactive capabilities suggest strong potential to redefine digital learning environments, positioning it as a significant force in the evolution

of e-learning systems (Mystakidis, 2022). Consequently, the metaverse has become a central topic in contemporary discussions on technological advancement and digital transformation. From a conceptual perspective, the metaverse can be categorized into four primary types: Augmentation, Lifelogging, Mirror Worlds, and Virtual Worlds, as illustrated in Figure 1.

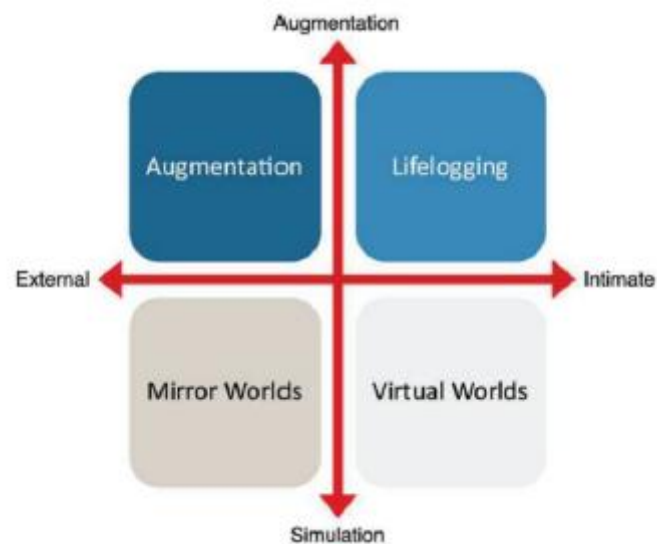


Figure 1 The Types of Metaverse (Suryodiningrat et al., 2022)

- Augmentation Metaverse refers to environments where digital information is layered onto the physical world to enhance users’ perception and interaction. Utilizing technologies such as AR, this form enriches real-world experiences by integrating virtual elements into immediate surroundings.

- Lifelogging Metaverse involves the systematic and continuous documentation of individuals’ daily lives. Through digital tracking and data recording technologies, personal activities, interactions, and environmental contexts are captured and stored for analysis or reflection.

- Mirror Worlds Metaverse represents digital replicas of real-world environments. These virtual environments function as digital twins, enabling users to explore and interact with simulations that closely resemble physical locations.

- The Virtual Worlds Metaverse consists of fully immersive and entirely computer-generated environments. Accessed primarily through VR technologies, these

spaces allow users to engage in social interaction, gaming, creative expression, and other digital activities within synthetic yet highly interactive landscapes.

PRISMA

This study adopts a systematic review methodology to address the research questions through a transparent, structured, and reproducible process. The review is guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework (’Gough et al., 2017; Page et al., 2021) which provides standardized procedures for identifying, screening, and synthesizing relevant studies. Following the application of predefined inclusion and exclusion criteria, selected publications were carefully examined to extract key findings. These findings were subsequently synthesized to generate evidence-based insights that directly respond to the research objectives.

The scope of this review encompasses scholarly works examining the application of the Metaverse in educational contexts in combination with Artificial Intelligence (AI). Particular emphasis is placed on the integration of Metaverse technologies with AI as an emerging educational innovation aligned with the United Nations Sustainable Development Goals (SDGs) and the broader societal transition toward an aging population. Only peer-reviewed articles published between 2020 and 2026 were considered. The detailed inclusion and exclusion criteria applied during the selection process are presented in Table 1.

Table1. Inclusion and Exclusion Criteria

Inclusion	Exclusion
Published between 2020-2026	Published before 2020
English language publication	Not in English
Doc. Type: Journal or Conference paper	Other Doc. Type (e.g. books)
Use of metaverse in education artificial intelligence	Not metaverse Not artificial intelligence
Focus on integration of metaverse and artificial intelligence, lifelong learning	Not integration
Can access / Open access	Can not access

To ensure comprehensive coverage of relevant literature, a systematic search strategy was developed using major academic databases, including Scopus, IEEE Xplore, and ScienceDirect. Frequently occurring keywords within related studies were analyzed to optimize search precision and recall (GALVEZ, 2018). Core search terms included “metaverse in education,” “artificial intelligence (AI),” and “lifelong learning.” Boolean operators (AND, OR, NOT) were strategically employed to refine and broaden the search results, thereby enhancing the rigor and completeness of the literature identification process.

