International Journal of Advanced Research in Education and Society
e-ISSN: 2682-8138 | Vol. 6, No. 5, 17-29, 2024
https://asianscholarsnetwork.com/asnet-journals

A Review of Mixed Reality Technologies on the Future of Higher Education

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Received: 7 August 2024 | Accepted: 15 November 2024 | Published: 31 December 2024

DOI: https://doi.org/10.55057/ijares.2024.6.5.2

Abstract: *This paper reviews the current status and future development direction of Mixed Reality (MR) technology in higher education through a literature review. It reveals that MR technology effectively improves students' participation, knowledge retention and practical operation ability by providing a highly interactive and immersive learning environment. At the same time, it points out that the widespread application of MR technology still faces challenges such as high hardware equipment costs, insufficient technical training for teachers and imperfect educational infrastructure. Through the analysis of the literature, future research directions are proposed, and it is recommended to promote the popularization and application of MR technology in the field of education through policy support, reduction of technology costs and strengthening of teacher training, so as to promote a more flexible and innovative education model.*

Keywords: Mixed Reality, Higher Education, Industrial Growth

1. Introduction

In today's digital age, the rapid development of educational technology is completely changing the traditional teaching methods. As an emerging educational technology, Mixed Reality (MR) has gradually entered the field of higher education and has shown great potential. Mixed reality (MR) is an advanced development in Virtual Reality (VR) and Augmented Reality (AR). The notion has been provided by Kishino (1994). MR visual displays are a specific category of VR technologies that combine real and virtual worlds along the "virtuality continuum," which spans from entirely real surroundings to entirely virtual ones (Kishino, 1994). MR technology helps students better understand complex concepts by creating a highly interactive and immersive learning environment (Cabero-Almenara et al., 2020). With the continuous advancement of technology, MR is not only widely used in the field of education, but is also redefining the boundaries and methods of teaching (Cabero-Almenara et al., 2020) (The MR product shown Figure 1).

Figure 1: Apple MR rendering
Source: DoNews, Oriental Securities Research institute

Traditional teaching methods (such as lectures and paper textbooks) are still effective in specific scenarios, but their effectiveness is very limited when it comes to abstract concepts and practical skills. MR technology provides students with a more intuitive learning experience by providing realistic 3D simulation scenes. For example, in medical education, students can practice complex surgical operations through virtual surgical simulators (Pregowska et al., 2022); in engineering education, students can operate equipment and conduct experiments in virtual laboratories (Karim et al., 2015). Through these innovative technologies, students are no longer just passive recipients of knowledge, but can actively participate in the simulation scenes to better master knowledge and skills. Existing research shows that the introduction of MR technology can not only increase student participation, but also enhance knowledge retention and comprehension. Cabero-Almenara et al. (2022) pointed out in their study that MR technology can promote students' collaborative and innovative thinking, especially in the arts and humanities. In addition, the research results of Yang et al. (2020) showed that VR laboratories significantly improved students' spatial thinking ability and practical operation ability in engineering disciplines (AR, VR and MR Product market revenue shown Figure 2). These successful application cases further prove the potential value of MR technology in higher education.

