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Transforming Education with Augmented and Virtual Reality: Applications, Challenges and Future Perspectives

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ABSTRACT

This study examines augmented reality (AR) and virtual reality (VR) technologies in education. It evaluates the applications of these technologies in different fields, their advantages, challenges, and aspects that need to be developed. The findings reveal that AR and VR are used intensively in general education, language education, health education, and STEM fields. Still, their use is limited in fields such as history and geography. While AR is effective in STEM education in areas such as visualizing abstract concepts and creating interactive learning environments, VR is more effective in health and art education, which require in-depth interaction and simulation. The study emphasizes the advantages of AR and VR, such as increasing student motivation, providing experiential learning opportunities, and providing content appropriate to individual learning paces. However, difficulties such as lack of technological infrastructure, high costs, and teachers not receiving sufficient training in these technologies stand out as the main factors preventing the widespread adoption of these technologies. In this context, projects and studies that reveal the potential benefits of AR and VR in fields with low usage rates, such as history and geography, should be encouraged. As a result, the role of AR and VR in education is increasing daily, and these technologies stand out as tools that transform education. Developing lower-cost devices, training teachers in technology integration, and integrating new technologies such as Metaverse can enable these technologies to be used by wider audiences. Future research and projects should ensure that AR and VR are used more effectively and make educational environments more interactive, inclusive, and accessible.

Keywords: Augmented Reality, Virtual Reality, Education Technologies, STEM

1. Introduction

Technologies used in education have created a significant transformation in making learning processes more effective and interactive. Digital tools and platforms offer students different learning experiences while allowing teachers to customize course materials and try various teaching methods. In recent years, augmented reality (AR) [1] and virtual reality (VR) [2] technologies have demonstrated revolutionary potential in education. These technologies attract attention with innovative applications such as visualizing abstract concepts, supporting experiential learning, and making learning materials more accessible. While AR enriches the physical environment with digital information, VR transforms learning into an in-depth experience by involving users in a completely virtual environment.

These technologies provide students with theoretical knowledge and involve them in a practical learning process. When the technologies used in education are examined, they constantly evolve to make learning processes more interactive, accessible, and practical. Figure 1 shows the technologies used in education. Among these technologies, smart boards and interactive screens facilitate the use of visual and dynamic content in classrooms while encouraging the active participation of students. These devices allow teachers to present course materials more effectively while enriching the learning experience by allowing students to perform operations directly on the screen. E-learning [3] platforms are considered one of the cornerstones of distance education. Platforms such as Moodle, Google Classroom, and Blackboard support the learning process by offering students various features such as online access to course materials, video lessons, exams, and discussion boards. In addition, gamification applications in education make education more fun and motivating. Game-based learning [4-15] content makes the learning

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process a more engaging experience, especially for children, and increases learning motivation. Educational robots are essential [16], especially in Science, Technology, Engineering, and Mathematics (STEM) [17] education. These robots, used to teach coding and algorithm development skills, contribute to developing students' creative thinking and problem-solving abilities. In addition, artificial intelligence (AI)-based systems offer students personalized learning experiences and content appropriate to their learning needs. Artificial intelligence has also become an important educational support tool, providing teachers with data to analyze students' performance and optimize learning processes. Finally, augmented reality (AR) and virtual reality (VR) technologies offer an innovative dimension to education. While AR enriches the physical world with digital information, VR provides a unique learning experience by transporting users to a virtual environment. These technologies increase students' participation by making the learning process more enjoyable, concrete, and experiential and making learning more permanent. These technologies strengthen students' learning processes while offering teachers more flexible and creative teaching methods.