Query Statement

TITLE-ABS-KEY ("metaverse") AND TITLE-ABS-KEY ("education") AND TITLE-ABS-KEY ("artificial intelligence") AND TITLE-ABS-KEY ("lifelong learning") AND PUBYEAR >= 2020 AND PUBYEAR <= 2026 AND (LIMIT-TO (LANGUAGE , "English"))

Result

The studies identified through the search were screened based on predefined criteria. This screening process was visualized through a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Flow Diagram, detailing each step and illustrating the number of studies excluded at each stage. Follow this, Identification, Screening, Eligibility and Included (Page et al., 2021).

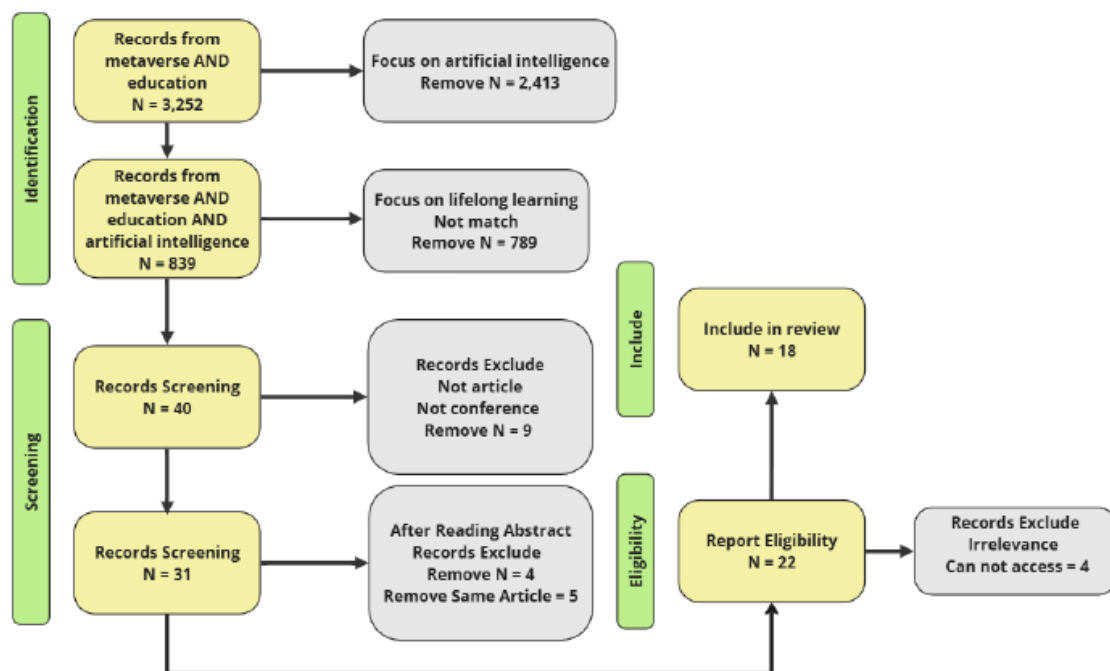


Figure 2 PRISMA Diagram

Based on the defined search strategy and the identification of core keywords related to metaverse, education, artificial intelligence (AI), and lifelong learning, with a publication timeframe limited to 2020–2026, a total of 18 relevant articles were initially retrieved. Following the application of the PRISMA screening and eligibility procedures, all 18 articles met the predefined inclusion criteria and were subsequently retained for final analysis.

The characteristics of the selected studies, organized according to the primary research questions, are summarized in Table 2. The table provides detailed information on each study, including the authors, year of publication, subject area, and the specific applications or roles of AI within the educational metaverse context.

