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Trend analysis of augmented reality in science education for supporting SDGs

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ABSTRACT

Introduction. One innovation that can enrich learning experiences and student motivation is technology, specifically Augmented Reality (AR). AR technology offers opportunities to provide a more interactive and immersive learning experience, which can support the achievement of the Sustainable Development Goals (SDGs). This research aims to explore the trend of using AR technology in science education as an effort to support the SDGs.

Methods. This study uses bibliometric methods and literature review to examine trends in the use of Augmented Reality (AR) technology in science education, with an emphasis on its contribution to the achievement of the Sustainable Development Goals (SDGs). This study aims to answer several main questions, namely: 1) What are the main trends developing in the application of AR in science education in the last five years based on literature indexed in Scopus? 2) To what extent are the authors' contributions and international collaborations related to this topic? 3) What are the innovations in AR technology that have been applied in science education and how do they support the SDGs? 4) What are the research gaps that still need to be addressed in the application of AR in science education? The approach used includes bibliometric analysis to produce quantitative results systematically with the help of VOSviewer software, as well as a literature review that refers to the PRISMA approach. Data were obtained from the Scopus database in December 2024, by screening international articles relevant to the focus of this research.

Results. Bibliometric analysis shows that the use of AR in science education is growing, with a significant increase in the utilization of this technology over the past 5 years. AR is proven to provide a more interactive learning experience and help students understand abstract science concepts, as well as increase their engagement in learning. This research also found that there is strong international collaboration in the development of AR applications in science education, as well as implementation challenges that need to be overcome. In addition, this study highlights some research gaps that need to be further explored to maximize the potential of AR in supporting the SDGs.

Practical significance. The implications of this study are significant for educators who utilize AR technology to enhance 21st century skills in students. The findings provide insight into current trends in science education and demonstrate the importance of technology integration in learning to support the achievement of the SDGs. This study is also a valuable reference for further research and development in the utilization of AR and other digital technologies in creating a more engaging and effective learning environment.

KEYWORDS

augmented reality, educational technology, literature review, SDGs, science education

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INTRODUCTION

Science education plays a crucial role in equipping future generations with the skills needed to face global challenges, including the achievement of the Sustainable Development Goals (SDGs) [1; 2]. For this reason, it is important for the education system to develop approaches that build 21st century skills, such as critical thinking, collaboration, creativity, and digital literacy, so that students can adapt to the rapid changes in an increasingly digitalized world [3; 4]. However, traditional learning methods, which often rely on lectures or simple laboratory experiments, often do not capture students' attention enough or are unable to explain complex science concepts in a way that is easy to understand [5; 6]. Therefore, the education system needs to adapt to technological developments to enhance learning experiences and motivate students to master complex scientific concepts [7; 8].

The transformation of education to face the demands of the 21st century is strongly influenced by rapid technological advances [9]. In this context, the use of technology in education is becoming increasingly important, especially to support the achievement of the SDGs, which demand integration between education, sustainability and technological innovation. In science education, particularly physics, conventional learning methods that are often limited in providing engaging and relevant learning experiences can lead to a lack of student motivation and interest [10]. Learning models centered on lectures, whiteboards, and simple conversations are often insufficient to capture the attention of a generation of learners who are already accustomed to technology. Students often find it difficult to understand physics, chemistry and biology subject matter due to a lack of real-world applications of the concepts taught, or limited opportunities to explore and interact more deeply with the material [11; 12]. The challenge in science education is how to create a motivating and relevant learning environment for students in this digital age.

One solution that can bridge the gap is to utilize technology that can offer a more interactive and immersive learning experience [13]. Technologies such as Augmented Reality (AR) open up great opportunities to improve science learning. AR can provide a more interactive learning experience, allowing students to interact directly with abstract scientific concepts, and show real-world applications of the concepts learned [14]. AR technology also allows students to explore the world of physics in greater depth, provides engaging visualizations, and enables virtual experiments that cannot be conducted in traditional classrooms [13]. Through technology-based learning approaches, students can be more actively involved in the learning process, improve their understanding of science concepts, and develop important 21st century skills such as problem solving, collaboration, communication, and digital literacy [15].

However, although the potential of AR in science education is increasingly visible, there are still many challenges in its application to support the achievement of SDGs. Research on how AR can be effectively integrated in science education and its contribution to achieving the SDGs is still limited. Therefore, it is important to explore trends in the use of AR in science education, as well as evaluate its impact on 21st century skills and sustainable development goals. This research aims to provide insights into the development of AR technology in science education and identify the potential and challenges in its application to support the SDGs.

RESEARCH METHODS

1. Methods of Analysis

This study combines bibliometric and literature review methods to analyze trends [16; 17] in the use of AR in science education as an effort to support the achievement of SDGs, particularly SDG 4 relating to quality education. This method allows the research to provide quantitative results through bibliometric analysis and qualitative insights through a structured and systematic literature review [18; 19]. In this study, bibliometric analysis serves to map publication trends, assess the contribution of articles in enriching knowledge, and evaluate literature sources from various perspectives [20].

2. Data collecting

Data for this study were collected through a search of scientific articles on the Scopus database covering literature relevant to the use of AR in science education. The articles selected were publications published in the period 2019 to 2023, to ensure relevance and up-to-date with the latest trends. The keywords used in the search were performed with the PRISMA method as follows.

