Metaverse in Engineering Education;

A Review of Application, Challenges and Future Prospect

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Abstract. The use of the metaverse in engineering education has the potential to enhance learning and collaboration. However, it is crucial to consider the potential limitations and challenges that may arise. This research aims to explore the implementation of the metaverse in engineering education, including the challenges faced and the future prospects for this technology. The study utilizes a case study analysis and comparison methodology to examine engineering education programs that incorporate metaverse technology. Five case studies namely virtual laboratories, virtual classrooms, virtual field trips, social networking, and collaborative projects were selected from the literature to provide real-world examples and understand the potential benefits and challenges of using the metaverse in engineering education. Through data analysis and discussion, this research aims to contribute to a comprehensive understanding of the effective utilization of the metaverse in engineering education while identifying areas for further exploration and development. Based on the findings, recommendations are made for the successful implementation of the metaverse in engineering education and future research directions in this area. Overall, this research will provide valuable insights for educators considering the use of the metaverse in engineering education and for researchers studying the potential of this technology in education.

Keywords: Metaverse, engineering education, virtual, immersive, interactive.

1 INTRODUCTION

Engineering education using the Metaverse is a topic that has garnered significant attention in recent years, as educators and policymakers explore the potential of this virtual shared space for enhancing the learning experience. The metaverse is a collective virtual shared space, created by the convergence of virtually enhanced physical reality and physically persistent virtual space, including the sum of all virtual worlds, augmented reality, and the internet. The term was coined by science fiction author Neal Stephenson in his 1992[1] novel Snow Crash [2], to describe a virtual reality-based society. The concept of the metaverse has evolved significantly since its inception, with

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the advent of new technologies such as virtual reality, augmented reality, and the Internet of Things. These technologies have enabled the creation of immersive virtual experiences that can be accessed from anywhere, at any time, and on a variety of devices. The development of the metaverse can be traced back to the early days of virtual reality [3], when scientists and engineers first began exploring the potential of using computer simulations to create immersive virtual environments. In the 1960s, Ivan Sutherland developed the first virtual reality headset, called the Sword of Damocles [4], which allowed users to experience a 3D virtual world through a headset and gloves. In the 1980s and 1990s, virtual reality technology continued to advance, with the development of haptic feedback systems and the first commercial virtual reality headsets. However, it was not until the widespread adoption of the internet in the late 1990s that the metaverse began to take shape. The emergence of social media platforms, online gaming, and virtual worlds, such as Second Life, enabled people to connect and interact with one another in virtual spaces [5, 6]. This laid the foundation for the metaverse as we know it today, where virtual and physical reality are increasingly intertwined. Today, the metaverse is a rapidly growing and evolving concept [7], with numerous applications in fields such as entertainment, education, and commerce. As technology continues to advance, the metaverse is expected to become an increasingly integral part of our daily lives, offering new and exciting opportunities for connection, collaboration, and creativity

In terms of education, the Metaverse offers a new platform for education that is immersive, interactive, and personalized, and has the potential to revolutionize the way we approach teaching and learning in the field of engineering [7]. However, there are also limitations and issues that must be considered when using the Metaverse for engineering education. One key limitation is the potential for technical challenges, such as hardware and software requirements, or limited internet connectivity. Ensuring that the Metaverse is accessible to all students is crucial to ensure that the benefits of this technology are not limited to a select few. One example of failure in the metaverse is the virtual world Second Life, developed by Linden Lab. Second Life was launched in 2003 and gained popularity in the mid-2000s as a platform for users to create and interact with virtual avatars in a 3D environment. However, the platform experienced a number of issues and controversies over the years, which ultimately contributed to its decline in popularity [8, 9]. Second Life's technical issues, limited content, and poor user experience contributed to its decline in popularity and eventual failure as a metaverse. Another important issue is the role that educators and other stakeholders play in the development and implementation of engineering education using the Metaverse. Educators must consider how to effectively integrate the Metaverse into their teaching practices, and how to support students as they navigate this new learning environment. Additionally, policymakers and administrators must consider how to regulate and support the use of the Metaverse in education, including issues related to privacy, security, and intellectual property.