Table2. Main data of the selected articles

No.	Authors	Year	Role of AI	Subject Area
(1)	(Abd El-Sattar, 2025)	2025	Intelligent NPCs Digital Twin	Special Education Immersive Technologies Metaverse
(2)	(Lampropoulos, 2025)	2025	Intelligent Tutoring Systems - ITS	Education
(3)	(Sathyasundari et al., 2025)	2025	Personalized learning	Education Management Ethics
(4)	(Suganya et al., 2025)	2025	Generative AI Adaptive Learning	Education
(5)	(Chen et al., 2024)	2024	Generative AI Natural Language Processing - NLP	Physical Education Metaverse
(6)	(Joshi et al., 2024)	2024	Tutoring Agents Adaptive Learning Explainable AI	Education Lifelong Learning
(7)	(Saneinia et al., 2024)	2024	AI with 5G network technology	Education Lifelong Learning Metaverse
(8)	(AlGerafi et al., 2023)	2023	Intelligently simulated environments of real-time interaction.	STEM Education Virtual Reality
(9)	(Dragunova et al., 2023)	2023	Adaptive Learning Chat Bot	Education Digital Technology
(10)	(Eppler & Spletter, 2023)	2023	Visual Learning Analytics	Education Knowledge Visualization
(11)	(Kruachotniku et al., 2023)	2023	AI-driven systems	Education Open Innovation Metaverse
(12)	(Phutela & Grover, 2023)	2023	AI is integrated with immersive technologies. AI supports instructional design processes.	Education Metaverse MOOCs
(13)	(Sa Don et al., 2023)	2023	AI contributes to the synthesis and dynamic generation of immersive environments.	Education Metaverse Serious games
(14)	(Yu, 2023)	2023	Tutoring Agents Intelligent Software Agents Reinforcement Learning	Education Immersive Learning AI
(15)	(Fu & Pan, 2022)	2022	AI integrated with other intelligent technologies	Education Metaverse
(16)	(Lin et al., 2022)	2022	Personal learning agent	Education Metaverse
(17)	(Wang et al., 2022)	2022	Intelligent Teaching Assistants Personalized learning	Open Education
(18)	(Y. Zhang et al., 2022)	2022	Deep learning	Education Metaverse

Beyond identifying emerging research trends in the integration of the Metaverse and AI, this study also seeks to examine the specific roles and applications of metaverse within AI-based research contexts. Investigates how AI is operationalized within immersive metaverse environments and how such integration contributes to the advancement of lifelong learning. These synthesized findings highlight the functional purposes, pedagogical strategies, and technological roles associated with AI-enhanced metaverse applications in education. A structured summary of these core issues is presented in Table 3.

Table3. AI-based use in Metaverse objectives.

Objective	AI-based	Description	Count
Intelligent Tutoring	Personalized learning Adaptive Learning Tutoring Agents Chat Bot	AI has been developed as an intelligent software agent or virtual tutor capable of analyzing learner behaviors and dynamically adapting its responses in real time. Functioning as an autonomous instructional intermediary.	10
Intelligent Learning Space	Intelligent Agent Generative AI Deep learning NLP	Environment is designed to support self-directed learning behaviors, with AI serving as a foundational support mechanism and generation of instructional materials and the deployment of interactive.	6
Sustainable ecosystem	AI-driven systems Deep learning	AI and big data analytics constitute foundational technologies underpinning intelligent simulation and immersive deep learning experiences within the Metaverse. This robust technological and socio-digital infrastructure provides essential support for the development of a sustainable ecosystem.	5
Simulations	Intelligent NPCs Digital Twin Machine Learning	AI is integrated with Metaverse technologies to establish interactive three dimensional learning environments and real-life simulations that enable learners to practice skills within safe and controlled settings.	4
Engagement	Intelligent NPCs Generative AI Chat Bot	AI are leveraged to develop interactive platforms designed to address the issue of learner disengagement in online course environments. AI create digital assistants, conversational chatbots, and adaptive learning systems that dynamically adjust content and instructional strategies based on learner needs.	3

The integration of Metaverse infrastructures with Artificial Intelligence (AI) represents a strategic educational innovation aligned with the United Nations Sustainable Development Goals (SDGs). It directly supports SDG4 by promoting inclusive, high-quality, and lifelong learning opportunities through immersive and adaptive digital environments. Simultaneously, the advancement of intelligent immersive infrastructures reflects SDG 9 (Industry, Innovation, and Infrastructure) by fostering innovation-driven knowledge societies, while equitable access to digitally mediated education aligns with SDG 10(Reduced Inequalities), emphasizing inclusive design in response to demographic aging and social vulnerability. A summary of each SDGs issues is presented in Table 4.

