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The role of metaverse in training and educational context: Potentialities, use-cases, and research directions

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Abstract

The rapid rise of smart devices and advancements in mobile computing, machine learning, and artificial intelligence have set the stage for the metaverse—a shared, immersive virtual world where people can interact through dynamic digital environments and avatars. This innovation is poised to transform various sectors, with education standing out as a key area of impact. In education, the metaverse promises to revolutionize learning by enabling students and instructors to engage in immersive virtual environments. Students can explore historical events, conduct experiments in virtual labs, or develop real-world skills in risk-free simulations. Educators can deliver adaptive and interactive lessons tailored to individual needs, creating more engaging and effective experiences. However, realizing the metaverse's potential requires overcoming significant challenges, such as improving technology scalability, ensuring seamless user experiences, and addressing data privacy concerns. This paper examines the metaverse's potential in education, highlights enabling technologies, and outlines key research directions to overcome current barriers.

Keywords: Education, Intelligence, Metaverse, Virtual reality

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1. Introduction

Over the past decade, we have witnessed the rapid proliferation of smart electronic devices, such as smartphones and tablets, alongside the unprecedented, fast-paced evolution of wireless telecommunication systems. These systems have been continually upgraded to ensure seamless connectivity, enabling everyone to access a wide range of smart services that make daily life more efficient and convenient. This evolutionary trend shows no signs of slowing, with the sixth generation (6G) of mobile wireless networks poised to deliver transformative services such as tactile internet, extended reality (XR), and autonomus driving further enhancing societal impact [1]. More specifically, these will lead toward the realization of the so called metaverse, where individuals interact with each-other through computer-generated environments in real-time [2, 3]. Thanks to its unique characteristics and features that allows users to engage in a brad spectrum of actvities, it is expected that the establishment of metaverse will positively impact different sectors such as health, gaming, manufacturing and education.

Within the educational sector, the realization of the metaverse will enable learners and instructors to interact in a virtual environment even if they are from different parts of the world, fostering then a more engaging and productive learning experience for both. For example, students will have access to interactive resources that can significantly enhance their learning process. At the same time, the integration of artificial intelligence (AI) and generative AI tools will allow teachers to automate time-consuming tasks such as homework correction, error analysis, personalized weakness identification, and even basic knowledge delivery. It is important to note, however, that education is not limited to traditional schooling; it should be envisioned more broadly to encompass all forms of

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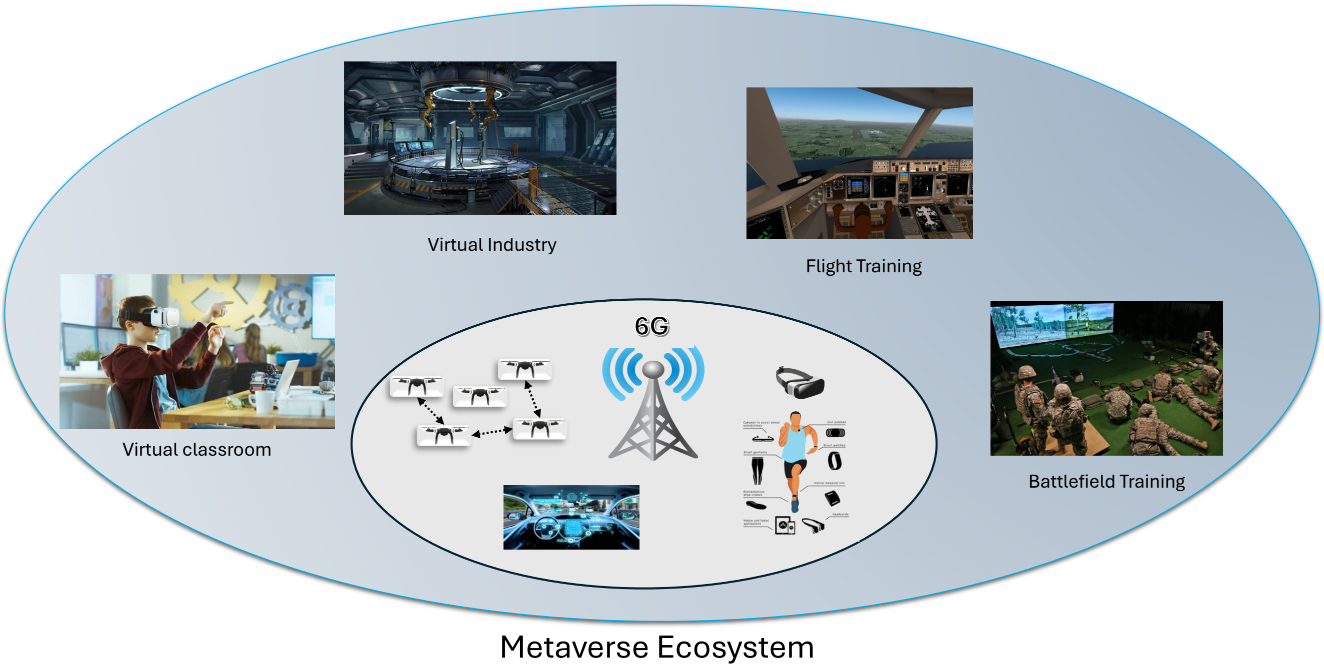

