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iJIM International Journal of Interactive Mobile Technologies

iJIM | eISSN: 1865-7923 | Vol. 19 No. 4 (2025) | OPEN ACCESS

https://doi.org/10.3991/ijim.v19i04.52845

PAPER

Digital Inclusion and Accessibility through Augmented Reality Mobile Technologies in Education: A Systematic Review

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ABSTRACT

Augmented reality (AR) is emerging to revolutionize education through the simulation of environments, transforming traditional teaching methods. This systematic literature review (SLR) rigorously explores the factors that influence the digital inclusion and accessibility of augmented reality technologies in education during the period 2022–2024. To carry out the research, the guidelines proposed by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method were followed, ensuring consistency in the information collected. Four highly relevant databases were considered, such as Science Direct, Scopus, Web of Science, and IEEE, taking into account suitability criteria, identifying 28 articles and 27 conferences in paper structure. The results show that 2023 was the year with the highest number of publications, with 45.45%. Also, among the prominent countries, India showed a remarkable predominance with 12.73% of manuscripts. In addition, the research showed that original articles accounted for 51%, highlighting their relevance over conferences. It is important to note that 72% of the manuscripts used for this review correspond to a quantitative approach, 16% to a qualitative approach, and 12% to a mixed approach. Finally, it is concluded that the study allowed us to contrast the difficulties faced by educational institutions in integrating RA, considering the scope and relevant aspects in research aligned to the object of discussion.

KEYWORDS

augmented reality (AR), education, digital inclusion, accessibility, digital divide

1 INTRODUCTION

In recent decades, humanity has had to face constant challenges that transcend international and cultural boundaries. There are uncontrollable social problems such as COVID-19, which has had an unprecedented impact globally [1], especially in the field of the education system, where alternative methods of teaching and learning had to be presented in order to cope with the difficult situation [2]. Education faces health

Chavez-Perez, J., Iparraguirre-Villanueva, O. (2025). Digital Inclusion and Accessibility through Augmented Reality Mobile Technologies in Education: A Systematic Review. *International Journal of Interactive Mobile Technologies (iJIM)*, 19(4), pp. 48–64. https://doi.org/10.3991/ijim.v19i04.52845

Article submitted 2024-10-13. Revision uploaded 2024-12-20. Final acceptance 2025-01-08.

challenges beyond those that have emerged; these triggers highlight accessibility gaps, such as inequality and inclusion, to promote learning opportunities available to all [3].

Society is immersed in an era where technology is an integral part of everyday life and leaders recognize that digital transformation is necessary to address complex problems and improve people's quality of life [4]. The implementation of technologies such as e-learning to reduce the digital divide and increase inclusion in the education system is trigger to raise awareness of decision-making to adopt new measures [5]. In this sense, it is important to highlight how adult education centers are adopting technological changes [6].

The advancement of cutting-edge technologies in software and hardware reduces limitations by allowing the elimination of physical presence in multiple settings [7], which leads to promoting opportunities for social inclusion of people with physical disabilities [8].

Augmented reality (AR) emerges to transform perception in educational scenarios, where interactive stimulations strengthen students' learning methodology [9]. Trust in digital information is a crucial aspect, as it is relevant to accuracy and credibility [10]. This technology explores the educational environment to align experiences in the areas of science and mathematics, demonstrating the understanding of concepts in an agile way, but with certain limitations in infrastructure to address learning [11], [12].

The impact of integrating AR is recognized by international organizations seeking social and inclusive development through demonstration projects to identify the exponential improvements that technology could offer in education [13]; however, despite practical applications in educational institutions and studies in related groups, no conclusive evidence has been found that AR promotes the experience in a concrete way [14]. Authorities should guarantee democratic and humanistic values when integrating new technologies so that society does not experience such drastic changes [15].

Consequently, it should be noted that the present systematic literature review (SLR) developed a detailed analysis of 28 articles and 27 conferences based on the format of academic papers from relevant databases in relation to both study variables.

This study is justified by the implementation of AR as a transformative medium in the learning methodology of the educational environment to promote inclusion and reduce digital divides. The study aims to identify the factors involved in the adoption, integration, and benefits of AR to improve the understanding of digital information in collaborative and immersive spaces.