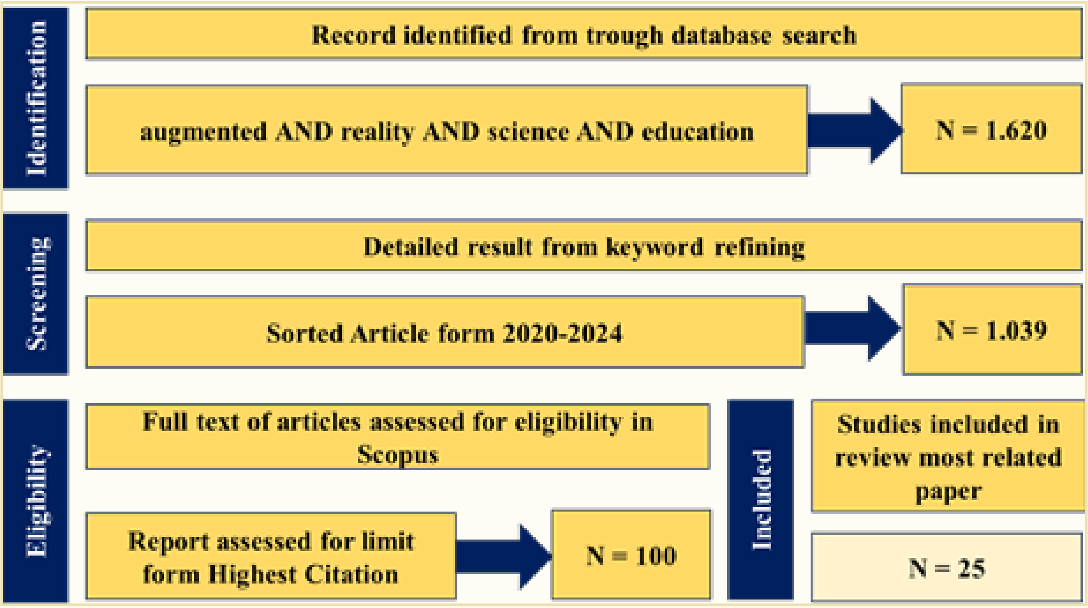


Figure 1 PRISMA Method Research Flow Chart

Bibliometric analysis was conducted using VOSviewer software to map and analyze publication distribution, keyword trends, and relationships between authors and countries involved [21;22] in AR research in science education. This step aims to identify the main patterns in the use of AR in science education, as well as the contribution of research to the achievement of SDGs. The analysis will also look at the distribution of research topics, international collaboration, as well as identifying increasing or decreasing trends in the number of publications. This research will present a synthesis of relevant findings, provide recommendations for further development [22; 23] in the application of AR in science education, and identify opportunities and challenges in integrating this technology to support the SDGs.

This research is limited to articles available in the Scopus database, with a focus on relevant publications between 2020 and 2024. Articles that do not prioritize the use of AR in the context of science education or that do not explicitly discuss its contribution to the SDGs will be excluded from the analysis.

RESULTS

1. Publication Trends AR Technology in Science education in the last five years

This research examines the application of AR technology in science education to support the achievement of SDGs. The literature search process was carried out through the Scopus database using the keywords listed in Figure 1. The results of this search illustrate the publication trends in the use of AR in science education from 2020 to 2024. The following are the results of publications regarding the use of AR for the last 5 years.

The trend of publications regarding the utilization of AR in science education has shown a significant increase in the last five years, which indicates the growing interest and recognition of the potential of AR in education. The trend results show that AR is still a relevant and growing topic in education. This is in accordance with [25] research, which says AR research has increased every year from 2002 to 2021.The increase in publications also illustrates that AR technology is increasingly being adopted by educational institutions at various levels, from primary education to higher education. This publication growth trend shows that there are many innovations and advancements in research related to the application of AR in education. Research focuses not only on the effectiveness of the technology, but also on the development of new methods, practical applications, and its influence on the development of students' skills and knowledge. This reflects that the use of AR in education continues to grow, and further research is needed to optimize its application.

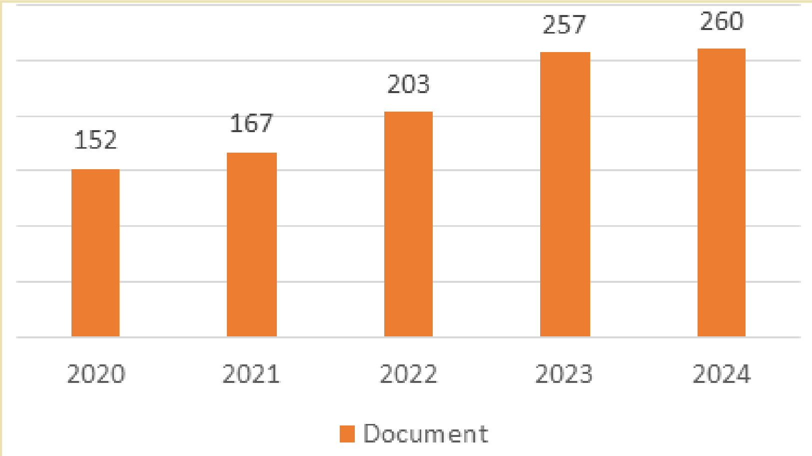


Figure 2 Number of Publications on the Use of Augmented Reality in Science Education in the Last 5 Years

Factors driving this growth include advances in AR technology itself, which is becoming more affordable and accessible, as well as a major shift in education triggered by the COVID-19 pandemic. Online learning introduced during the pandemic is driving the adoption of technologies that can deliver a more meaningful learning experience [26], such as AR, which allows students to interact with subject matter in a more engaging way even at home [27]. In addition, the need for innovation in learning methods, especially in the field of science that requires visualization of complex concepts, makes it more urgent to adopt AR technology that can make learning easier to understand and more interesting for students [28]. AR allows students to interact directly with the subject matter, thus aiding the understanding of difficult concepts in science [29]. AR can contribute to the achievement of SDG 4 Quality Education by providing a new, more interactive way of teaching science.