Figure 1. Representation of the Metaverse ecosystem.

learning. For instance, as illustrated in Figure 1 the metaverse can also play a transformative role in training employees within industrial sectors or preparing pilots before they operate real planes or steer large ships, as well as military training, providing a safe and immersive environment for skill development.

However, to date the possibilities of implementing such enhanced metaverse based educational systems remain limited. This mainly derives from the technical challenges that still needs to be addressed within the underlying network infrastructures. Indeed, in order to guarantee an optimal level of interaction between humans and the metaverse environment, in addition to guarantee high levels of throughput for data exchange between devices, the underlying communication and computing infrastructure needs to meet the requirements of ultra-reliable and low-latency communications (URLLCs), i.e., no more than 1 ms end-to-end (E2E) latency and a packet error probability lower than 10^{-7} [4].

Under these perspectives, this paper provides an overview about the main potentialities of the metaverse in the educational secto. More specifically it provides:

- A brief yet exhaustive introduction to the concept of metaverse, with particular attention in illustrating the main components for the implementation of metaverse-based educational scenarios;
- An illustration about the potential educational scenarios that can be realized through the metaverse;
- Challenges and future research direction in order to fully foster the full roll-out of this type of services.

The rest of the paper is organised as follows. Section 2 goes through the concept of metaverse, illustrating the main key enabling technologies and a layered version. Subsequently, different metaverse based educational scenarios are illustrated in section 3, while section 4 discusses the main challenges and next research directions. Finally, conclusions are provided in Section 5.

2. The metaverse framework

This section provides an overview about the concept of metaverse, illustrating its main components, and how they will will play a crucial role in the educational sector. In addition, a layered version of the metaverse ecosystem is also provided.

2.1. The concept of metaverse: Main components

As already mentioned before, the concept of metaverse is the result of combining different key modern technologies. In particular, the main ones can be summarized as follow:

1) *Augmented/Virtual Reality*, which represent the main building block. Indeed, the metaverse uses the AR/VR principles to create completely new environment either full virtual or as supeirposed digital layers to real object, which provides the users with full immersive experiences. In other words, it will be possible to realize simulated experiences similar to or completely different from the real world, as well as combining real world features with virtual world aspects which provide the final end user with experiences full of innovation and creativity.

2) *Internet of Things* paradigm, where the data generated from smart devices will be collected, analysed and processed in order to deliver metaverse applications personalized for each specific users or covered area. This will permits to enhance the quality of life as well as to meet the requirements and needs of the users.

3) *Big Data Analytics*, which represent another important building block. Indeed, thanks to these tools, the huge amount of data generated from IoT devices will be used in order to predict future outcomes and trends in metaverse-driven applications. This might include applications like sales, marketing, advertising, and so on. Furthermore, this will allow people to have a full immersive experience where in addition to simply the contents they will be able to navigate through or be prompted with related contents.

4) *Web 3* representing an evolution of the conventional World Wide Web, where ownership of online contents and components was traditionally limited to domain names. In contrast, through the use of distributed ledger technology, the Web3 paradigm enables users to become legitimate owners of their content, granting them complete authority and control over it.

5) *Blockchain:* Thanks to its capability of providing autonomous management of assets and applications, the adoption of blockchain-based technologies is becoming even more popular among different industrial sectors. The adoption of blockchain technology within metaverse-based educational solutions will enable the possibility of efficiently and safely securing data and digital information of metaverse users, which currently represents a major common concern among learners and educators. Last but not least, the adoption of blockchain will enable the possibility of enhanced trust and authority among users. This will encourage more IoT devices to participate and assist in the development of educational contents.