2 LITERATURE REVIEW

Previous studies have addressed the adoption and integration of AR technologies to enhance learning. A study by [16] implemented a social model of disability to identify areas of improvement in children's attitudes towards their peers with disabilities, using an awareness-raising approach, resulting in understanding and reduction of disability stigma. Similarly, in [17] they chose to use a reciprocal interview method to strengthen voice and raise awareness of experiences of marginalization, analyzing academic dual groups. The results showed that fragility depended on teachers' experience-based self-questioning.

The study [18] evaluated the impact of a mobile application called "PluggerdAR" implemented to foster enthusiasm for learning in children aged 6 to 9 years, showing 100% adoption of interactive learning experience. Similarly, [19] analyzed the adoption of AR to identify influencing factors of integration in the education sector through a qualitative approach of 427 teachers of natural sciences, showing limiting results in its implementation in Vietnam.

The work [20] proposed to address the lack of universal AR platforms by developing a system for iOS and Android devices. Their model achieved real-time interactive access functionalities, enriching students' learning. On the other hand, work [21] used partial least squares structural equation modelling (PLS-SEM) on 65 students to evaluate the impact of AR on eight study hypotheses, demonstrating that the technology's own characteristics encouraged its adoption and that the perceived value of the tasks was not influential.

3 METHODOLOGY

This study set out to investigate the scientific literature using the comprehensive qualitative approach to analyze the existing information, with emphasis on the application of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method [22].

The standardization of the systematic process proposed by PRISMA in its 2020 version includes aspects of precision in the present study, allowing the transparent visualization of search and selection through the use of flow charts, considering inclusion and exclusion criteria [23]. This incorporation ensures that systematic reviews are replicable for future studies, providing high-quality information.

In the analysis of the scientific literature, PRISMA guidelines were used to ensure the synthesis of relevant studies, objectively focused on the impact of digital inclusion through immersive AR environments in the educational environment during the period 2022–2024. To address the process of collecting, searching, and selecting specific information, the parameters established by the PRISMA framework were followed, considering identification, eligibility, and acceptance criteria. Therefore, the scientific studies had to comply with the following aspects of inclusion.

- Derive from scientific databases recognized for their high credibility, reliability and thoroughness, which guarantees the scientific robustness of the systematic review study.
- Correspond to the time interval 2022–2024, as this is the most suitable time frame to explore the most relevant conceptual constructs.
- Word terminology linked to AR and inclusion technologies in education, to ensure that the collected scientific papers are closely related to the research focus.
- Be written in 'English,' to ensure a wider range of information at international level relevant to the study variables.

The following aspects were taken into account for the exclusion and discarding of scientific papers:

- When the publication date was prior to the year 2022, because the information is considered outside the research scope of the systematic review.
- When the content of studies found was not in full agreement with the object of research, as it would not contribute to answering the questions of the present review work.
- When the information in the documents distances itself from the subject of the review, since in such cases, it would not support the construction of the study.

The information search process included the following databases recognized for their value in the scientific literature: Science Direct, Scopus, Web of Science, and IEE.

During the first step of the research, a search was carried out using relevant English language terms related to the study: "augmented reality," "education," and "technologies." Subsequently, criteria filters were applied to establish the year of publication, with the aim of considering only those articles and conferences published between 2022 and 2024. Consequently, the results obtained included 28 articles and 27 conferences in paper structure; these studies address with relevance the construction process and are aligned with the object of study.

The distribution of the papers that form part of the systematic review is presented below:

- Science Direct: 364 scientific articles were located, only 10 were selected.
- Scopus: 266 scientific articles were found, of which 18 were selected.
- Web of Science: 306 scientific articles were found, of which five were included.
- IEEE: 278 scientific articles were identified, of which 24 remained for the study.

From the moment of the initial compilation, the selected documents were catalogued according to their origin, with the aim of carrying out a more efficient analysis of the scientific literature. For the detection of duplicates, the Mendeley software was used, taking advantage of its organizational functionality; however, more detailed management was sought with the incorporation of another tool, which led to the export in XML format of the documents of each database stored in Mendeley, to later import them into Microsoft Excel. The result obtained was the identification of 109 duplicates between the four databases used in the study. We then proceeded to improve the structuring of the studies that remained, considering the year of publication, type of publication, and country of origin.