Overall, this growing publication trend shows that AR has great potential to transform science education, while supporting the achievement of the SDGs. Growing research in this area is expected to accelerate the adoption of AR globally, opening up opportunities for educational solutions that are more inclusive, sustainable, and more engaging for future generations.

Publication citation data related to the use of AR in science education shows significant fluctuations from 2020 to 2024. Fluctuations in the number of publication citations related to the use of AR in science education reflect the dynamics of interest and influence of this technology in the academic world. Spikes in the number of citations that occur in certain years indicate that AR has become a topic that attracts widespread attention among researchers, especially after 2020. This surge indicates a growing recognition of the potential of AR in improving the quality of learning, especially in teaching complex science concepts through more interactive means. The large number of citations in these periods shows that research on AR is not only exploratory, but also shows results that are relevant and useful for the development of technology-based education.

The significance of these citations is the recognition of AR's great contribution to education, showing that this technology has made a real impact in modernizing teaching and learning. The high number of citations indicates that the researcher has delved deeply into the literature, thus providing a strong theoretical basis for the research conducted [30]. From the data, the high citations reflect the importance of AR in supporting the achievement of SDG 4 Quality Education, by improving the learning experience and providing better access to education through technology. Although there is a decrease in the number of citations, this does not diminish the importance of AR in the development of innovative and sustainable science education. Instead, it opens space for more research focused on a deeper understanding of how AR can be applied more effectively and sustainably in education, in accordance with the broader sustainable development goals (SDGs).

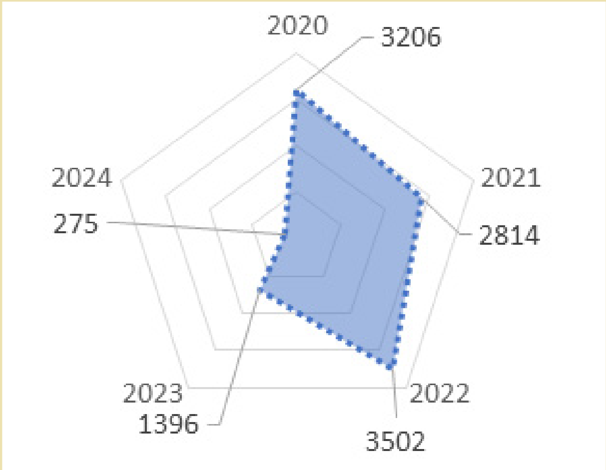
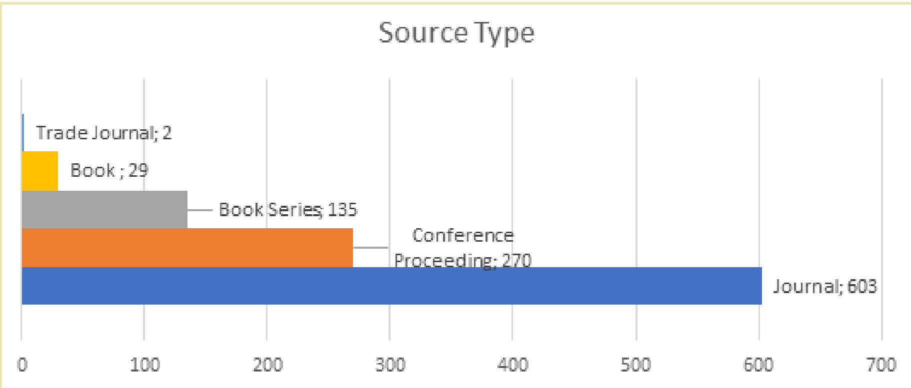


Figure 3 Distribution of research publications cited by AR in Science Education in the last 5 years

Analysis of the types of sources and types of documents in publication trends on the use of AR in science education shows the dominance of journal articles as the most widely produced form of publication. Of the available data, 603 publications came from journals, indicating that scientific journals are the main medium for researchers to publish their findings related to the application of AR in science education. This reflects that research on AR in science education tends to be more in-depth, data-driven, and published in an academically accredited format, which is accessible to the global scientific community. In addition, the conference with 270 publications also shows the importance of scientific forums as a place to share the latest findings and have direct discussions regarding the application of AR in educational contexts. Conferences are often a venue for presenting innovative ideas and current research before it is fully published in journals, so the high number at this conference indicates that the topic of AR in science education is a dynamic and rapidly evolving area of research.