SDG	Achieve of SDG	Count
SDG4	<ul style="list-style-type: none"> • The Edu-Metaverse holds strong potential to reduce educational disparities between urban and rural communities, ensuring equitable access to high-quality learning opportunities . • By overcoming constraints related to time, location, and cost, immersive virtual environments promote inclusive and equitable education, particularly benefiting learners with special needs and socioeconomically disadvantaged groups. • The integration of Education 4.0 and Classroom 4.0 frameworks fosters adaptive, technology-driven learning models that support lifelong learning. • The implementation of Metaverse-based immersive learning modules reduces dependence on physical infrastructure, printed materials, and travel, thereby lowering carbon footprints and contributing to sustainable education. • Generative AI integrated with the Metaverse enables the provision of accessible, on-demand learning resources, helping bridge educational gaps in underserved and remote areas. 	16
SDG9	<ul style="list-style-type: none"> • Strategic partnerships with private-sector organizations support the co-development of advanced Metaverse infrastructures and the establishment of national standards based on high-level technological foundations. • Industry–education collaboration promotes co-innovation, enabling virtual internships and practice-oriented training modules aligned with real-world workforce demands. • The deployment of advanced technological infrastructure such as IoT-enabled smart classrooms and high-performance computing systems and strengthens the digital education ecosystem. 	4
SDG10	<ul style="list-style-type: none"> • Addressing digital equity within the Metaverse requires supportive policies and infrastructure subsidies to mitigate socio-digital inequalities, particularly between urban and rural regions. • Immersive educational innovations within the Metaverse provide safe virtual environments for individuals with autism to develop essential daily living skills through interactive simulation-based learning. 	3

Discussion

Q1. What are the trends in educational research in the AI-integrated metaverse between 2020 and 2026?

The findings indicate a clear acceleration of research activity from 2022 onward, with a notable concentration of studies published between 2023 and 2025. This temporal clustering suggests that AI-integrated Metaverse research has shifted from conceptual exploration to applied experimentation within a relatively short time frame.

1. Conceptual to Functional AI Integration: Early studies (2022) primarily emphasized AI integration with immersive platforms at a structural level, focusing on system integration and intelligent technologies in Metaverse environments. However, by 2023–2025, research increasingly examined functional roles of AI, including.

- Intelligent Tutoring Systems (ITS)

- Tutoring agents and personal learning agents
- Chatbots and conversational agents
- Generative AI for dynamic content creation
- Deep learning and reinforcement learning applications.

2. Personalized and Adaptive Systems: Across the dataset, the most recurrent AI role was intelligent tutoring and adaptive learning systems. This dominance suggests that personalization has become the central research priority in AI-Metaverse education. The trend such as a shift toward learner-centered instructional models, emphasis on real-time behavioral analytics and increasing reliance on AI as an autonomous instructional mediator.

3. Immersive Simulation and Digital Twins: A secondary but significant trend concerns AI-powered simulations, including intelligent NPCs and digital twin technologies. These applications extend beyond personalization toward experiential learning and skills rehearsal within safe, controlled virtual environments.

4. Sustainable Ecosystem: AI and big data as foundational technologies supporting sustainable educational ecosystems. This reflects a conceptual broadening of the field from instructional enhancement toward socio-digital ecosystem development.

Q2. How is AI being used in metaverse learning environments to promote lifelong learning?

The thematic synthesis reveals five primary AI-enabled objectives in Metaverse learning environments. These objectives collectively support lifelong learning through personalization, autonomy, adaptability, and sustained engagement.

1. Intelligent Tutoring: The most prevalent function of AI involves intelligent tutoring, adaptive learning systems, tutoring agents, and chatbots. These systems such as Adjust instructional difficulty, monitor learner behavior in real time and autonomous instructional intermediaries.

2. Intelligent Learning Spaces: These supporting self-directed learning. Identified AI as foundational in designing intelligent learning spaces, automatic generation of instructional materials, interactive simulations, conversational support, and self-directed exploration.

3. Sustainable Ecosystem: AI and big data as foundational infrastructure technologies. In lifelong learning systems, this infrastructure, data-driven improvement, long-term scalability, and cross-institutional integration.

4. Simulation-Based: Digital twins, Intelligent NPCs, and Real-life scenario such immersive environments are essential for lifelong skill maintenance, reskilling, and upskilling particularly relevant in aging societies where experiential engagement may enhance cognitive stimulation.

5. Engagement: AI-driven digital assistants and generative content dynamically adjust learning experiences to sustain motivation. Given that emotional isolation is a documented limitation of 2D e-learning, AI-enhanced immersive interaction may reduce disengagement especially important for socially isolated older adults.

Q3. How do AI-enhanced education systems in a metaverse contribute to achieving the SDGs?

The findings demonstrate alignment with three primary SDGs: SDG4, SDG9, and SDG10.