Figure 1 provides the number of documents identified during the search for information in the entire database. The sequential process followed the parameter framework proposed by the PRISMA method.

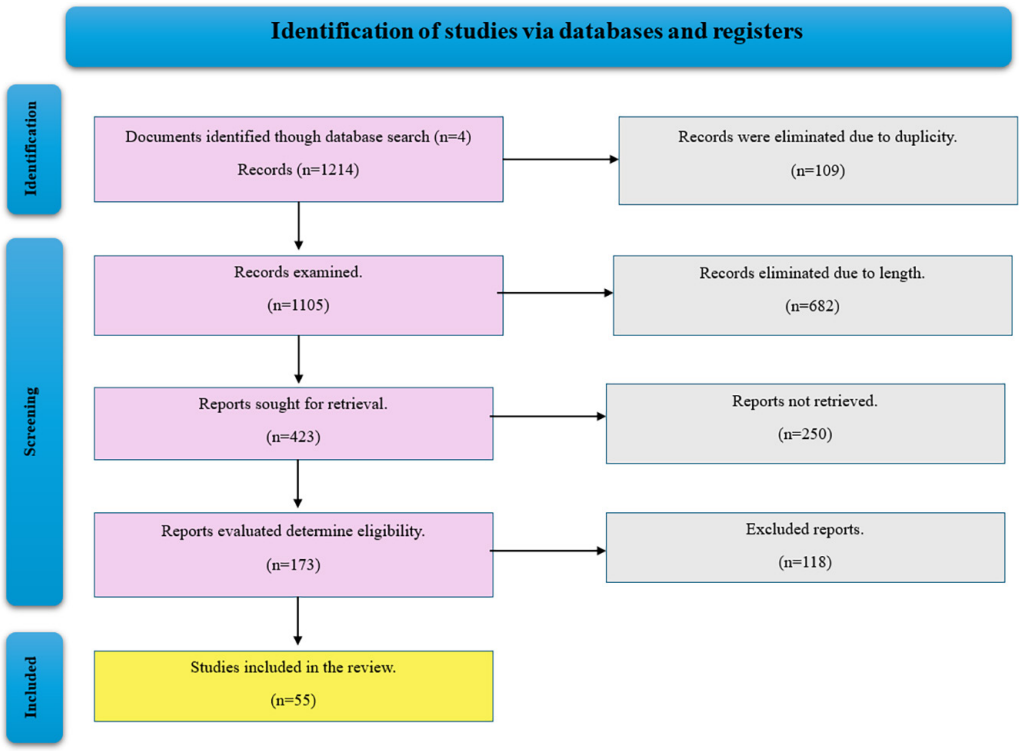

Fig. 1. PRISMA methodology

4 RESULTS

The results of the review were derived and structured from an initial database of 1214 records. After an exhaustive analysis of criteria by inclusion, exclusion, and application of filters, a final target count of 55 studies was obtained. In the initial phase, documents aligned by keyword terminology were identified and selected, yielding 1214 enquiries. The percentage distribution of studies collected by each database was as follows: Science Direct accounted for 29.98%, Scopus contributed 21.91%, Web of Science covered 25.21%, and IEE contributed 22.90%.

In the second phase of the process, selection parameters were established. This stage is called "expose on screen" because it shows the results of 423 records, based on the year of publication, during the period 2022 to 2024. Thus, 25.30% came from Science Direct, 22.70% from Scopus, 26.95% from Web of Science, and 25.06% from IEEE.

The third phase consisted of assessing the suitability of titles in the available documents, looking for those that had keywords or descriptions in the context of the focus of the study. At this point, 250 documents were excluded, and 173 remained, where 14.45% were from Science Direct, 29.48% from Scopus, 19.08% from Web of Science, and 36.99% from IEEE. The relevance of the process ensures the integration of studies, increases the quality of analysis, and aligns the information to build the conceptual framework.