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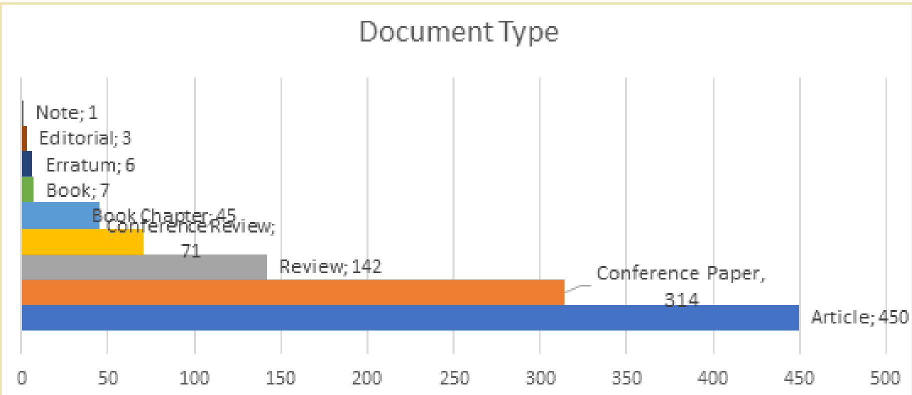


(b)

Figure 4 Distribution Types of publications on AR distribution in Science Education in the last 5 years

In terms of document type, articles are the most dominant form of publication with 450 documents, indicating that AR research in science education is more often presented in a structured article format with more detailed analysis and based on scientific methodology. Meanwhile, conference papers with 314 publications show that conferences are still an important means of presenting preliminary findings or ongoing research results, and often lead to more interactive discussions.

Overall, this data illustrates that AR in science education is not only an accepted topic in scientific journals, but also actively discussed in conferences. The predominant publication in articles and conferences suggests that AR has a direct impact on innovation in education and the advancement of scientific thinking in the field. These sources and document types also show that although the technology is still in its infancy, AR research continues to grow and attract the attention of academics across various publication platforms.

2. Top 5 authors, affiliations, and languages with the most publications in each AR research topic category in Science Education

Table 1

Top 5 Authorship, Affiliates, and Language in Each Research

Top Authorship		Top Affiliation		Top Language	
Author	Total	Affiliation	Total	Language	Total
Huwer, J.	9	Chitkara University, Punjab	11	English	1.002
Mantri, A.	7	Universiti Teknologi Malaysia	9	Spanish	27
Cai, S.	6	National Taiwan Normal University	9	Chinese	5
Moro, C.	6	Institute for Digitalisation of Education of the NAES of Ukraine	9	Russian	4
Semerikov, S.O.	6	Atatürk Üniversitesi	8	Koeran	3

Table 1 describes the top authors, affiliations, and languages used in AR-related publications in science education revealing some interesting patterns. The author with the most contributions in this field is J. Huwer, who is listed with 9 publications, followed by A. Mantri, and S. Cai, with 7 and 6 publications, respectively. The dominance of these authors indicates that they have a significant role in AR research and development in science education. In terms of affiliations, Chitkara University, Punjab leads with a total of 11 publications, followed by Universiti Teknologi Malaysia and National Taiwan Normal University, each with 9 publications. The existence of these affiliations also reflects the growing international collaboration in exploring the potential of AR to improve the quality of education.

In terms of language, the majority of AR publications in science education are in English (1,002 publications), which is the dominant language in the global academic literature, allowing the resulting findings and innovations to be more accessible to the international scientific community [31]. However, there were also significant numbers of publications using Spanish, Chinese, and Russian, with 27, 5, and 4 publications, respectively, indicating a sizable contribution from these language-speaking countries in AR research. This suggests that while English remains the main language of global scientific publication, there is also an increase in collaboration and publication in other languages that allows knowledge of AR in science education to spread more widely to different parts of the world. Overall, these data reflect the globalization of research in AR, where researchers and affiliates from different countries and languages are actively involved in advancing the use of this technology for education. With increased international collaboration and language diversity in publications, AR in science education.

3. Research Trends on AR Use in Science Education Worldwide

Based on the number of published AR in Science Education documents, it shows that the United States takes the top spot with 131 documents, indicating that the country has a dominant role in the development and research of AR for education. China also shows significant research contributions with 93 documents, indicating that the country has taken great strides in technology adoption in the education sector, including AR. China's strong position in technology and innovation allows AR research to flourish there, influencing education policy and supporting new approaches to education that are more interactive and effective. Spain, Germany and India with 63, 61 and 55 documents respectively show that these countries are also actively contributing to the advancement of AR in science education. This reflects the great attention to educational technology development in Europe and Asia, with increased utilization of AR as a tool to provide more engaging and immersive learning experiences [32]. Malaysia, Turkey, and Indonesia with 53, 50, and 49 documents show that developing countries are also increasingly playing an important role in AR research. These countries are increasingly realizing the potential of AR to improve the quality of education, and many have started projects to implement AR in classrooms, especially to support more interactive and immersive science learning. On the other hand, the United Kingdom and Taiwan, with 46 and 31 documents, also show good contributions although in slightly lower numbers. Overall, this data shows that AR in science education has become a global concern, with countries around the world actively engaged in research and development of this technology. This increase in research contributions from various countries reflects a growing awareness of the potential of AR in creating a more inclusive, engaging and technology-based education.