Then, as one can easily noticing, the establishment of the metaverse ecosystem through the aforementioned technologies will provide outstanding benefits and capabilities for delivering high quality educational services in all sectors.

2.2. Layered structure of metaverse

According to [5], the metaverse can be view as a set of 7 different layers. Each of these layers includes different components and various supporting technologies aimed at providing captivating and immersive user experiences. In particular, as depicted in Figure 2, using a bottom-up approach the following layers can be identified:

- *Infrastructure:* This encompasses a range of technologies, including computational resources, artificial intelligence and blockchain, which result necessary to create a fully operational and interconnected virtual environment. Merged with the high communication speed and efficient bandwidth utilization provided by the underlying 5G/6G network infrastructures, these allow to deliver high-quality contents without network bottlenecks.

- *Human interface:* This mainly represents the layer that allows humans to come closer to machines. More specifically, this layer contains different technologies such as bio-sensors, handled smart devices, which thanks to the high connection capabilities provided by the underlying infrastructure will be possible to the users to experience the metaverse in all its potential.

- *Decentralization layer:* This plays a pivotal role in order to sustain and guaranteeing possibilities for the scalability of the metaverse ecosystem. More specifically, it guarantees the interoperability between different heterogeneous devices as long as new ones are added.

- *Computing:* All the computing capabilities necessary to provide and maintain AR/VR capabilities are grouped within this layer. Furthermore, it integrates all the AI features that manage and analyze data from different sources, formats, and characteristics. In other words, there represents the core of the metaverse.

- *Content creator economy:* This represents the layer filled with contents generated by different content creators. Basically it is the financial part of the metaverse where content creators and users themselves can find huge financial potentials.

- *Discovery:* This layer is intended to provide a representation of what users are doing in order

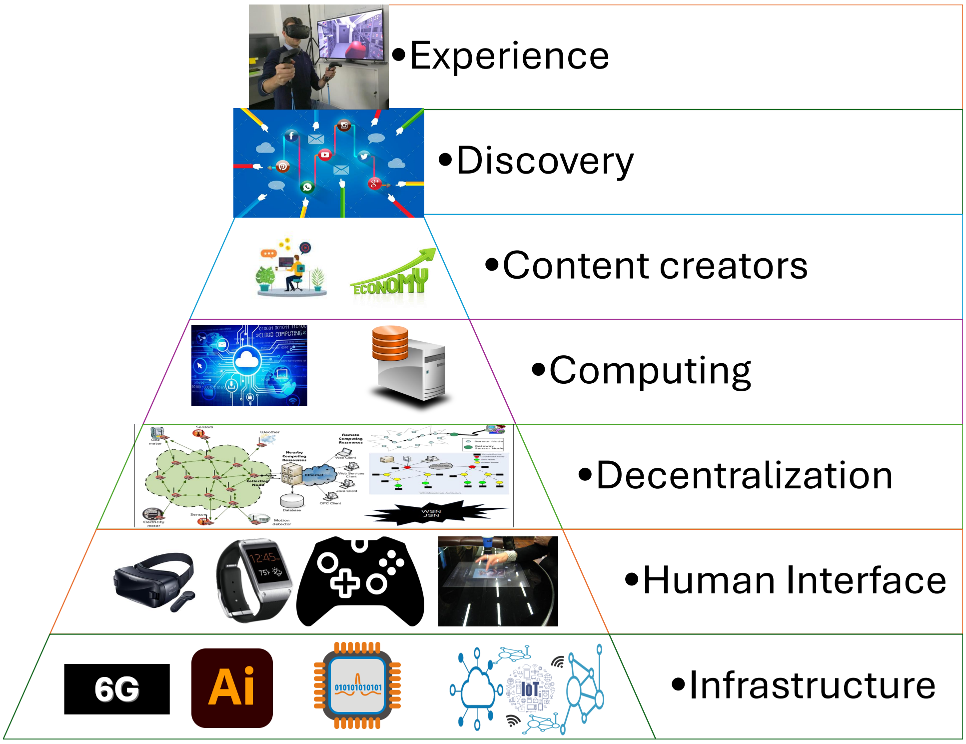

Figure 2. Layered representation of Metaverse.

to deliver personalized and trend-related services. Then in this layer we can place all the different type of discovery tools and notifications ranging from search engines and real-time community-driven content sharing to social media posts and advertisements.