To illustrate the potential of engineering education using the Metaverse, consider the example of a virtual laboratory. In a traditional laboratory setting, students may be limited by physical constraints such as equipment availability and space constraints. In a virtual laboratory, students can access a wide range of equipment and materials, and can conduct experiments in a simulated environment that is safe and controlled. This allows students to learn and practice engineering skills in a way that is not possible in the physical world. In summary, the incorporation of the Metaverse into engineering education holds potential for enhanced learning experiences and improved student outcomes. However, it is crucial to carefully evaluate the limitations and potential issues surrounding this technology in order to ensure its ethical and effective utilization. This research aims to investigate the potential of incorporating the Metaverse into engineering education by examining five different applications, identifying limitations, and addressing challenges. The selected case studies provided real-world examples to understand the potential benefits and challenges of using the metaverse in engineering education. Through case study analysis and discussion, this research aims to contribute to a comprehensive understanding of the effective utilization of the metaverse in engineering education, while identifying areas for further exploration and development.

2 METHODOLOGY

The methodology for this research study involves a case study analysis to gain a deeper understanding of the challenges and successes of engineering education programs that have implemented metaverse technology. Five case studies were selected from real-world implementation of metaverse technology into engineering education program. To identify these case studies, a comprehensive literature review was conducted, encompassing published research on engineering education using the metaverse, relevant books, journal articles, and online communities.

Data collection for each case study involved gathering documentation, reports, and publications related to the programs. From the collected data, common themes, patterns, and trends across the selected case studies were identified. Special attention was given to the benefits and challenges experienced in each program, as well as the strategies employed to overcome obstacles and enhance learning outcomes. The findings from the data analysis were then discussed and interpreted in a comprehensive manner. The limitations and issues associated with the use of the metaverse in engineering education were explored, along with the challenges faced during implementation. Recommendations were provided to address these challenges and maximize the benefits of metaverse technology in engineering education. Additionally, the future prospects and potential advancements in the field were discussed.

3 CASE STUDY

Based on the findings from the literature review, five case studies were selected that would represent a diverse range of metaverse applications in engineering education namely virtual laboratories, virtual classrooms, virtual field trips, social networking, and collaborative projects. These cases will serve as real-world examples to gain insights into the challenges and successes of utilizing the metaverse in engineering education.

3.1 Virtual laboratory

A virtual laboratory metaverse is a digital environment that allows users to conduct experiments, simulations, and other research activities in a virtual setting. It is similar to a virtual reality (VR) laboratory, but it is typically accessed through a web browser or other software application and does not require the use of VR headsets or other specialized hardware. In a virtual laboratory metaverse, users can interact with virtual instruments, equipment, and other objects as if they were in a physical laboratory. This can be useful for a variety of purposes, such as educational demonstrations, collaborative research, and prototyping new ideas. Some possible features of a virtual laboratory metaverse might include:

1. Virtual instruments and equipment that behave as closely as possible to their real-world counterparts
2. 3D visualization tools for data analysis and visualization
3. Collaboration tools that allow multiple users to work together in the same virtual space
4. Simulation tools that allow users to conduct experiments or simulations under different conditions
5. An extensive library of virtual objects and materials that can be used in experiments or simulations

There are many potential applications for a virtual laboratory metaverse, including education, research, and industry. It could be used to teach scientific concepts and techniques to students, to facilitate collaboration among researchers from different institutions, or to allow engineers and scientists to prototype and test new ideas before building physical prototypes. Some examples of virtual laboratory projects include Labster, developed by a Danish company[10-13], and Virtual Lab, developed by the University of California, San Diego [13]. Both of these projects offer a range of virtual lab simulations covering various scientific and technical subjects. The University of Colorado Boulder has developed the Virtual Physics Lab [14, 15], a collection of online simulations that allow students to explore physical concepts and conduct experiments in a virtual setting while the University of Massachusetts has developed Virtual ChemLab [16], a series of online simulations that allow students to conduct experiments and explore chemical concepts in a virtual laboratory setting. All these projects typically allow users to conduct experiments, simulations, and other research activities in a virtual setting, using virtual instruments and equipment.