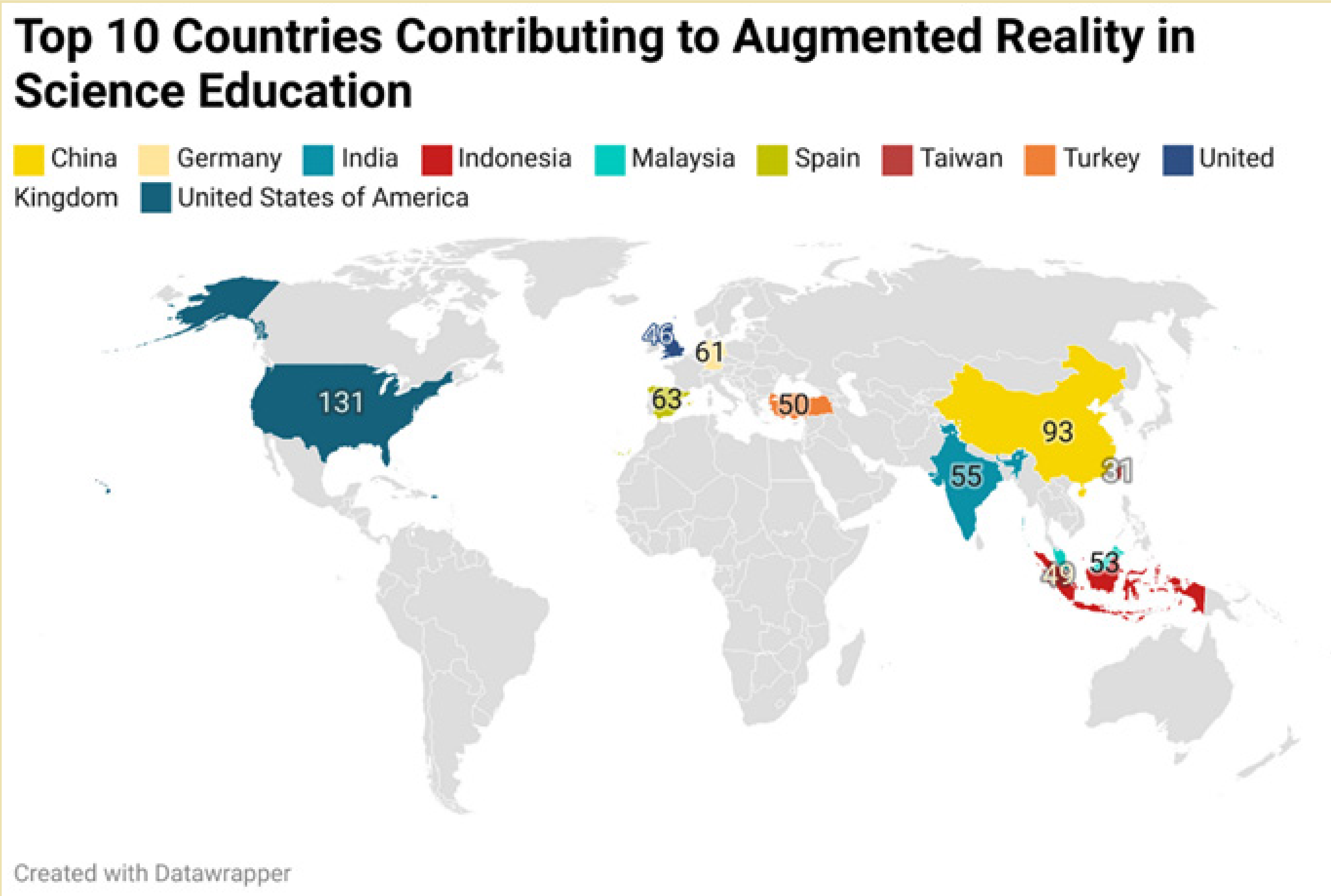


Figure 5 Top 10 Research contributions of AR trends in world Science Education in top countries

4. Visualization mapping of research trends in Augmented Reality in Science Education

Table 2

Top 10 keywords of AR trends in Science Education over the past 5 years

All Augmented Reality in Science Education					
Keywords	Occurrence	Total Link Strength	Keywords	Occurrence	Total Link Strength
Augmented Reality	702	4722	E-Learning	132	1193

Virtual Reality	288	2331	Teaching	84	855
Students	217	1822	Learning	68	700
Education	174	1409	Learning System	75	672
Engineering Education	156	1289	Education Computing	72	635

The data shows the top keywords related to the use of AR in science education over the past five years. Each keyword has two important metrics, namely Occurrence, which shows how often the keyword appears in related publications, and Total Link Strength, which measures how strong the keyword's relationship is with other keywords in the analyzed literature network [33]. These metrics provide insight into how dominant or relevant a topic is in AR-related research in science education.

From the data, Augmented Reality is the most dominant keyword, with very high occurrence and large total link strength, indicating that AR is a major center of attention in science education research. This technology is in focus because of its ability to deliver interactive learning experiences, which accelerate students' understanding of abstract science concepts [14; 30]. The high occurrence of Virtual Reality keywords also shows that VR is often used in conjunction with AR, enriching the learning experience with more immersive and realistic simulations.

The keywords Students and Education indicate that AR is increasingly focused on improving the student experience and the overall quality of education. The use of AR in the context of science education can strengthen student engagement in learning, leading to a deeper understanding of the material [35]. In addition, the Engineering Education keyword indicates that AR is also widely applied in the field of engineering education, where this technology allows students to learn through virtual simulations and experiments that are difficult to do in a physical environment.

Overall, this data reflects that AR has become a very important tool in creating a more interactive, technology-based, and well-rounded science education experience. This trend supports the achievement of SDG 4 Quality Education, which prioritizes inclusive, equitable, and quality education. With AR technology, the learning process is not only limited to the delivery of information, but also allows students to learn actively, creatively, and applicatively [36], thus creating more equitable educational opportunities that are relevant to global technological developments.