In the final phase of the analysis, we proceeded to identify those studies in the scientific literature that were relevant in relation to the research objectives; this led to reviewing the abstracts by reading them and confirming the validity of the access link to the document, ensuring that the studies could be consulted in their entirety, eliminating access problems. As a result, the process culminated in the selection of 55 scientific papers, managing to exclude 118 studies during the final review process, as they did not meet the previously established evaluation criteria.

Figure 2 shows the final distribution of studies in their respective databases used for the systematic review.

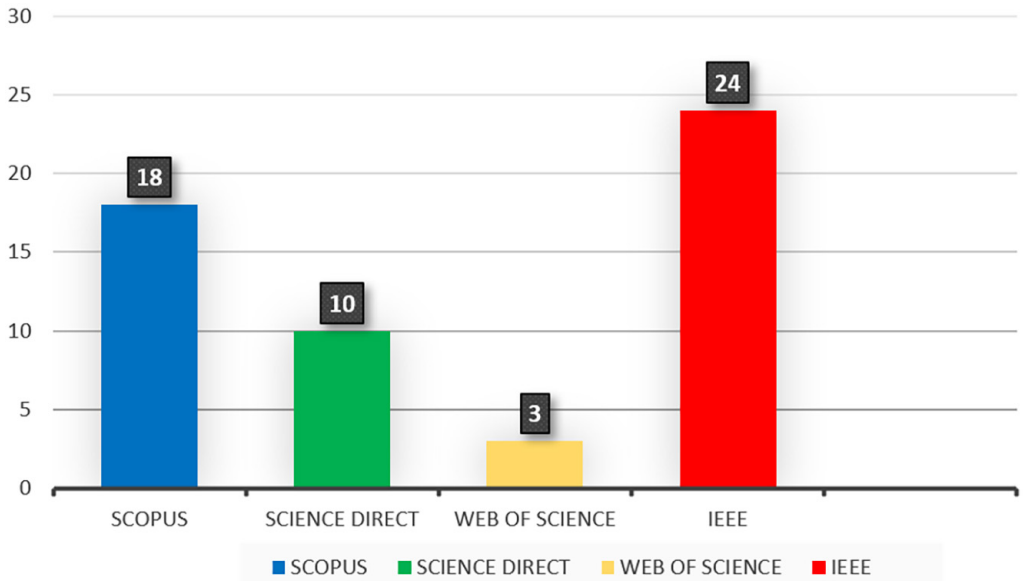

Fig. 2. Distribution of studies by database

The analysis of the 28 articles and 27 conferences revealed a heterogeneous distribution between the period 2022 and 2024. Where 30.91% were published in 2022,

45.45% during 2023, and 23.64% during 2024. As presented in Figure 3, 2023 was the most prolific year in terms of relevant publications on the topic.