- *Experience:* This is the top layer where the metaverse dematerializes the physical space and provides people with immersive social life experiences through sicual life and community interactions, as well as different types of creative and interactive activities like e-gaming.

3. Metaverse in education: Application scenarios

This section illustrates how the usage of metaverse is able to provide better performances in terms of skill development and better understanding when compared with traditional online resources. In this context, examples within different educational scenarios are provided within the following subsections.

3.1. School Virtual Classrooms

The establishment of virtual classes through the adoption of AR/VR technologies represents the most common educational scenario realized through the metaverse concept. In this context, it will be possible to provide substantial benefits such as minimizing the need to travel to school since avatars of both learners and teachers can be realized, as well as interact within virtual spaces. In addition, how highlighted from recent studies, the realization of Virtual Classrooms promotes the establishment of a healthy and engaging learning experience where students can interact and cooperate regardless of their physical location [6–8]. Last but not least, the possibility of realizing virtual teaching scenarios is helpful also for the teachers. Indeed, as already illustrated in [9], it is possible to take advantage of virtual environment in order to analyze teachers' competence and practices in different context of a teaching session. For example how queries and suggestions during virtual classes are handled. Such practices result helpful in improving teaching skills of in-service teachers , as well as enhancing the teaching skills of preservice teachers.

3.2. Maritime and Aircraft Training

The potential for establishing virtual environments to support training, monitoring, control, and learning has been thoroughly explored within this field. The literature demonstrates the proven effectiveness of such technologies in the maritime and aviation sectors [10]. For instance, studies indicate that adopting AR/VR technology for training significantly reduces errors while requiring less effort and time. In this context, various AR-based platforms have been developed to facilitate training for pilots and workers in both the aviation and maritime industries. These applications range from pilot training to preparing personnel responsible for inspection and maintenance tasks [11–15].

3.3. Military Defense

Military defense training is another key area where virtual environments have proven highly impactful in education. Defense organizations like the Defense Advanced Research Projects Agency (DARPA) are increasingly adopting military simulations over conventional training methods [16]. Leveraging advanced high-level architectures, these simulations provide safe, collaborative scenarios designed to prepare soldiers for executing war strategies. This shift offers notable benefits. For example, virtual replication of specific scenarios significantly cuts costs associated with travel and logistics for troop exercises. Moreover, it allows soldiers to practice using specialized armed equipment without exposure to real-world dangers. Platforms such as the DEIMOS Military VR Trainers exemplify this approach, offering metaverse-based training scenarios tailored to activities like shooting, tactical maneuvers, and observation under various environmental conditions [17].

3.4. Industrial sector

The adoption of metaverse-based solutions also plays a vital role in employee training. Virtual industrial environments provide workers with opportunities to enhance their skills through hands-on experience with various tasks in a risk-free setting. Furthermore, integrating metaverse concepts within factories offers benefits such as improved efficiency and enhanced monitoring of the entire production chain. For example, AR/VR technology and simulations enable global teams to collaborate in real time on factory design and planning. Additionally, planning experts worldwide can be trained and involved in testing new design tools and techniques [18, 19]. This approach is exemplified by BMW, which leverages 3D-enabled capabilities to frequently reconfigure its factories and train employees for new vehicle launches. Moreover, the metaverse facilitates the development of collaborative robotic environments, allowing humans and robots to work together to boost factory efficiency and productivity. This transition is becoming increasingly necessary as the volume of tasks across industries continues to rise. By generating millions of synthetic images that replicate real-life conditions, metaverse environments can also streamline the training of autonomous and collaborative industrial robots.

4. Current Challenges and next research directions

Although the adoption of metaverse-based solutions will provide substantial contributions and benefits in different context and scenarios, there are still some challenges that need to be addressed before guaranteeing its full deployment. This section provides the most relevant challenges that could hinder the implementation and deployment of metaverse for educational services.

4.1. Underlying Infrastructure maturity

This field poses significant challenges for the successful implementation of metaverse services, particularly those involving interactions among users from different locations worldwide. Ensuring high levels of Quality-of-Service (QoS) and Quality-of-Experience (QoE) is critical, especially for avatar-based interactions. Achieving this requires optimal resource allocation to meet URLLC requirements, even for long-distance communication.