3.2 Virtual Classrooms

A metaverse virtual classroom is a virtual space where students and teachers can come together to learn and interact in a 3D immersive environment. These classrooms are accessed through virtual reality or augmented reality technologies, and they offer a range of features and tools to support learning and collaboration. In a metaverse virtual classroom, students can participate in lectures, discussions, and group projects, and they can also interact with virtual objects and environments to enhance their learning experience. Metaverse virtual classrooms are becoming increasingly popular as a way to deliver online education, and they offer significant benefits for both students and teachers, including the ability to access classes from anywhere and the ability to create a more interactive and engaging learning environment. One example is Edverse[17], the education metaverse, is a revolutionary platform that is changing the way education is delivered online. Edverse focuses on integrating education with the metaverse to offer a unique and immersive learning experience. Edverse's Metaverse Classroom is a virtual classroom offers 3D immersive learning experiences that are unlike anything previously seen in the education sector. Students can join classes from the comfort of their own homes, and teachers no longer need to worry about physical infrastructure or making sure their presentations are heard at the back of a room. Research on virtual reality classroom showed significantly better learning motivation, learning outcomes and positive impacts on learning students' achievement scores [18-20]

3.3 Virtual field trips

The virtual field trips allow students to visit and explore engineering sites and projects that they might not have been able to visit in person, due to factors such as distance, time, or cost. They also provide students with an immersive, interactive learning experience that allows them to see and experience engineering concepts and processes in a real-world context [21]. The use of the metaverse as a tool for virtual field trips [22] can enhance and enrich the learning experience for engineering students, by providing them with the opportunity to explore and learn about real-world engineering sites and projects from the comfort of their own computers. One example of a virtual field trip for engineering education could be a tour of a manufacturing plant or a research and development facility. The field trip could be conducted entirely online, with students accessing video or virtual reality tours of the facility, or it could be a combination of online and in-person elements, with students participating in a guided tour of the facility in person while also being able to access additional resources and information online. During the field trip, students could learn about the engineering principles and technologies used in the facility, as well as the design and operation of the facility itself. They could also see firsthand how engineering concepts are applied in real-world settings, and have the opportunity to ask questions and interact with engineers and other professionals working at the facility. This type of field trip could be particularly beneficial for students who may not have the opportunity to visit such facilities in person, or for those who are interested in pursuing a career in engineering and want to learn more about the types of work that engineers do. There are many subjects can be done as field trips including digital heritage, construction management and engineering (Figure 1), tourism[[23], architecture and more.

Fig 1. A field trip of an engineering construction [21]

3.4 Social Networking

Social networking events utilizing the metaverse as their backbone, such as metaverse concerts, e-sport gaming, expos, and awards ceremonies, have garnered international attention. Metaverse concerts [24-26], in particular, have revolutionized the entertainment industry by providing virtual performances that transcend geographical limitations. Efforts by researchers play a crucial role in supporting these endeavors [27]. E-sport gaming events within the metaverse have thrived, attracting global participants and elevating the industry. Tournaments like the Metaverse Legends Invitational and the Virtual Gaming Expo showcase top players, cutting-edge technologies, and the future of gaming. Through the metaverse, competitive gaming has been transformed, offering immersive experiences and expanding the industry's reach. Research also shows that games are leading the way in metaverse [28]. The survey conducted in November 2021 revealed that the metaverse is highly favored among gamers in the United States, with a significant 60% expressing a personal interest in utilizing it for their gaming experiences. This makes gaming the predominant choice for metaverse usage [29]. Furthermore, expos [30], metaverse meeting [31], tourism [23],museum [32] and awards ceremonies benefit from the metaverse's immersive capabilities, enabling broader participation and enhanced experiences. Overall, these events demonstrate the metaverse's potential to reshape social networking and foster virtual engagement on a global scale.

3.5 Collaborative Projects

The metaverse can serve as a versatile platform for various collaborative activities, including but not limited to, educational pursuits, research initiatives, and project development [33, 34]. One example of a collaborative projects using a metaverse platform is the Virtual Futures Salon [35], a series of virtual events that bring together experts and thought leaders from a variety of fields to discuss and explore emerging technologies and their impacts on society. The Virtual Futures Salon is hosted in the VR World metaverse platform, which allows attendees to participate in a fully immersive and interactive environment. During the Virtual Futures Salon, attendees are able to participate in panel discussions, attend lectures and workshops, and engage in networking and social activities with other attendees. The events are open to the public and are typically focused on topics related to technology, science, and society. One of the key benefits of using a metaverse platform for collaborative projects like the Virtual Futures Salon is the ability to bring together people from different locations and backgrounds in a shared virtual space. This allows for more efficient and convenient collaboration, as participants do not need to physically travel to a central location in order to participate. It also allows for a more immersive and interactive experience, as attendees are able to interact with each other and with virtual objects and environments in real-time.