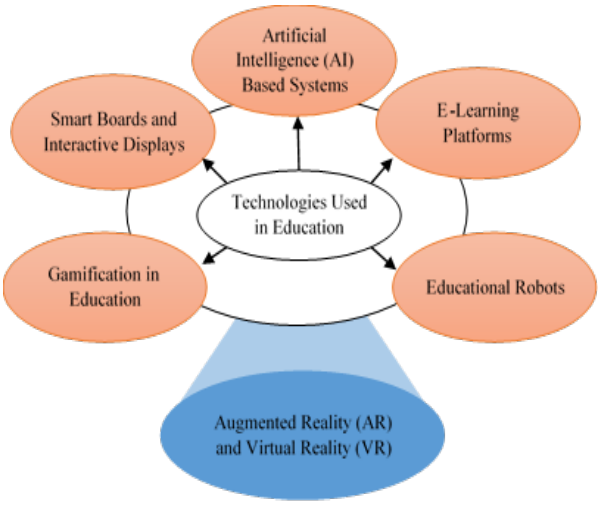

Figure 1. Technologies Used in Education

AR and VR technologies have a wide range of applications that offer an innovative learning environment in education. These technologies, which stand out with their advantages, such as visualizing abstract concepts, increasing students' interest in learning, and creating a participatory learning process, make learning more effective. While virtual laboratories allow students to experiment in a safe environment, augmented reality applications have the potential to make learning materials more meaningful and interesting. In addition, these technologies offer customized content suitable for individual learning speeds, better meeting students' learning needs. However, some obstacles exist to the widespread use of AR and VR in education. High hardware costs, lack of infrastructure, and insufficient teacher competence in these technologies make adopting AR and VR more widely tricky. In this context, this article examines AR and VR's current and potential applications in education, the benefits they provide, and the challenges encountered in detail. It also aims to be a comprehensive guide for researchers and educators by offering suggestions on how these technologies can be integrated more effectively in the future.

2. The Role and Advantages of AR and VR Technologies in Education

Augmented Reality (AR) and Virtual Reality (VR) technologies transform learning processes in education and offer students a more interactive and hands-on experience. These technologies stand out by concretizing abstract concepts, offering individualized learning opportunities, and providing safe learning environments. Studies on the use of AR and VR in education show that these technologies effectively increase learning motivation and better understanding of conceptual information. AR and VR encourage students' active participation in the learning process thanks to their interactive features.

Experiential learning is one of the most substantial aspects of AR and VR. While VR-based virtual laboratories allow students to conduct complex experiments without real-world risks, AR applications enrich learning materials with digital information. These technologies are practical tools for students with different learning styles by offering content suitable for individual learning speeds. Another advantage of AR and VR is that they offer safe and controlled learning environments. Especially in high-risk fields such as medicine, VR-based simulations allow for hands-on learning of complex procedures. As a result, AR and VR technologies create a revolutionary change in education. However, to use these advantages effectively, the technological infrastructure needs to be strengthened, and teachers need to adapt to these technologies.

3. Background

This article was prepared using a systematic literature review method to understand the role and impact of AR and VR technologies in education. The literature review was conducted to cover peer-reviewed articles and conference proceedings published between 2010-2024. In the study, comprehensive academic review methods were used to access academic studies addressing the application areas of AR and VR in education. Various international academic databases were used in the review processes.

3.1. Literature Review and Data Sources

This study conducted a comprehensive literature review to examine the use of AR and VR technologies in education. Leading academic databases such as Web of Science, Scopus, and Google Scholar were used in the review process. Academic articles and conference proceedings published between 2010 and 2024 were

included in the study. The keywords used in the literature review are given in Figure 2. These keywords cover various aspects of AR and VR in education and allow us to explore examples of applications of these technologies in different disciplines. In the review, only peer-reviewed articles and studies that provide a methodological framework were evaluated, and publications that did not directly focus on educational applications were excluded [1-140].