5. Findings on Augmented Reality in Science Education over the past 5 years

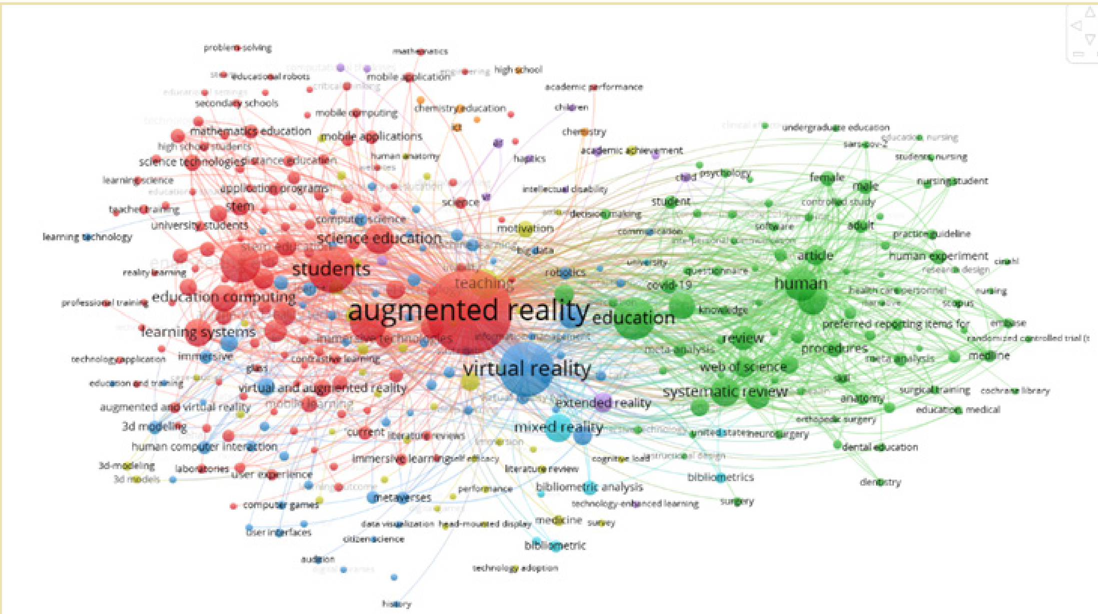
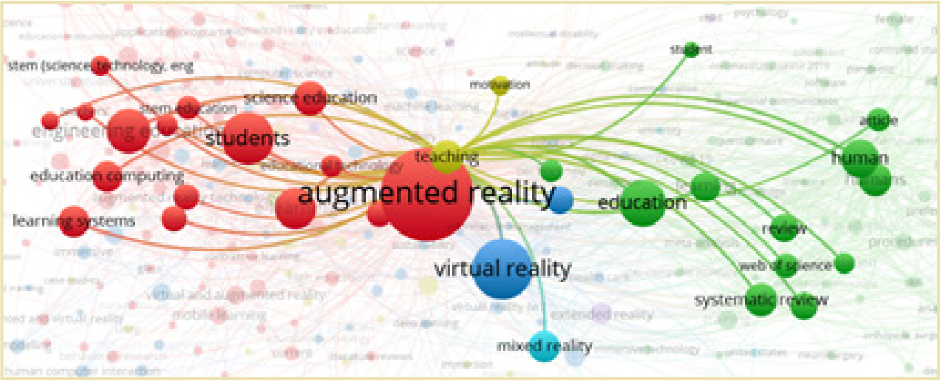


Figure 6 Visualization mapping of keyword occurrences across AR in Science Education over the last 5 years



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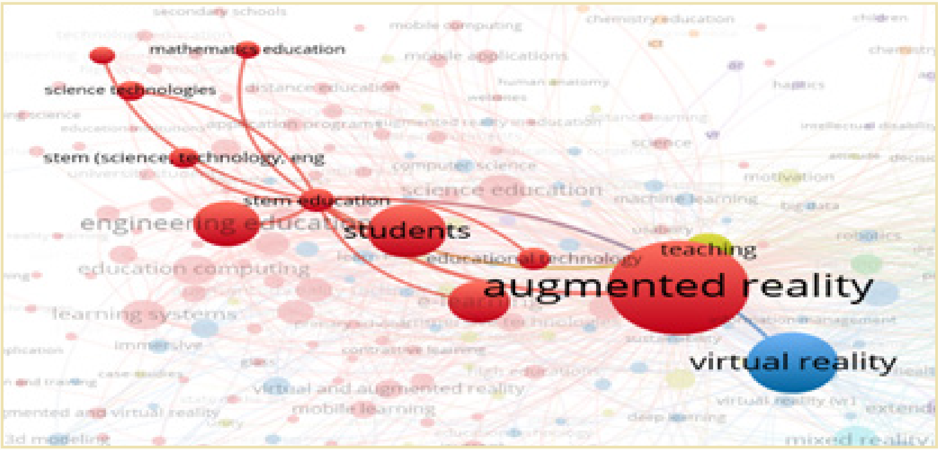