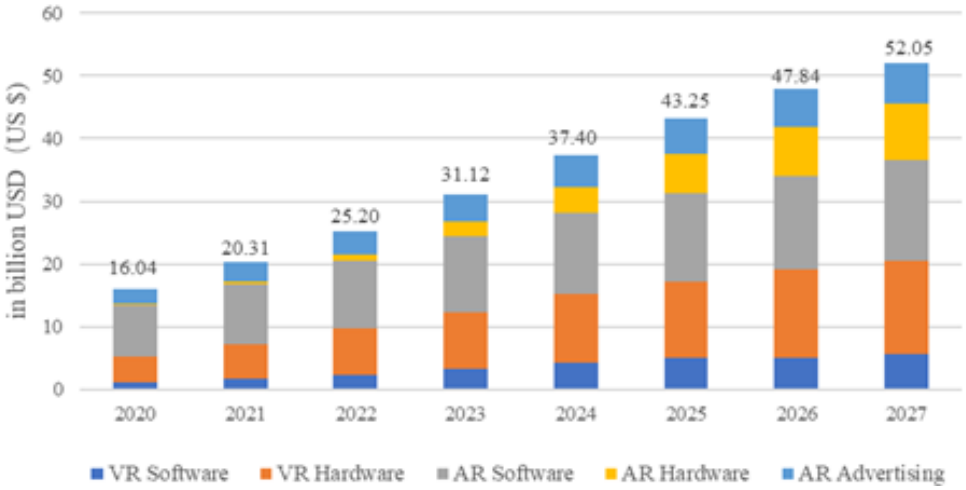

Figure 2: AR, VR and MR Product market revenue
Source: Statista Market Insights

Although MR technology has shown great application potential in education, its widespread application still faces many challenges, and the current user usage in the education field is not high. First, the high cost of hardware equipment and software systems makes many educational

institutions discouraged, especially small and medium-sized colleges and universities with limited (Alnagrat et al., 2022). Secondly, the degree of teachers' mastery of new technologies has also become an important constraint. Many teachers lack the corresponding technical training and cannot effectively integrate MR technology into teaching. In addition, the infrastructure construction of educational institutions has also formed a bottleneck for the application of MR technology, especially in terms of network bandwidth and computing power (Alowayr, 2021). Existing facilities may not be able to support high-performance MR applications (Consumer Preference Market Survey shown Figure 3).

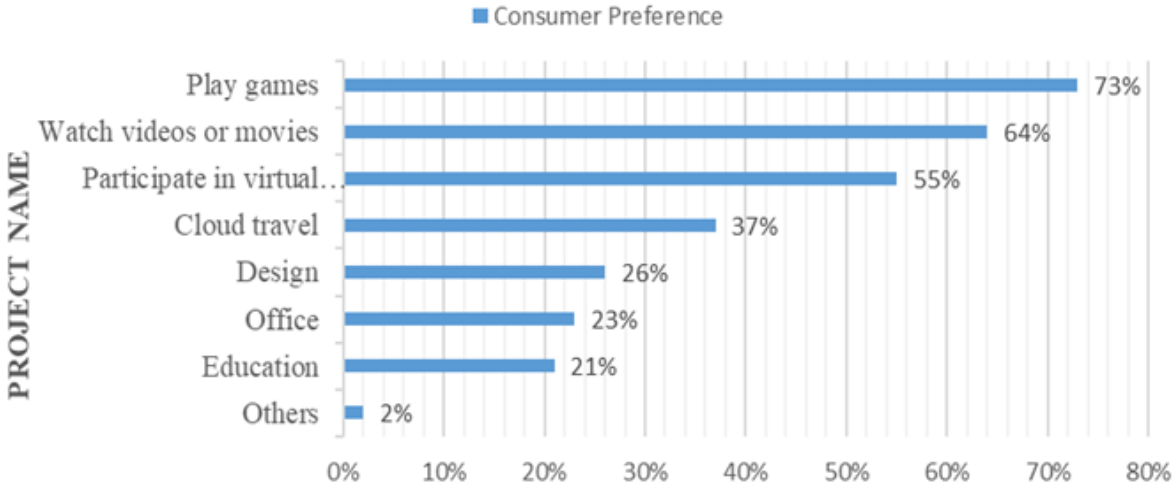

Figure 3: 2023 Global MR Consumer Preference Market Survey
Source: (Newzoo, 2024)

This paper aims to evaluate the current status and future development direction of MR technology in higher education through a systematic literature review, with a particular focus on the optimization path at the level of technology cost and education policy, analyse its potential advantages and challenges, and provide suggestions for future research and practice.

2. Technologies Overview

MR is a combination of VR and AR, which can achieve seamless connection between virtual environment and real world (Kishino, 1994). With the help of advanced sensors, display devices and powerful computing power, MR technology can accurately superimpose virtual content on the real world, and can also allow users to fully immerse in the virtual environment, thereby creating a highly interactive and immersive learning experience (Cabero-Almenara et al., 2020). The key lies in the ability to capture user actions in real time and feedback them to the virtual scene in a timely manner, so that users can interact efficiently with virtual and real elements (Alnagrat, et al., 2022).