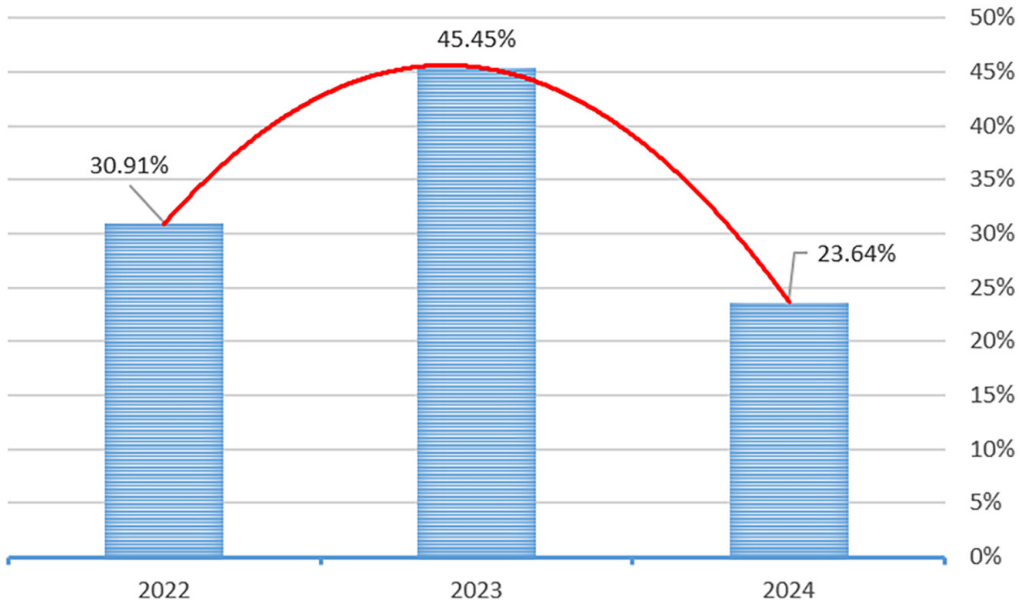

Fig. 3. Scientific literature by year of publication

Along the same lines, the corresponding studies were identified over the years, where in 2022 it was revealed that 3.64% came from Science Direct, 5.45% from Scopus, 3.64% from Web of Science, and 18.18% from IEEE. In 2023, an increase was evident denoting 18.18% belonging to Scopus, while 14.55% to IEEE, 10.91% to Science Direct, and 1.82% to Wos. On the other hand, in 2024, 3.64% to Science Direct, 9.09% to Scopus, and 10.91% to IEEE. Figure 4 shows the statistical information of studies by time frame.

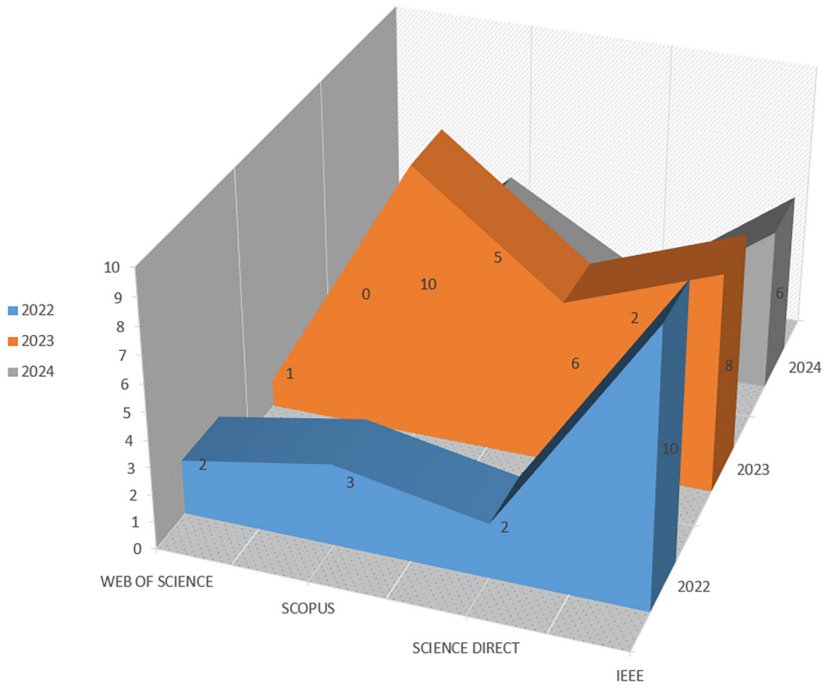

Fig. 4. Number of studies per year and databases

According to the statistical data obtained after processing the information, it is shown that the predominant papers originate from India, representing a value of "12.73%," followed by countries such as Indonesia at 10.91%, Spain at 9.09%, Greece at 7.27%, among other countries. The documents are in the English language globally, as shown in Figure 5.