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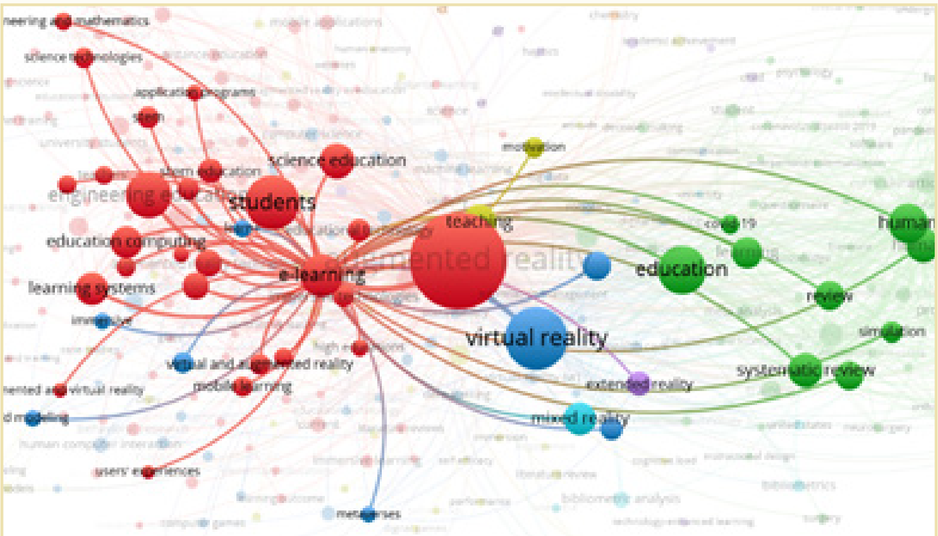

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Figure 7 Mapping keyword visualization more specifically on AR related topics in Science education

The results of the bibliometric visualization mapping that shows the relevance of AR to more specific keywords in the field of science education provide important insights into the direction of research and application of this technology. In the mapping, AR has a close relationship with concepts such as teaching, e-learning, student, education, motivation, and science education. This relevance indicates that AR is not only seen as a technological tool, but also as a pedagogical approach that can improve various aspects of the learning process [37].

AR's relationship with teaching confirms that this technology plays an important role in classroom teaching methods. AR enables more interactive teaching, allowing students to interact directly with the subject matter visually and three-dimensionally [38]. This provides a more immersive learning experience, where students not only passively receive information, but can also see and feel scientific concepts in a more tangible way [30]. In addition, e-learning is a key element in this mapping, which suggests that AR is highly relevant in the context of online learning that allows students to learn the subject matter directly even if they are not in a physical classroom [39].

The association of AR with students and motivation shows that this technology has great potential in increasing students' learning motivation. AR creates a more engaging learning environment, with visualizations that make it easier to understand complex concepts in science [40]. Through a more enjoyable and immersive learning experience, students are more likely to actively engage in the learning process and maintain their attention longer, which can ultimately improve learning outcomes. In addition, AR's relationship with education and science education shows that this technology has a significant impact in education in general, especially in science education. AR provides a new way of teaching science in a more visual and contextualized way, allowing students to better understand scientific principles. AR offers a powerful tool for enhancing science education, particularly in making abstract concepts more tangible and easier to understand. For instance, AR can be used to visualize complex chemical structures in 3D, helping students grasp molecular behavior more intuitively. Chen and Liu [29] explored this in a chemistry course, demonstrating how AR can provide students with interactive experiences to experiment with elements and visualize their behavior in a way that traditional methods cannot. In a similar context, Nandyansah et al [41] investigated the use of AR in teaching the atomic model in physics. Their study, focusing on the Physics AR tool, showed that AR technology can significantly improve students' abstract thinking skills by providing visualizations of atomic structures that were otherwise difficult to conceptualize. Furthermore, Celik et al [42] explored the application of mobile AR in biology education, specifically in studying cardiac anatomy. They found that AR helped students better understand the spatial relationship between the anatomy of the heart. So it can be said that AR technology plays an important role in the transformation of science education and can help achieve the SDGs, especially in improving the quality of education and scientific understanding among the younger generation.

Based on the results of bibliometric visualization mapping, it is found that AR has a very strong relevance to the concept of STEM education in the context of science education. This keyword mapping shows that AR is not only related to science education in general, but also strongly related to STEM-based learning, which is increasingly becoming a global focus to prepare students for the challenges of a complex modern world. The association of AR with STEM education signifies that this technology provides great benefits in creating more immersive and interactive learning experiences in the fields of science, technology, engineering and math [43]. In STEM education, AR is used to introduce abstract and difficult-to-understand concepts through more concrete three-dimensional visualizations Thus, AR supports STEM education by introducing the practical and applicable aspects of engineering and technology concepts, and enhancing students' ability to think critically and creatively in solving problems [44].

Overall, this keyword mapping confirms that AR in science education is not only relevant to technical aspects, but also to pedagogical and psychological aspects. AR has the potential to enrich science learning experiences, both in the physical classroom and in the e-learning context, while increasing student motivation and engagement. Thus, the utilization of AR in science education can contribute significantly to the achievement of better global education goals.