4 DISCUSSIONS

4.1 Challenges

Based on the case studies, it shows that the metaverse offers many benefits and opportunities for students and educators [36, 37]. Furthermore, the use of the metaverse in engineering education can help to bridge the gap between classroom learning and real-world applications [38]. However, several issues and limitation of using metaverse were identified. These include issues related to availability, user experience, data privacy and security, cost, integration with traditional education methods, and the limitations on the types of activities and experiences that can be provided within a virtual environment [39-42].

Availability: One of the main issues with using a metaverse in engineering education is that not all students may have access to the technology or infrastructure needed to participate. This could include things like high-quality computers, fast internet connections, and the necessary hardware and software to run the virtual environment. Students who do not have access to these resources may struggle to fully participate in the metaverse and may be at a disadvantage compared to their peers [43].

User experience: Navigating a virtual environment can be challenging, especially for students who are not familiar with the software or hardware required. This can lead to frustration and difficulty in learning, which may impact the overall effectiveness of the metaverse as a learning tool.

Data privacy and security: Metaverses often collect and store large amounts of personal data from users, which can include things like user names, email addresses, and activity within the virtual environment. While this data may be used to improve the user experience, it also raises concerns about data privacy and security. In the context of education, it is important to ensure that sensitive information such as grades and personal details are protected [44, 45].

Cost: Developing and maintaining a metaverse can be a costly endeavor, as it requires the development of virtual environments, the creation of content, and the provision of technical support. There may also be additional costs associated with accessing and participating in the metaverse, such as fees for software licenses or subscription-based models.

Integration with traditional education: Incorporating a metaverse into traditional education can be a significant shift in the way teaching and learning are conducted. This may require the development of new curricula, the training of faculty to use the virtual environment, and the adoption of new technologies. It can be a challenge to integrate the metaverse into existing educational systems and processes.

Limited scope: While a metaverse can offer a wide range of learning opportunities, it may be limited in terms of the types of activities and experiences it can provide. For example, hands-on laboratory experiments or fieldwork may not be possible within a virtual environment. This can limit the scope of what can be learned through a metaverse and may require the use of other teaching methods to supplement the virtual learning experience

In summary, the limitations can be categorized into four main challenges in implementing metaverse technology: technical, accessibility, usability, and pedagogical. The following section discusses these challenges and suggests ways to overcome them.

Technical challenges: Metaverse platforms rely on complex technology and require high-quality hardware and software to function properly. This can be a challenge for educators who may not be familiar with the technology, or who may not have access to the necessary hardware and software. Additionally, the technology used in metaverse platforms may be prone to glitches or other technical issues, which can disrupt the learning experience.

To address technical challenges, educators can ensure that they have access to the necessary hardware and software, and can provide training and support for students and teachers who are new to the technology. It may also be helpful to have a technical support team or resource available to troubleshoot any issues that arise.

Accessibility challenges: Metaverse platforms may not be accessible to all students, due to factors such as the cost of hardware and software, or the availability of high-quality internet connections. This can create barriers to participation and may limit the effectiveness of metaverse-based learning.

To address accessibility challenges, educators can consider using metaverse platforms that are available on a range of devices, including smartphones and tablets, in addition to desktop computers. They can also provide support and resources for students who may not have access to high-quality internet connections or who may need assistance with hardware and software.

Usability challenges: Metaverse platforms can be complex and may require a learning curve for users, particularly those who are new to virtual environments. This can be a challenge for educators who need to teach students how to use the platform effectively, and for students who may struggle to navigate the virtual space [46].

To address usability challenges, educators can provide training and support for students and teachers who are new to metaverse platforms, and can design learning activities that are user-friendly and easy to understand. It may also be helpful to provide resources and support for students who may have difficulty navigating the virtual environment

Pedagogical challenges: Metaverse platforms offer a number of potential benefits for teaching and learning, but they also present some pedagogical challenges. For example, it may be difficult to recreate the same level of interaction and engagement in a virtual environment as in a physical classroom. Additionally, it may be challenging for educators to adapt traditional teaching methods to the virtual environment, or to design effective metaverse-based learning activities.