2.1 Virtual Reality

VR technology mainly uses head-mounted display devices (such as Oculus Rift or HTC Vive, etc.) to completely bring users into a computer-generated three-dimensional virtual environment (Chen & Duh, 2018). In the field of education, VR technology is widely used to simulate complex experimental scenes and real operations (Pregowska et al., 2022). Taking medical education as an example, medical students can simulate surgery through VR; engineering students can complete experimental projects with certain risks in virtual laboratories (Karim et al., 2015). The advantage of VR technology is that it allows students to

learn in a fully immersive virtual environment, while at the same time effectively improving students' practical skills and cognitive abilities (Pellas et al., 2020).

2.2 Augmented Reality

AR technology superimposes digital information on the real world seen by users through mobile devices and smart glasses (such as Microsoft's HoloLens) (Matsutomo et al., 2017). Unlike VR technology, AR technology does not completely remove users from reality, but places virtual objects in the real environment, allowing users to observe and manipulate virtual content in real scenes (Onime et al., 2018). In the field of education, AR technology has been widely used in many fields such as architecture and history. For example, students can use AR technology to view three-dimensional models of historical buildings in a real environment to better understand their structure and historical background (Cabero-Almenara et al., 2020).

2.3 Mixed Reality

MR technology, as a fusion of VR and AR, has the remarkable feature of being able to capture and fuse virtual and real content at the same time (Kishino, 1994). In an MR environment, users can be fully immersed in the virtual world as in VR, and can also interact with the real world as in AR (Chen & Duh, 2018). This technology has great development potential in the field of education, especially in disciplines such as medicine and engineering that require high practical operations (Pregowska et al., 2022). For example, MR technology allows students to use virtual equipment in real laboratories, thereby improving their operational capabilities and reducing resource waste (Antoniou et al., 2015).

2.4 Technological advantages and potential

The advantages of MR technology are mainly reflected in immersion and interactivity. It can not only provide students with realistic virtual scenes to help them understand complex abstract concepts, but also encourage students to participate in learning more actively through real-time interaction and feedback (Alnagrat, et al., 2022) (as shown in the virtual continuum in Figure 5). With the gradual decline in the cost of hardware equipment and the continuous advancement of technology, the application prospects of MR technology in future education are very broad (Cabero-Almenara et al., 2020).

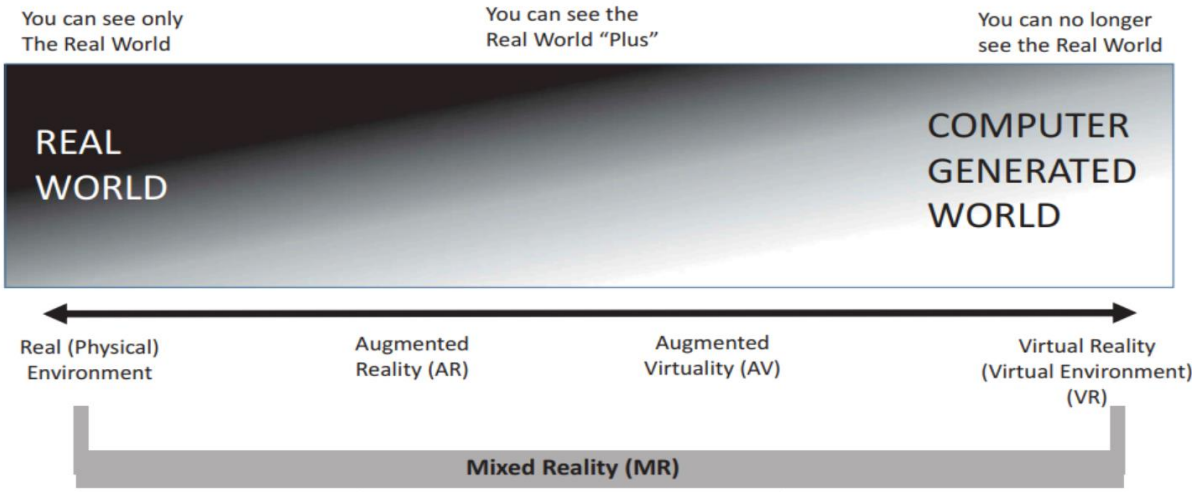

Figure 4: Simplified representation of a "virtuality continuum"
Source: (Alnagrat, Che Ismail, et al., 2022)

3. Literature Review

3.1 Application of MR in higher education

MR technology creates a new way to learn that is both engaging and collaborative by adding virtual elements to the real world (Onime et al., 2018). MR technology offers a safe and effective means of developing practical skills, particularly in disciplines like engineering and medicine (Chen & Duh, 2018). MR technology can raise student engagement and learning outcomes by offering interactive and interesting learning experiences. MR offers numerous advantages and uses in various educational situations.