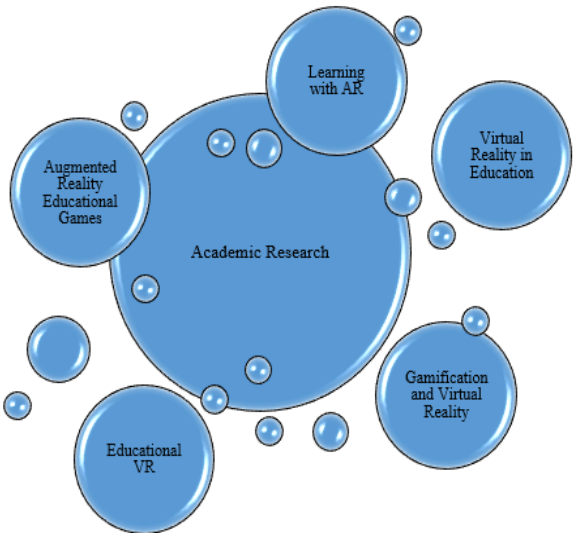

Figure 2. Keywords Used in the Literature Review

There are many educational fields where VR and AR are used, including studies in the Stem field [15,17,19,23,24,37,38,40,51,54,63,64,71,80,82,84,89,108–110,120,124,126,127], studies in the Language field [2,8,15,21,23,26,30,53,58,68,71,92,96,97,106,113,116,123,126,135,137,139], studies in the Health field [9,13,20,22,33,36,49,61,95,131], studies in the History field [2,21,32,48,53,63,76,85,90,113,118,136], studies in the Art field [13,21,59,87,132], studies in the Special field [15,19,21,22,28,39,44,58,64,67,68,79,93,94,96,97,100,104,106,111,121], studies related to K12 [21,37,58,128], studies in the Engineering field [2,15,17,18,20,28,51,53,57,58,64,66,75,78,81,89,99,101,110,122,132], studies in the Geography field [46,54,90,134], studies in the Business education field [4,11,15,44,61,68,76,79,84,94,104,108,118,133], studies in the Physical field [8,36,42,44,48,49,63,64,67,70,113,121,128,132,135], studies in the chemistry field [23,42,70,75,83,85,87,106,108,132] and studies in the biology field [23,24,42,46,55,71,79,82,85,88,106,110,120,128,130,135].

3.2. Data Analysis Process

The studies obtained from the literature review were examined using the content analysis method. In this process, thematic classification and analysis of the studies will be carried out. Thematic analysis is carried out in the literature review by categorizing the results obtained according to the application areas of AR and VR technologies in education. These categories include STEM education, medical education, language learning, history and cultural education, special education, and rehabilitation. The studies were also classified according to their methodological approaches and technologies. Then, the studies were examined regarding the benefits AR and VR technologies provided in education and the difficulties encountered. This analysis determined advantages such as student motivation, visualization of concepts, effects on learning outcomes, and difficulties such as technological costs and teacher qualifications. The quantitative data obtained are analyzed according to years, and their prevalence is examined using trend analysis. An analysis is also made of how publication trends change over the years and how diversity in application areas corresponds. The quantitative and qualitative findings presented by the studies were examined in detail, and a general assessment was made of the effects of AR and VR in education. In particular, data such as the impact on students' learning success, teachers' perception of these technologies, and the potential of technology to improve educational materials were highlighted. Graphs, tables, and figures were used to present the analysis results.

4. Analysis and Findings

In this section, the findings obtained from the literature on the role, advantages, application areas, and challenges of AR and VR technologies in education are presented in detail. The findings are organized thematically, and each theme is supported by literature. Academic studies on the role of AR and VR technologies in education have shown a rapid increase in recent years. This shows that the rate of technology adoption in education is increasing, and this area is gaining importance. Table 1 summarizes this increase by keywords over the years and reveals the popularity trend of AR/VR technologies in education.

Table 1. Change in Publication Counts by Year for Keywords

Keywords	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Total
Virtual Reality in Education	86	65	75	76	68	120	170	280	419	772	1030	1260	1620	1940	2420	10401
Augmented Reality Educational Games	1	2	6	4	3	1	2	3	3	7	8	21	15	30	48	154
Gamification and Virtual Reality	0	0	0	0	3	6	9	13	23	32	54	82	100	200	220	742
Educational VR	16	16	9	5	14	22	26	56	99	160	180	290	320	430	500	2143
Learning with AR	2	8	6	23	18	21	37	31	66	98	109	140	170	190	190	1109
Total	105	91	96	108	106	170	244	383	610	1069	1381	1793	2225	2790	3378	14549

As seen in Table 1, the number of studies conducted with the keyword “Virtual Reality in Education” has increased significantly, especially after 2020. This shows that VR applications in education are rapidly spreading, and academic interest is increasing. Similarly, studies conducted with the keywords “Educational VR” and “Learning with AR” have also shown a steady increase. However, it is observed that studies conducted in more specific areas, such as “Augmented Reality Educational Games” and “Gamification and Virtual Reality,” are more limited.

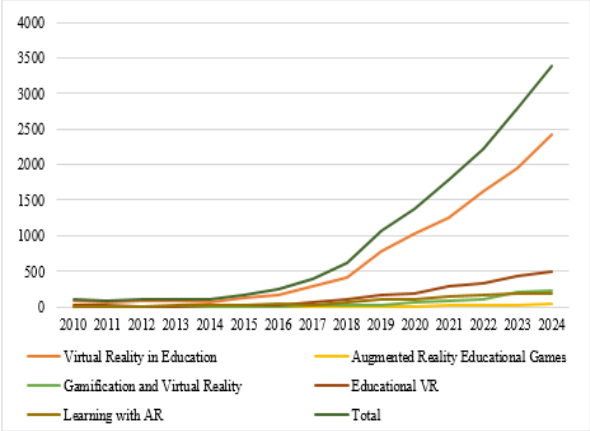

Figure 3. Yearly Trends in AR and VR-Related Publications in Education

The graphical representation of the research results is given in Figure 3. When Figure 3 is examined, it is seen that there has been a significant increase in studies related to education, especially in recent years.