Recent studies have proposed solutions to address these challenges. For instance, [20] introduced a Hierarchical Multi-Agent Reinforcement Learning (HiMARL) mechanism to optimize resource allocation in networks, accommodating numerous users consuming e-learning content on mobile devices. HiMARL employs a prioritization policy to maximize QoS for learners accessing diverse video content. Similarly, [21] presented the QoE-aware Adaptive Multimedia Mobile Learning (DQAMLearn) framework, which uses a client-server architecture in Adaptive Learning Systems (ALS) to deliver multimedia educational content in a quality-aware manner. This framework reduces network traffic while maintaining high learning outcomes and QoE for learners.

Additionally, deploying smart education systems in developing countries presents unique challenges. Authors in [22] identified barriers such as underdeveloped ICT infrastructure, limited digital resources, and insufficient back-end software support. To address these issues, they proposed the vSmartEdu framework, a hybrid online/offline web-based system based on a service-based architecture (SBA). With independent functional modules communicating through a shared information bus, vSmartEdu supports both online and offline operations. The framework's prototype demonstrated its effectiveness across different educational levels and use cases.

4.2. Computational capabilities

The realization of metaverse services hinges on mechanisms capable of creating virtual worlds that closely mirror the real world. This is essential to provide users with ultimate immersive experiences that transcend conventional digital interactions. Achieving such capabilities, however, involves addressing significant technological challenges. Foremost, it requires the collection of vast amounts of data from sensors and IoT devices, which is processed and analyzed in order to maintain the seamless and realistic nature of the metaverse experience.

Given the magnitude of these data processing requirements, it becomes clear that robust solutions are necessary to address these computational demands. As highlighted in [23], one promising approach lies in the adoption of distributed-based solutions, where edge-enabled computing systems play a pivotal role. These systems effectively mitigate computing resource constraints on metaverse platforms by distributing processing workloads closer to the data sources. This not only reduces latency but also ensures more efficient utilization of computational resources, enabling smoother and more immersive experiences for users.

In addition to distributed computing, implementing efficient mechanisms for computing acceleration is imperative. Such advancements will facilitate the rendering of complex and immersive environments within metaverse platforms. For educational applications, these features are particularly transformative. They enable learners to engage with highly interactive, visually rich virtual environments, enhancing both the quality and effectiveness of their educational experiences. Moreover, these advancements hold the potential to redefine next-generation education by fostering deeper engagement and collaboration between learners and educators on metaverse platforms.

4.3. Security and privacy

The metaverse's foundation is deeply rooted in the exchange and utilization of data among users, particularly for building virtual environments and personal avatars. This encompasses not only conventional data types like images, videos, audio, and documents but also sensitive information such as biometric data and facial gestures crucial for AR/VR applications. Consequently, addressing data security and privacy issues is vital. The integration of digital identities and immersive experiences in the metaverse presents significant privacy challenges, especially concerning educational content and the potential exposure of trainer identities. For instance, improperly secured biometric data or facial gestures collected through AR/VR technologies could be exploited. Such vulnerabilities include attacks on head-mounted displays, where manipulated images in a user's field of vision can cause disorientation.

To counter these risks, safeguarding user privacy in the metaverse requires several measures, such as improving data transparency, updating legal frameworks, strengthening control mechanisms, and refining technical designs [24].

Furthermore, as AR/VR devices paired with Brain–Computer Interface technology enable metaverse applications to analyze user thought processes and predict behavior, it becomes essential to secure sensitive data exchanged between users and service providers. Another pressing concern is copyright protection. With the metaverse driving the growth of diverse online educational platforms, managing digital rights to prevent copyright infringements on educational resources will be critical. Blockchain technology offers an effective solution in this regard, ensuring the protection of educational content and safeguarding intellectual property rights linked to technology transfer resources [25].

5. Conclusion

The establishment of the metaverse is poised to completely revolutionize our everyday lives. It will enable individuals to interact with others and carry out daily activities within shared virtual environments in a fully immersive way. This transformation extends to the educational sector, where both educators and learners will be able to engage through virtual spaces. Leveraging AI and virtual reality, these spaces will offer more engaging and interactive experiences. Additionally, they can provide safer environments for certain types of learning and training activities. In essence, metaverse-based scenarios will pave the way for more immersive and efficient educational frameworks. This paper presented an overview of the key components of the metaverse and explored the diverse educational and training scenarios it can facilitate. Furthermore, the challenges and outlines future research directions needed to ensure the successful roll-out of metaverse-based services have been also highlighted.

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