MR technology enables human-computer interaction in a variety of ways, such as somatosensory manipulation, gesture recognition and voice control, allowing users to interact with virtual objects. For example, the use of a high-speed camera allows the position of the user's hand to be tracked so that 3D models can be manipulated in a gesture-controlled interface that does not require (Dalim et al., 2016).

As a structured form of entertainment, games can be applied in education through MR Technology. Gamification, refers to the application of game design elements and game technologies to non-game contexts (Deterding et al., 2011) in order to increase user engagement and motivation. Studies have shown that location-based MR Games not only increase user immersion, but also positively affect learner engagement and learning motivation (Oleksy & Wnuk, 2017).

Visualization helps to present abstract concepts, such as electromagnetic fields, which are difficult for most students to understand because they are essentially invisible and complex. However, visualization approaches are very advantageous for students to examine and acquire a more thorough comprehension of magnetic fields, especially when another object is present (Matsutomo et al., 2017).

MR technology can aid educators in delivering more thorough explanations of abstract concepts, while also fostering students' motivation in obtaining abstract knowledge. Keller came up with the ARCS model, which says that using MR technology in the classroom makes students more focused, interested, confident, and happy (Keller, 1987). Professional educators who use MR technology to teach math and physics to their students get them more interested in learning and help them understand abstract ideas like vectors, gravity, and so on (Karim et al., 2015).

MR technology is very helpful for training, especially when it comes to medical training. For instance, MR training tools let doctors practice on real patients without putting their safety at risk. Today, AR-based navigational surgery is an important part of medical training in many hospitals. Using virtual technology helps doctors get better at their jobs, and the trainees who are learning feel like they have less work to do (Bric et al., 2015).

MR Applications have been used in several fields, including medical education, STEM education (science, technology, engineering, and mathematics). For example, MR Technology provides a realistic and consequence-free testing environment that helps medical students practice complex surgical skills (Antoniou et al., 2015). Virtual laboratories can provide students with an opportunity to conduct experiments at any time and any place, which makes up for the shortcomings of traditional laboratories (Liu et al., 2015).

Governments all over the world have backed the advancement of magnetic resonance technology. Initiatives related to policy not only quicken the development of technology but also lay a strong basis for the expansion of the business. To encourage their application in sectors like education, healthcare, and industry, several nations have already started development plans for virtual and AR technologies (Alnagrat, Ismail, et al., 2022). Market study indicates that the MR technology market is growing quickly. The market potential for MR technology is enormous given the advancement of technology and the expansion in application scenarios. MR technology is predicted to expand quickly in the next years, particularly in the domains of healthcare and education (Chan et al., 2022). While developing, MR technology encounters several technical obstacles and market prospects despite its wide range of applications. From a technical perspective, MR technology must deal with problems with user interaction, software compatibility, and hardware performance. MR technology must react in the market to the variety of user needs and shifting influencing elements. These obstacles should be resolved and MR technology should find wider applications with ongoing technical progress and market maturity (Rokhsaritalemi et al., 2020).

The market for MR technology is growing quickly due to ongoing technical advancement and broadening application domain. Applications of MR technology is giving industries from industrial manufacturing to education and healthcare hitherto unheard-of possibilities (Pregowska et al., 2022). According to market research, MR technology is predicted to have a substantial growth in the next years as technology advances and user acceptance rises. Ahead, the MR technology development trend will broaden and become more varied. Technically, MR devices will get lighter, more comfortable, and more powerful, and software and content will get richer and more customized. Application-wise, MR technology will become more important in sectors like healthcare, education, and industrial manufacturing before progressively affecting more sectors and daily life. The way people live and work is predicted to be significantly changed by MR technology as it develops further and reaches market maturity.