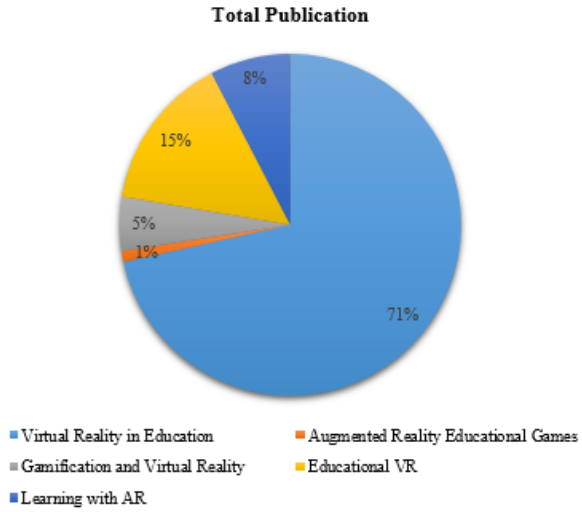

Figure 4. Proportional Distribution of Keywords Across Educational Fields Using VR and AR

The most significant slice in Figure 4 (71%) shows that the focus is on a general area of AR and VR in education and that this area is dominant in the literature. In contrast, the smallest slice (less than 1%) represents a topic with limited academic interest, and the potential has not yet been explored. The medium-sized slices (5%, 8%, 15%) indicate areas that have received more balanced attention but need development. This proportional distribution is an essential guide to determining the focal points and gaps between AR and VR in education. In future research, this imbalance can be eliminated by focusing more on areas with small proportions.

Figure 5. Yearly Distribution of Total VR and AR Publications

When the total number of publications by year is examined in Figure 5, it is seen that academic interest in using AR and VR technologies in education has increased significantly over time. The total number of publications, which was only 105 in 2010, reached 106, with a limited increase until 2014. This period can be considered a discovery phase in which the potential of AR and VR in education was beginning to be realized. Interest in these technologies accelerated from 2015 onwards, and the number of publications was 170 in 2015 and 383 in 2017. There was a rapid increase, especially after 2019, and the total number of publications reached 1069 in 2019 and 3378 by 2024. The sharp increase in this period can be interpreted as a result of the more widespread use of AR and VR technologies in education and the increase in interest in digital solutions such as distance education due to technological developments and the pandemic. This high number of publications in 2024 shows that the impact of AR and VR in education is still rising and that this trend will accelerate in the future, especially with the integration of innovations such as Metaverse. This demonstrates that the digital transformation in education is accelerating and that AR and VR are central to this transformation.

Table 2. AR and VR Applications by Educational Field

Educational Fields	VR	AR	Total
Stem	129	177	306
Language	324	294	618
Health	339	186	525
History	47	47	94
Art	190	102	292
Special	136	75	211
K12	120	120	240
Engineering	297	199	496

Geography	33	31	64
Business	102	96	198
Physical	205	123	328
General	915	1020	1935

Table 2 shows how AR and VR are used in different educational fields, and some areas show significant differences. General Education stands out as the field where both VR and AR are used the most, with 1935 applications. Here, AR is slightly more preferred than VR, with a rate of 52.71%. Language Education ranks second with 618 applications, and VR has a more dominant position in this field than AR. Health Education ranks third with 525 total applications, and with a rate of 64.57%, VR surpasses AR in healthcare applications. It is noticed that VR is used more frequently in some fields than others. For example, Art Education stands out as a field where VR is more dominant, with a rate of 65.07%. Similarly, Special Education VR is seen to be preferred by 64.45%.

On the other hand, AR surpasses VR in the STEM field, with a rate of 57.84%. This situation shows that AR is seen as a more effective tool in areas that require visualization and interaction, such as STEM. It is noteworthy that VR and AR usage are equal in some educational areas. It has been observed that both technologies are used at a 50%-50% rate in areas such as History Education and K12 education. This shows that both technologies offer similar advantages in these areas and complement each other. However, it is noteworthy that the use of AR and VR in areas such as Geography Education is quite limited, and the total number of applications is only 64. This situation shows that geography education is not sufficiently evaluated regarding technological integration and that AR and VR applications should be developed in this area. Low application rates in areas such as geography indicate that the opportunities offered by these technologies have not been fully explored.