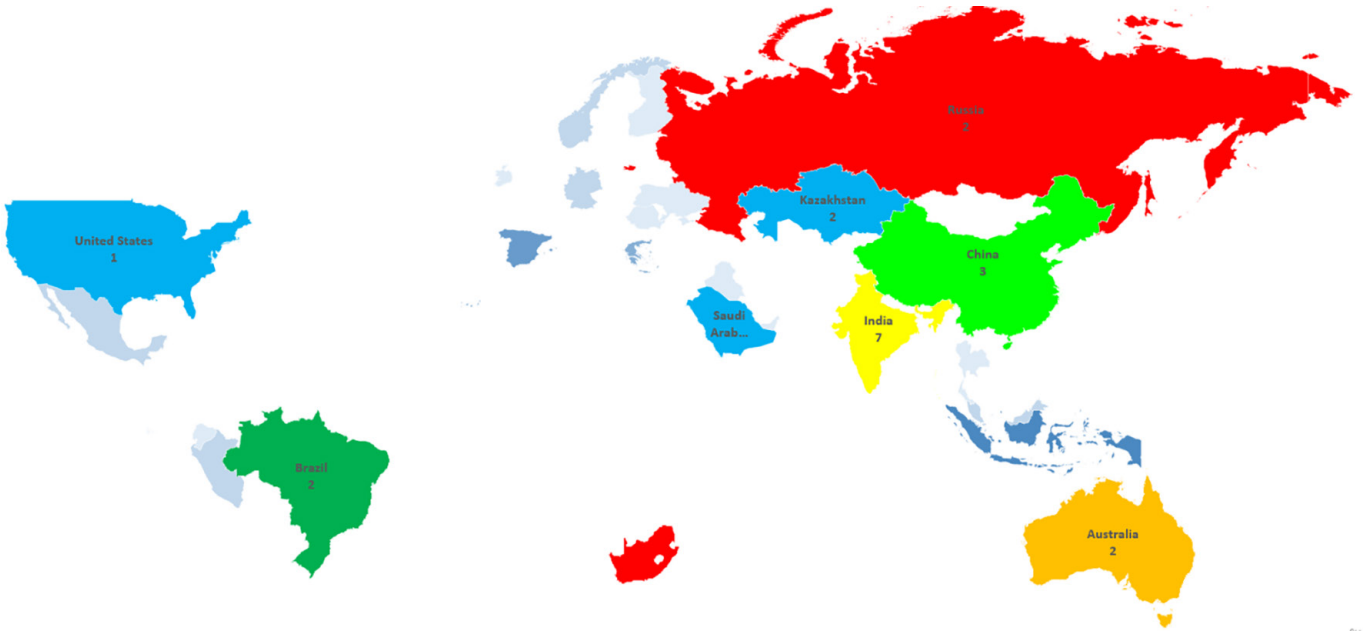

Fig. 5. Scientific literature reviews by country

Figure 6 also shows the categorization of the bibliography according to the type of research, with a breakdown that shows that 51% of the documents analyzed represent 28 articles and 49% correspond to 27 conferences under a paper structure. Figure 6 shows the predominance of the type of scientific publications.

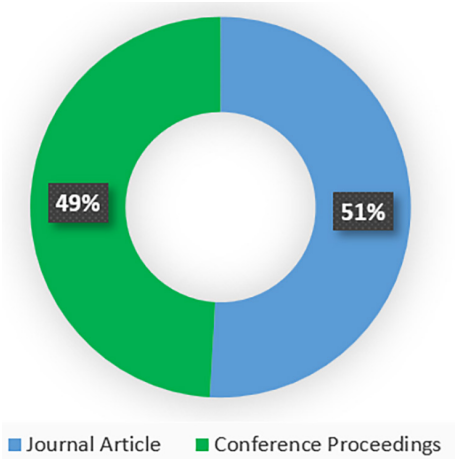

Fig. 6. Documents included in the research according to bibliographic classification

On the other hand, the studies were classified into three methodological approaches, showing the contribution of each database, where the qualitative approach for Scopus represented the highest percentage with 7.27%, while IEEE contributed with 5.45% and Science Direct with 3.64%. Likewise, for the quantitative approach, the IEEE database accounted for 32.73%, Scopus for 21.82%, Science Direct for 14.55%, and Web of Science

for 3.64%. As for the mixed approach, 5.45% in IEEE, 3.64% in Scopus, and 1.82% in Web of Science. In short, Figure 7 provides the distribution of studies previously mentioned.