3.2 Limitations of MR technology

Although MR technology has shown many advantages in higher education, its limitations also exist. First, hardware cost is the main obstacle for many educational institutions to introduce MR technology. High-quality MR equipment is expensive and has high maintenance costs, which puts financial pressure on educational institutions. Second, many teachers are less familiar with MR technology and lack sufficient technical training, which makes it difficult for MR technology to be fully utilized in teaching. In addition, the existing technical infrastructure cannot support the high bandwidth requirements of MR in many regions, especially in developing countries or economically underdeveloped areas, and the promotion of MR technology is still difficult.

Existing literature shows that MR technology has brought a new teaching model and rich learning experience to higher education. Whether in engineering, medicine or arts and humanities, MR technology has shown great application potential. However, its application process still faces challenges such as high cost and insufficient technical training for teachers. Therefore, future research should further explore how to reduce the cost of MR technology and provide more technical support for educators to promote the widespread application of MR technology in education (The application of MR technology in education shown Table 1).

Table 1: The application of MR technology in education

Ref.	Year	Innovation	Research Context	Theories	IT Adoption Diffusion	Findings
(Aljowaysir et al., 2019)	2019	A MR application to augment traditional classroom settings	focusing on non-native English speakers, students with hearing disabilities, and students with language-based learning disabilities	N/A	MR and AI technologies in classroom settings	MR can make education more adaptive and personalized.
(S.-C. Chen & Duh, 2018)	2018	Text mining method to classify MR research into six topics	Educational applications of MR, using text mining on 3330 articles	Latent Dirichlet Allocation (LDA)	MR technologies in educational settings, particularly higher and K-12	MR can increase engagement and motivation in students; has applications in various educational contexts
(Tang et al., 2020)	2020	Analysis of MR in learning design	Educational technology and learning design	Learning design theory	Adoption of MR in learning environments	MR can enhance learning effectiveness
(Pellas et al., 2020)	2020	Systematic review of MR literature	Compilation of MR research across different fields	Systematic review methodology	Overview of MR adoption in various contexts	Provides a comprehensive understanding of MR research trends
(Hayes et al., 2013)	2013	3D MR classroom with simulated students	Educational technology, focusing on professional educator training	Presence, Immersion	MR classrooms for professional educator training	Presence, suspension of disbelief, and immersion impact learning outcomes
(Flavián et al., 2019)	2019	Analysis of VR, AR, and MR technologies in enhancing customer experiences	Customer experience in retail and marketing	Customer experience theory	Adoption of immersive technologies in retail	VR, AR, and MR can significantly enhance customer engagement and satisfaction
(Petruse et al., 2024)	2024	Comparison of MR and traditional learning methods	Education, comparing different learning methods	Educational effectiveness	Adoption of MR in educational settings	MR can be more effective than traditional methods in certain contexts

4. Methodology

This study adopts the method of systematic literature review (SLR) to analyze the application status, challenges and future development direction of MR technology in higher education.

4.1 Literature Search

This study conducted a systematic literature search in multiple databases, mainly including Scopus, Web of Science, Google Scholar, and IEEE Xplore. The following keywords and their combinations were used in the search: "Mixed Reality", "Virtual Reality", "Augmented Reality", "Higher Education", "Immersive Learning", "Educational Technology", etc. In order to reflect the latest developments in MR technology, the retrieved literature was limited to literature published between 2015 and 2024. During the literature search, the Boolean logic operators "AND" and "OR" were used to improve the accuracy of the search results. For example, the keywords "Mixed Reality AND Higher Education" or "VR OR AR AND Educational Technology" were used to retrieve different application scenarios of MR technology in higher education. After screening, about 300 documents met the preliminary requirements.

4.2 Inclusion and Exclusion Criteria

We screened the results of the literature search by first filtering out literature that was not relevant to the study through titles and abstracts; then we read the full text of the remaining literature to ensure that it met the research needs.