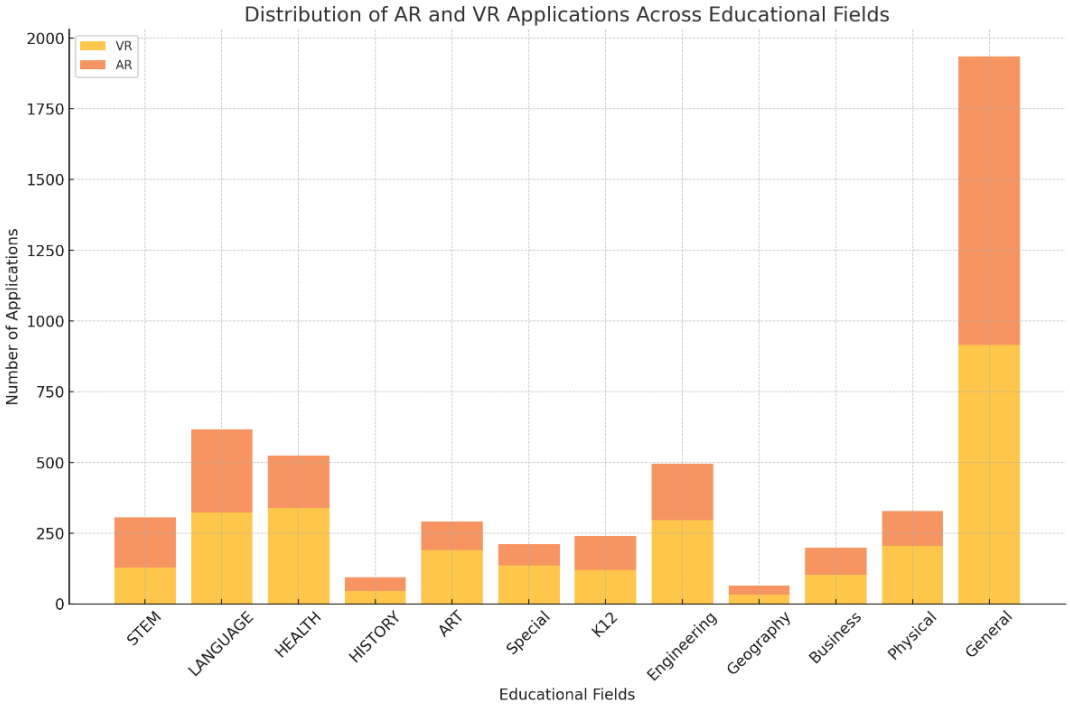

Figure 6. Utilization of VR and AR Across Different Educational Fields

Figure 6 visually presents how VR and AR applications are distributed in different educational fields. While general education stands out as the field where both VR and AR are most intensive, it is seen that AR contributes slightly more than VR here. It is observed that VR is used more frequently than AR in language education and health education. It is understood that VR is preferred more than AR, especially in health education, due to its simulation and real-life experiences. The graph shows that VR has a significant superiority over AR in art and special education.

In contrast, the dominance of AR in the STEM field is striking. AR is thought to be more effective in fields such as STEM, which require visualization and the transfer of concepts from abstract to concrete. In history and K12 education, VR and AR are used equally, indicating that both technologies provide similar benefits in these fields.

Table 3. Development and Milestones of VR and AR Over the Years

Year	Development or Milestone
2010	Early research on the initial applications of AR and VR in education began.
2015	Accessibility increased with the commercialization of VR devices like Oculus Rift.

2016	AR/VR applications began to gain popularity in STEM fields, particularly virtual laboratories..
2020	The use of AR/VR technologies in remote education accelerated with the pandemic.
2023	The integration of gamification techniques and VR in educational games began to be more widely adopted..
2024	Efforts toward the full integration of AR and VR technologies in education were expanded

Table 3 shows the development of AR and VR technologies in education and their critical turning points. Early research on these technologies began in 2010, and attempts were made to explore potential application areas. The commercialization of VR devices such as Oculus Rift in 2015 increased the accessibility of these technologies and paved the way for their broader use in education. 2016 represents a period when AR and VR became widespread with applications such as virtual laboratories in the STEM field. 2020, with the pandemic, became a critical period when AR and VR were used more widely for experiential and interactive learning in distance education environments. In 2023, combining gamification techniques with VR in educational games increased student motivation and created more interactive learning environments. Finally, in 2024, efforts to fully integrate AR and VR technologies into educational processes gained momentum, and it is aimed for these technologies to become a more comprehensive and accessible educational tool. This development process reveals the transformation of AR and VR from initial experimental tools to an important part of today's education system.