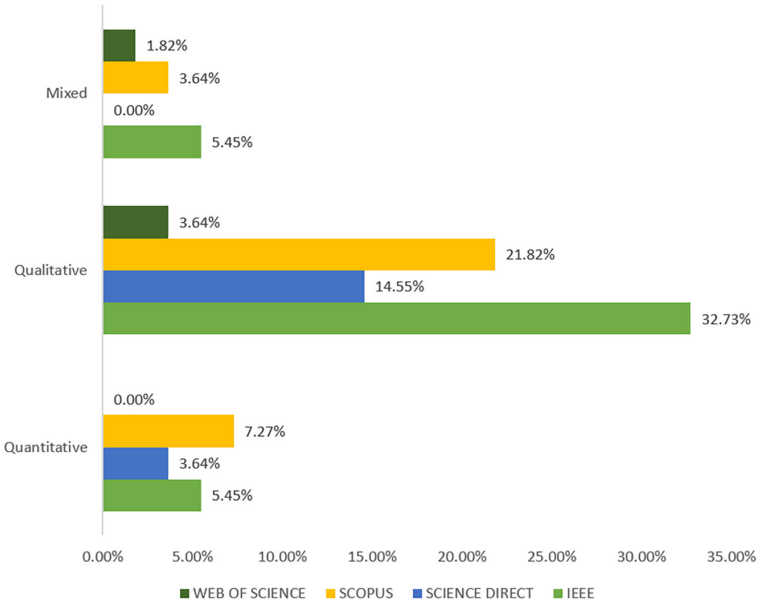

Fig. 7. Scientific literature incorporated in research by methodological approach

For the outcome, the VosViewer bibliometric visualization and analysis tool was used to identify the key terms with the highest concurrence in the selected studies. The analysis revealed predominant words such as "augmented reality," which showed links to "usability" environments in "games," highlighting that adoption depended on interacting with practical environments. Likewise, "education" denoted "accuracy" in circumstances of "pandemics" such as "COVID-19," integrating new study methodologies such as "virtual reality." These terms showed a close connection with the framework presented by the studies addressing the object of research. The analytical approach allows for a holistic view of the issues highlighted in the studies analyzed, and this is evident in Figure 8.

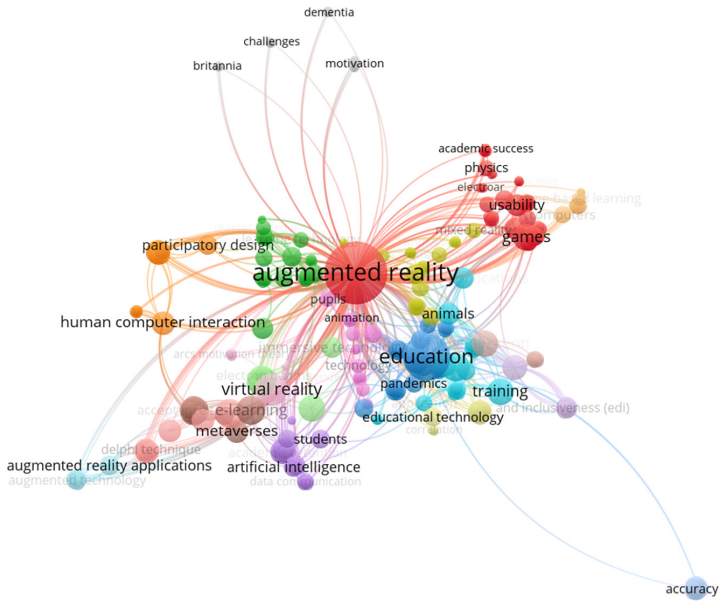

Fig. 8. Bibliometric exploration of the analyzed literature

5 DISCUSSION

RQ1: What impact does AR technology have on education in marginalized groups?

Augmented reality technology has provided benefits in the education of people belonging to marginalized groups, its impact is highlighted by the improvement of critical digital awareness, accessibility, inclusion and the reduction of digital divides. Furthermore, it has been relevant in improving learning methodologies and encouraging their adoption, motivating learners to develop new competences. These results are related to the finding of the study by [16] where a social model of disability was implemented in a marginalized group, reducing social barriers to acceptance. It also relates to the work of [18] where they evaluated the effectiveness of AR tools, such as PluggedAR, demonstrating 100% acceptance. However, the literature needs to be expanded to objectively identify the trend of improvement in marginalized segments. Table 1 presents the impact of AR adoption on marginalized groups.