4.3 Inclusion criteria

The literature must focus on the application of MR technology (including VR and AR) in higher education; The article must provide empirical data or empirical research on how MR technology affects learning outcomes; The literature should describe in detail the MR technology used, specific application scenarios and related technical characteristics; Only peer-reviewed journal articles and conference papers are allowed.

4.4 Exclusion criteria

Literature that only discusses basic education (such as K-12 education) or commercial applications; Literature that lacks empirical data and only discusses concepts or opinions;
Literature that lacks detailed descriptions of technology applications or has no research directly related to higher education.
The 300 initially screened articles were further screened, and 25 articles were finally retained for detailed analysis.

4.5 Data Extraction

From the selected literature, data extraction is performed according to preset standards. The main goal of data extraction is to ensure that key information related to the research question is collected from the literature for subsequent analysis. The main contents of data extraction include the following aspects:

Educational context: the disciplines in which MR technology is applied (e.g. engineering, medicine, arts and humanities, etc.);Technology type: the specific type of MR technology used in the literature (e.g. VR, AR, or MR);Learning outcomes: the impact of MR technology on student learning outcomes (e.g. engagement, knowledge retention, practical skills, etc.);Challenges and limitations: the challenges encountered in implementing MR technology mentioned in the literature (e.g. technology cost, device accessibility, teacher training, etc.)

4.6 Data Analysis

After the data extraction is completed, the thematic analysis method is used to classify and analyze the extracted data. Thematic analysis is a widely used qualitative research method that can reveal key issues in a specific field by identifying themes and patterns in the literature. In this study, the thematic analysis mainly revolves around the following core themes: Application scenarios and effects: application scenarios of MR technology in different disciplines and educational backgrounds and its impact on learning outcomes; Technical advantages and limitations: advantages and educational potential of MR technology as well as its limitations and challenges in higher education; Future development trends: by analyzing the prospects and suggestions in the literature, summarize the application prospects of MR technology in future education (The data analysis process shown Figure 4).

During the analysis process, the research team classified the relevant literature on each core topic and summarized the main findings and conclusions of each literature. For the literature on quantitative research, key data in the research results were extracted, such as student participation, improvement in academic performance, etc.; for qualitative research, the researchers' discussions on the advantages and limitations of the technology were extracted.

Figure 5: Data Analysis

5. Challenges and limitations

Although MR technology has shown great potential in the field of higher education, it still faces many challenges and limitations in its widespread application, mainly focusing on technology costs, infrastructure, teacher training, and privacy and data security (Cabero-Almenara et al., 2020).

5.1 Technology Cost

The high cost of hardware and software is one of the main obstacles to the promotion of MR technology in the field of education (Alowayr, 2021). High-quality VR equipment, AR equipment (such as Microsoft's HoloLens) and corresponding computing hardware are expensive, and the financial pressure brought by the purchase and maintenance of these equipment is relatively large for small and medium-sized educational institutions (Almufarreh, 2023). In addition, the development of customized educational software and applications also requires a large amount of capital investment, which makes educational institutions face budget constraints when introducing these technologies (Alnagrat, et al., 2022). Many schools are hindered from popularizing these advanced technologies due to equipment costs and limited technology development budgets (Pregowska et al., 2022).

5.2 Infrastructure Requirements

The efficient operation of MR technology depends on high-bandwidth network connections and high-performance computing devices (Matsutomo et al., 2017). Many educational institutions, especially those in developing countries or remote areas, lack the network and

hardware infrastructure required to support MR technology (Cabero-Almenara et al., 2020). Even in institutions with better equipment, insufficient network bandwidth can cause delays in interactions in the virtual environment, which in turn affects students' learning experience (Pellas et al., 2020). Insufficient infrastructure not only increases the difficulty of implementation, but may also limit the teaching effect of MR (Onime et al., 2018).

5.3 Teacher Training and Technology Acceptance

MR technology provides a wealth of teaching tools for education, but many teachers are not familiar with this technology and lack the skills to use MR for teaching (Almufarreh, 2023). Teachers need to invest a lot of time and energy to learn how to use these devices and integrate them into course design (Cabero-Almenara et al., 2020). At the same time, some teachers may be skeptical about new technologies and believe that traditional teaching methods are more reliable (Alowayr, 2021). This difference in technology acceptance has affected the popularity of MR technology in the field of education to a certain extent (Pregowska et al., 2022).