To address pedagogical challenges, educators can experiment with different teaching methods and approaches in the virtual environment, and can seek feedback from students and colleagues to identify those that are most effective. They can also consider incorporating elements of traditional classroom-based instruction, such as discussion and group work, into metaverse-based learning activities. Additionally, educators can seek out resources and guidance from experts in the field of metaverse-based learning in order to stay up-to-date on best practices and strategies for effective teaching and learning in the virtual environment

4.2 Future prospects

The future prospects of engineering education are vast, as the skills and knowledge gained in this field will be invaluable in shaping and contributing to the development of the metaverse. Here are a few prospects for the future use of metaverse platforms in engineering education:

Skill development: The use of metaverse in engineering education has the potential to offer immersive, experiential learning opportunities that can improve skill development in various fields. The metaverse could potentially make learning more exciting and motivating for students by gamifying it. Additionally, the use of 3D technology, augmented reality, and virtual reality in the metaverse could provide valuable hands- on experience for students in fields such as electrical, mechanical, electronics, and civil engineering, where practical implementation is important for skill development.

Communication: The future of metaverse in digital communication is likely to be significant, as the technology has the potential to revolutionize the way that we communicate and interact with one another. The use of virtual reality technology in the metaverse allows for the creation of virtual environments where people can meet and interact with one another in a more immersive and interactive way. This could potentially lead to the development of new social platforms and virtual communities, as well as new business and professional networking opportunities. The use of the metaverse in digital communication could also facilitate more effective remote work and collaboration, as it allows for the creation of virtual meeting spaces and shared virtual workspaces. As virtual reality technology continues to advance and become more widespread, it is likely that the use of metaverse in digital communication will become more prevalent, potentially becoming a mainstream method of communication and interaction

Technological devices: In the future, it is expected that the metaverse will have a strong connection with technological devices, including virtual and augmented reality headsets, smartphones, and tablets, that are affordable and of high quality. These devices will likely be the primary means of accessing and interacting with the metaverse, with virtual reality technology being the most common way to experience it in a more immersive and interactive manner. It is also possible that augmented reality technology could be utilized to access the metaverse, overlaying virtual elements onto the real world. These devices will likely be able to access the metaverse through specialized apps or web browsers.

Research and development: Further research and development is needed to explore the most effective ways of using metaverse platforms for engineering education. Efforts by Huynh-The, Pham[47, 48] demonstrate the exploration of the role of AI, including machine learning algorithms and deep learning architectures, in the foundation and development of the metaverse. Another potential area of research is the use of game-based learning and gamification in engineering education [49, 50], and the impact of these approaches on student motivation and learning outcomes. These areas of research have the potential to significantly enhance the quality and effectiveness of engineering education, and could lead to significant improvements in student outcomes. Other areas of potential research include the impact of the metaverse on student retention and success rates in engineering programs, as well as the potential benefits and challenges of using the metaverse in engineering education. Investing in this research and development will help to ensure that metaverse-based engineering education continues to evolve and improve over time.

5 CONCLUSION

The integration of a metaverse into engineering education has the potential to improve the learning and collaboration experiences of students. However, it is also necessary to consider any potential drawbacks or challenges that may arise. Five real-world case studies of the use of the metaverse in engineering education namely virtual laboratories, virtual classrooms, virtual field trips, professional net-working, and collaborative projects were presented to demonstrate how metaverse has been implemented in engineering education. By providing immersive and interactive learning environments, the metaverse allows students to engage with complex concepts and theories in a more meaningful way. It also provides a platform for students to collaborate and work on projects with their peers in a virtual setting. By simulating real-world scenarios and situations, students can gain practical skills and experience that can be directly applied in the workplace.

In the field of engineering education, there are several promising areas for future research and development involving the use of the metaverse. These include exploring the most effective ways to integrate the metaverse into engineering curricula, and comparing the effectiveness of different virtual learning environments. Additionally, research could be conducted on the integration of AI and machine learning into engineering education, including the potential benefits and challenges of using these technologies in the classroom. Overall, this research endeavor will offer valuable insights to educators considering the adoption of the metaverse in engineering education and to researchers investigating the potential of this technology in education. By addressing the challenges, discussing the benefits, and suggesting future prospects, this research aims to support informed decision-making and foster advancements in the field of engineering education.

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