Table 1. Impact of AR on marginalized groups

#	Impact	Quantity	References
1	Improving digital awareness	3	[24], [25], [26]
2	Motivation	4	[27], [28], [29], [30]
3	Inclusion	6	[31], [32], [33], [34], [35], [36]
4	Accessibility	3	[37], [38], [39]

RQ2: What are the technical barriers to adopting AR technology in promoting educational inclusion?

Promoting digital inclusion in the education sector poses several challenges, especially when it comes to integrating AR, since there are obstacles that hinder the adoption of immersive technology, such as infrastructure problems, lack of pedagogical training, incompatibility of devices, and educational regulations. These factors mark gaps to be addressed, which need to be reduced to achieve effective adoption in educational institutions. Social barriers are supported by the research of [19], where they analyzed the adoption of AR through a qualitative approach of a group of 427 teachers, resulting in a lack of pedagogical skills and technological knowledge. It is also associated with the work [20], where they used an AR platform for engineering simulations, addressing challenges in software resources; the result showed an improvement in 3D model accessibility and interaction. However, there are more relevant obstacles that need to be addressed. Table 2 presents the most recurring barriers to adopting augmented reality.

Table 2. Technical barriers to adopting AR

#	Impact	Quantity	References
1	Challenges in collaboration	3	[28], [29], [40]
2	Non-interactive development	5	[25], [31], [32], [34], [35]
3	Pedagogical training	5	[38], [41], [42], [43], [44]

RQ3: What are AR's tools to improve digital inclusion and accessibility?

Digital inclusion is favored by integrating technological tools that have been developed for immersive AR environments; their accessibility is key to deepening their application in various sectors of knowledge such as science, chemistry, physics, and even languages with presence in various stages of preschool, adolescence, and university students, together with the development of prototype 3D models for mobile devices compatible with different operating systems, which facilitates digital inclusion. In this sense, the results are related to the findings of the work [18], where they showed the effectiveness of PluggedAR to offer visual representations on mobile devices, promoting agile learning. Also, it relates to the work [20] where they implemented immersive environments to provide functionalities to facilitate understanding and hands-on learning. Table 3 presents the main AR tools for digital inclusion in education.

Table 3. AR tools for digital inclusion in education

#	Impact	Quantity	References
1	PhysXR in physics	4	[45], [46], [47], [48]
2	Vuforia SDK Kit in scoreboards	5	[39], [49], [50], [51], [52]
3	Technology in engineering	11	[37], [41], [53], [54], [55], [56], [57], [58], [59], [60], [61]
4	Aplikasi AR for secondary education	8	[24], [26], [27], [46], [62], [63], [64], [65]
5	3D overlay models in children	13	[25], [29], [30], [31], [32], [34], [36], [66], [67], [68], [69], [70], [71]
6	EnvisionAR in autism	2	[33], [72]
7	ZooAR & AnimalCircle	2	[40], [73]
8	SejarAR in gamification	4	[35], [74], [75], [76]
9	AR prototype for languages	2	[44], [77]

6 CONCLUSION

The SRL study analyzed the scientific literature to identify the trend provided by digital inclusion through AR technologies in the educational environment during the period from 2022 to 2024. The study considered a total of 55 studies of which 28 corresponded to original articles and 27 conferences in paper structure, this finding considered criteria for accepting documents with greater relevance to the object of study, excluding unrelated cases.

Information was obtained by incorporating 10 studies in Science Direct with 18.18%, Scopus with 18 in 32.73%, Web of Science with 3 in 5.45%, and IEEE in 24 with 43.64%. Studies have expanded knowledge about AR, showing that the incorporation of technological tools presents challenges that must be mitigated to improve educational outcomes.

Scientific literature review has facilitated a deeper understanding by rigorously analyzing existing studies on AR, highlighting relevant factors in its adoption, such as lack of technical resources and adequate infrastructure, staff training, and difficulties in adapting content in curricula; these challenges affect all students, regardless of their socio-economic status or special needs. The above contributes to the existing discussion, providing a solid basis for future research to address further shortcomings in the field of AR, specifically in the education sector.

Regarding the limitations of SLR, the findings identified that previous studies lacked methods to continuously assess the impact of AR, as they were compared to other technologies that were not relevant to the features provided by immersive environments.

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