5.4 Data security and privacy issues

With the widespread application of MR technology, data privacy and security issues have become challenges that cannot be ignored (Onime et al., 2018). MR technology collects a large amount of user data, including student behavior data, interaction records, and biometric information (Alnagrat, et al., 2022). The use and storage of this data may face the risk of privacy leakage. In addition, educational institutions need to comply with relevant privacy regulations to ensure the security of student data (Pregowska et al., 2022). How to effectively manage this data and protect user privacy is a key issue that needs to be solved in the promotion of MR technology (Alowayr, 2021).

6. Future Trends and Recommendations

With the continuous advancement of technology, the application prospects of MR technology in higher education are very broad. In the future, the development of MR technology will be driven by innovations in hardware, software and related technologies, and will change the education model at multiple levels (Cabero-Almenara et al., 2020).

6.1 Combination of MR and AI

The combination of artificial intelligence (AI) and MR technology will be one of the important trends in the future development of education. AI can provide intelligent support for MR, dynamically adjust learning content and virtual scenes based on students' learning behavior, progress and performance, and provide personalized teaching experience (Almufarreh, 2023). Through AI algorithms, educators can monitor students' learning process in real time and adjust teaching strategies based on feedback data (Alnagrat, et al., 2022). This intelligent learning environment will be able to meet the personalized needs of different students and help improve learning efficiency and effectiveness (Pregowska et al., 2022).

6.2 Integration of 5G and MR technology

The popularization of 5G technology will provide important support for the development of MR technology. The high-bandwidth, low-latency 5G network can greatly improve the real-time and interactivity of virtual and AR applications, thereby improving students' learning experience (Matsutomo et al., 2017). In the future, with the help of 5G networks, complex virtual experiments and immersive learning scenarios will be able to run more smoothly, especially in remote learning and cross-campus collaboration (Onime et al., 2018). 5G will become a key driving force for MR technology (Cabero-Almenara et al., 2020).

6.3 Seamless integration of virtual and real

As hardware devices improve, MR devices will become more portable and affordable, allowing students to access virtual learning content anytime and anywhere (Pellas et al., 2020). With more convenient technology, students will be able to seamlessly access virtual objects in real environments, thereby increasing learning flexibility and participation (Pregowska et al., 2022). For example, students can use virtual laboratories in real classrooms for remote operation, which will greatly expand the time and space limitations of education (Alnagrat, et al., 2022).

6.4 Widespread application in multiple disciplines

As the technology matures, MR technology will be applied in more disciplines (Cabero-Almenara et al., 2020). In addition to engineering, medicine, and art, where MR is already widely used, MR technology will be extended to fields such as business, psychology, and social sciences (Alowayr, 2021). For example, business schools can use MR technology to simulate market scenarios to help students understand economic principles; psychology courses can use virtual environments to simulate situations and study students' behavioral responses (Onime et al., 2018). This wide cross-disciplinary application will further promote the popularization of MR technology in higher education (Pellas et al., 2020).

7. Conclusion

MR as a combination of VR and AR is bringing a revolution to higher education. By providing students with an immersive and interactive learning experience, MR technology has greatly improved many limitations in traditional teaching. From virtual laboratories to surgical simulations to virtual museums, MR technology not only broadens students' access to knowledge, but also provides educators with innovative teaching tools.

In a systematic review of the application of MR in higher education, this paper found that existing research is mainly concentrated in the fields of medicine and engineering, while the application of arts and humanities is yet to be further explored. In addition, although a large number of literatures have shown the potential of MR technology in improving student engagement and learning outcomes, its widespread application still faces many technical and financial challenges. Through the review and analysis of existing literature, this paper aims to propose future research directions, especially in terms of how to reduce the application cost of MR technology, improve teachers' technology acceptance, and promote technology popularization through policy support, so as to provide reference for future educational technology applications.

In general, MR technology has brought new teaching models and learning methods to higher education, which not only improves students' learning outcomes, but also provides broad space for innovation and development of future education. By overcoming current technical challenges, MR technology will become an indispensable and important part of future higher education, promoting further innovation and optimization of teaching methods.

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