Table 3

Overview of the most cited papers showing the contribution of AR in Science Education in supporting the SDGs

Author	Year/ Cited	Level of Education
Sahin, D., Yilmaz, R.M. [45]	2020/243	Junior High School
Altmeyer, K. et al [46]	2020/108	College
Jesionkowska, J. et al [47]	2020/102	Senior High School
Chen, S.-Y., Liu, S.-Y. [29]	2020/78	Junior High School

Petrov, P.D., Atanasova, T.V. [48]	2020/63	Senior High School
Salar, R. et al [49]	2020/60	College
Chen, C.-H. [50]	2020/53	Elementary School
Del Cerro Velázquez, F., Méndez, G.M. [51]	2021/50	Junior High School
Çetin, H., Türkan, A. [52]	2022/45	Elementary School
Lu, S.-J. et al [53]	2020/44	Elementary School
Flores-Bascuñana, M. et al [54]	2020/40	Elementary School
Osadchyi, V.V. et al [55]	2021/38	General
Turan, Z., Atila, G. [56]	2021/37	Junior High School
Lo, J.-H. et al [57]	2021/36	Elementary School
Harun et al [58]	2020/31	Senior High School
Enzai, N.I.M. et al [59]	2020/29	College
Celik, C. et al [42]	2020/29	College
Ilona-Elefteryja, L. et al [60]	2020/27	Junior High School
Gonzalez, A.A. et al [61]	2020/22	College
Karagozlu, D. [62]	2021/21	Junior High School
Jiang, S. et al [63]	2022/17	Senior High School
Chen, S.-Y. [64]	2020/10	Elementary School
Czok, V. et. al [65]	2023/4	College
Latipah, J. et al [66]	2021/1	General
Kulkarni, R.V., Harne, R. [67]	2024/0	College

Based on a review of the most cited publications on the contribution of AR in science education, it can be seen that AR technology has had a significant positive impact at various levels of education, ranging from elementary school to higher education. These studies show that AR can improve conceptual understanding, student engagement, as well as positive attitudes towards science learning, which greatly supports the achievement of the Sustainable Development Goals (SDGs), especially SDG 4 on quality education.

Overall, these data suggest that AR not only improves student learning outcomes in science education, but also supports the development of important skills in 21st century education, such as, technology skills, and collaboration, all of which contribute to the overall achievement of the SDGs. The integration of AR in science education opens up great opportunities to bring education closer to the real world, improve the quality of learning, and provide long-term impact for a more globally competitive future generation [13].

By supporting quality education and innovation in education, Augmented Reality plays a very important role in driving the achievement of the Sustainable Development Goals (SDGs) [1; 64]. AR not only improves quality and engagement in science learning, but also creates a more inclusive and sustainable environment for students around the world [65]. Going forward, AR has great potential to be further integrated in educational curricula at various levels, and become an enabler for the positive changes needed to achieve the SDGs in the 21st century.

DISCUSSION OF THE RESULTS

In this section, the implications of the bibliometric results and their significance for the field of science education, particularly with regard to the use of AR technology. The findings demonstrate the growing integration of AR in science education and its strong correlation with key educational concepts such as teaching, student motivation, e-learning, and STEM education. The data obtained from the bibliometric visualization mapping revealed some important insights into the role of AR in improving learning experiences and supporting the achievement of the SDGs, particularly SDG 4 on quality education. The bibliometric mapping shows that AR is not just a technological tool, but also a transformative pedagogical approach, offering interactive and immersive learning experiences.

AR's ability to actively engage students is an important factor in its ability to increase motivation and participation. By providing hands-on experiences, AR transforms passive learning into an interactive process, which encourages deeper engagement. This is in line with research [40; 41] showing that AR helps to improve abstract thinking and increase students' interest in science subjects. The link between AR and STEM education is another important finding. As STEM education becomes a global priority, the potential of AR to make abstract concepts in science, technology, engineering, and math more tangible and interactive is crucial. Several studies [42; 43] underline how AR enhancing students' understanding of technical concepts through 3D visualization and simulation is highly relevant in the context of STEM education.

Bibliometric analysis also confirms that AR has a positive impact on different levels of education, from primary school to higher education, contributing to better conceptual understanding and improved student attitudes towards science. These findings suggest that AR has the potential to support the SDGs by improving education quality, fostering critical thinking, and preparing students for the challenges of the 21st century. However, integrating AR in education presents challenges, including the need for teacher training and technological infrastructure. Despite these obstacles, the benefits of AR in improving educational outcomes justify its continued integration into the curriculum. As AR develops, its role in advancing the SDGs and transforming education will continue to grow. In conclusion, AR is a technological tool that can improve the quality and accessibility of science education, making it more engaging and effective. The findings from this study suggest that AR's contribution to education will continue to grow, offering long-term benefits to learners and global education goals.

CONCLUSION

Based on the analysis of trends in the use of AR in science education, it can be concluded that AR has great potential to support the achievement of SDGs, especially in improving the quality of education and creating a more inclusive and interactive learning experience. The use of AR in science education can encourage the development of 21st century skills. The major emerging trends in the application of AR in science education show that this technology is increasingly being used to improve students' understanding of complex scientific concepts at various levels of education. Significant contributions from various authors around the world, with countries such as China, Germany, India, Indonesia and several European countries active in research related to the application of AR in science education. AR technology innovations that have been applied in science education include the use of AR-based applications for visualization of science concepts, such as simulation of chemistry, physics, and biology experiments. This technology not only improves concept understanding but also encourages active and constructive learning. In the context of the SDGs, the application of AR supports SDG 4 (Quality Education) by creating more effective learning experiences. Although AR has shown positive impacts in science education, further research is needed to identify challenges and barriers in its application, as well as how this technology can be integrated more effectively in STEM education curricula based on local context and specific needs. Therefore, further research exploring the utilization of AR in science and STEM education is essential to ensure that this technology can be more optimal in supporting the achievement of the SDGs. Overall, AR provides great potential to revolutionize science education and contribute to the goals of the SDGs. Therefore, more comprehensive follow-up research, including the exploration of technology-based STEM concepts and the development of more effective AR implementation strategies, will be crucial in creating higher quality and sustainable science learning.

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