5. Discussion

In this study, the use of AR and VR technologies in different areas of education is analyzed and their effects on educational processes are analyzed comprehensively. As a result of the examinations, it is seen that AR and VR have a strong potential in the field of education. However, it is seen that this potential cannot be transferred to every field of education at an educational level. These technologies, which are used intensively in areas such as general education, language education and health education, are seen to have limited usage rates in some areas such as history and geography. This situation shows that the opportunities offered by AR and VR in certain areas have not been sufficiently investigated and that more research and application should be done in these areas. When evaluating the effects of AR and VR in education, the advantages offered by these technologies are remarkable. While AR facilitates understanding abstract concepts in fields requiring visualization, such as STEM, VR stands out as a more effective tool in fields requiring simulation and interaction, such as health and art. In addition, both technologies are important in increasing students' motivation, providing experiential learning opportunities, and providing content suitable for individual learning paces. However, challenges such as lack of technological infrastructure, high costs, and inadequate teacher training make it difficult for these technologies to be widely adopted.

Another issue is why AR and VR are used less in some educational fields. For example, geography education has the lowest usage rate, with only 64 applications. This shows that geography education does not benefit sufficiently from AR and VR's interactive and visualization-oriented features. Similarly, a similar situation applies to history education. Pilot projects and applications emphasizing AR and VR's potential benefits should be developed in such fields.

In the future, the role of AR and VR in education is expected to increase even more. In particular, developing low-cost devices, disseminating teacher training programs, and integrating new technologies, such as the metaverse, into education will be essential steps in this process. The development of more sophisticated and practical applications in areas where these technologies are used intensively, such as health, STEM, and general education, also has the potential to transform educational processes. On the other hand, investments in areas with low usage rates, such as history and geography, will enable the impact of AR and VR in education to spread to a broader range.

As a result, the role and effects of AR and VR in education have been evaluated in terms of both advantages and challenges, and the transformation potential of these technologies in education has been revealed. Future research and applications should ensure that these technologies are used more widely and effectively and provide each student with a more interactive and participatory learning experience. In this context, increasing the role of AR and VR in education will be possible not only with technological advances but also with the development of pedagogical approaches.

This study has some limitations. These limitations arise from the characteristics of the methods and data sources used. First of all, only literature published in English was examined, and access to studies in other languages was not provided. In addition, focusing on a specific period (2010-2024) may result in excluding older or newer publications. Finally, searches based on specific keywords may limit the coverage of all aspects of the literature.

5. Conclusion and Future Perspectives

This study examines the use of AR and VR technologies in education. The areas where these technologies are used in education, the benefits they provide, the difficulties experienced, and the areas that need to be developed are explained in detail. When the studies conducted in the field of AR and VR technologies are examined, it is seen that their use in general education,

language education, health education, and STEM fields is more intense than in the fields of history and geography. As a result of the evaluations, it is seen that although AR and VR have potential, the opportunities they can offer in some fields are not fully utilized. When we look at the STEM field where AR technology is used, it is seen that it comes to the fore in visualizing abstract concepts, and VR technology comes to the fore in areas that require interaction and simulation, such as health and art. AR and VR have many advantages in education. They excite students more, enable them to learn by doing, and create content that works for different learning styles. However, it is not easy to introduce AR and VR to schools everywhere. The technology is not widespread enough, it is expensive, and many educators have difficulty using these tools effectively. We should use this technology more to show how it can stimulate interest in subjects that are not currently popular with students, such as geography and history. Experts predict that AR and VR will play a larger role in education as time goes by.

The creation of cheaper devices will make these technologies more accessible and accessible to a wider audience. In addition, launching training programs to increase teachers' skills in using these technologies will strengthen the impact of AR and VR on education. Bringing new technologies such as the Metaverse into classrooms can provide students with more realistic and personalized learning experiences. The creation of more advanced and personalized AR and VR applications in areas such as health, STEM, and general education will increase the impact of these technologies. At the same time, we should support test projects and studies to increase the use of AR and VR in courses such as history and geography.

In conclusion, AR and VR technologies have an important role in the digital transformation of education. In order for these technologies to be used effectively, the technological infrastructure needs to be developed and pedagogical approaches need to be restructured. Future studies should ensure that AR and VR are used more effectively in all areas of education and aim to make education more interactive, inclusive, and accessible with these technologies.

Conflict of Interest

The authors declared that no conflict of interest.

Authors' contributions

The contributions of the authors are equal in the article.

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