1. SDG4-Quality Education: The dominant emphasis on personalized learning and intelligent tutoring directly supports, inclusive and equitable education, adaptive instructional delivery and continuous lifelong learning opportunities.

2. SDG9-Innovation and Infrastructure: Research emphasizing AI-driven systems and 5G integration and development of these, advanced digital infrastructure, immersive learning platforms and digital innovation ecosystems.

3. SDG10-Reduced Inequalities: AI-integrated Metaverse platforms reduce multiple forms of inequality by these, removing geographical barriers, supporting adaptive access for vulnerable populations, and enabling safe digital participation.

Q4. What implications do these findings hold for learning in the context of an aging society?

The context of an aging society is closely intertwined with the concepts of lifelong learning and adult education. The reviewed literature highlights several significant implications of AI and Metaverse technologies for learning in later life.

1. These technologies enable seamless learning continuity beyond formal schooling, employment, and even retirement, allowing individuals to remain engaged in education throughout their lifespan. (Chen et al., 2024)

2. AI-driven systems support experiential and self-directed learning models, offering the flexibility and personalization particularly suited to older adults who prefer interest-based and autonomous learning pathways. (Chen et al., 2024; Wang et al., 2022)

3. Immersive virtual interaction technologies enhance accessibility for vulnerable populations and individuals with physical limitations groups in which older adults are often represented by allowing participation through virtual identities, thereby reducing educational inequality. (Y. Zhang et al., 2022)

4. Generative AI facilitates adaptive learning across all stages of life, functioning as a personalized assistant that delivers tailored learning pathways and content aligned with potentially slower learning paces in older adulthood. (Saneinia et al., 2024; Suganya et al., 2025)

5. The provision of immersive three-dimensional simulations reduces the need for physical travel, enabling safe, cost-effective, and accessible learning experiences. Compared to traditional environments, virtual spaces create more equitable opportunities for lifelong participation in education. (Sathyasundari et al., 2025; Yu, 2023)

Conclusion

This systematic review synthesized 18 peer-reviewed studies published between 2020 and 2026 that examined the integration of Artificial Intelligence (AI) into metaverse-based learning environments. The analysis provides a structured overview of emerging research trends in education, the alignment of AI-enhanced Metaverse systems with the Sustainable Development Goals (SDGs), and their implications for learning within the context of an aging society.

First, the findings reveal a clear evolution in research trajectories. Early studies primarily focused on integrating AI into the technological infrastructure of the metaverse. In contrast, more recent research emphasizes pedagogical applications, particularly intelligent tutoring systems, adaptive learning models, generative AI, and immersive simulations. This progression reflects a transition from technological experimentation

toward learner-centered educational systems capable of scaling sustainably across broader educational ecosystems.

Second, AI plays a pivotal role in advancing lifelong learning within Metaverse environments. Tools such as intelligent tutoring systems, adaptive learning agents, chatbots, and generative AI support personalized learning pathways and continuous skills development. AI-driven immersive simulations further enable learners to practice and refine competencies in safe and controlled virtual environments. These components collectively enhance flexibility, self-directed learning, and ongoing reskilling—core characteristics of lifelong learning in knowledge-based societies.

Third, the findings demonstrate strong alignment between AI-enhanced Metaverse education systems and the Sustainable Development Goals. SDG4 (Quality Education) is supported through inclusive, adaptive, and lifelong learning opportunities. The development of AI-driven digital infrastructures aligns with SDG9 (Industry, Innovation, and Infrastructure), while expanded access to geographically unconstrained and personalized learning environments contributes to SDG10 (Reduced Inequalities). Accordingly, AI-integrated Metaverse systems function as both structural and transformative mechanisms in advancing sustainable educational development.

Within the context of an aging society, the significance of these findings becomes particularly pronounced. AI-enhanced immersive learning environments can mitigate mobility limitations, reduce social isolation, and support cognitive engagement among older adults. Adaptive learning systems accommodate diverse individual capacities, while virtual spaces create learning opportunities without requiring physical travel. These characteristics position the Metaverse as a promising digital platform for active aging and lifelong participation in education.

However, effective implementation requires careful consideration of age-friendly design, equitable access to technology, supportive policy frameworks, and appropriate ethical governance. Without inclusive planning and responsible regulation, such technologies may risk reinforcing existing social inequalities rather than alleviating them.

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