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Trends and Prospects for Augmented Reality in Higher Education: A Bibliometric Analysis.

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Abstract

This article analyzes the integration of augmented reality in higher education through a systematic literature review, using the Scopus database. The objective is to identify the main research trends, influential authors, and the most active institutions in this field between 2002 and 2024. The methodology includes bibliometric analysis using R and VOS VIEWER software, focusing on scientific production by year, country, author, and institutional affiliation. The results show a significant increase in publications starting in 2010, with accelerated growth between 2019 and 2024. The United States leads the scientific production, followed by Spain and the United Kingdom. The Monterrey Institute of Technology (ITESM) and the National Science Foundation are the main institutions funding augmented reality research. It is also observed that most authors publish few papers, while a small group is highly productive, under the principles of Lotka's Law. The study concludes that augmented reality has gained importance in higher education, offering new opportunities for research in the design of learning experiences and evaluation of their impact. As this technology evolves, more publications and studies are expected, consolidating its transformative potential in educational environments.

Keywords: Virtual reality, Augmented reality, Learning, Education, Educational innovation.

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INTRODUCTION

In recent decades, immersive technologies have revolutionized various sectors of society, and among them, augmented reality (AR) has established itself as one of the most disruptive. AR allows the superimposition of digital elements over the physical environment, creating an enriched and transformative experience that merges the real with the virtual (Shih et al., 2020). In an increasingly digitized world, AR has gained popularity in areas such as entertainment, medicine, manufacturing, architecture, and commerce. However, its potential to transform education, particularly in highereducation, has generated a growing wave of academic research exploring how this technology can revolutionize teaching and learning (Lai and Cheong, 2022) (Roberto et al., 2024).

Globally, AR has demonstrated its ability to enhance the interaction between the user and their environment by introducing digital elements that enrich the perceptual and cognitive experience. Advances in mobile devices, smart glasses, and digital platforms have facilitated the adoption of AR, allowing it to be accessible to a wider audience (Herskovitz et al., 2020). Unlike virtual reality (VR), which completely immerses the user in a digital environment, AR allows users to maintain a connection to the physical world while interacting with digital

objects and content (Balakrishnan et al., 2021). This quality makes it especially attractive in areas such as education, where the integration of interactive digital elements can enrich the learning process without disconnecting the student from reality.

The impact of AR in education is related to its ability to enhance understanding of complex concepts, promote student motivation, and provide a more dynamic and personalized learning experience. In higher education, where students are often confronted with abstract and theoretical subjects, AR offers the opportunity to visualize and experience content that might otherwise be difficult to comprehend (Kerr and Lawson, 2020). Higher education faces significant challenges in a globalized and highly competitive environment.

The need to adapt teaching methods to the demands of the 21st century has driven the search for new ways to integrate advanced technologies that enhance the educational experience. In this context, AR has positioned itself as a powerful tool to transform the teaching-learning process, offering immersive experiences that go beyond traditional theoretical lessons. Technological advances have enabled universities and research centers to develop interactive learning environments, where students canexplore complex concepts in a visual, dynamic and practical way (AlGerafi et al., 2023).

One of the main advantages of AR in higher education is its ability to make learning more accessible and inclusive. By providing detailed visual representations of abstract concepts, AR can help students with different learning styles better understand information. Students who have difficulty grasping theoretical concepts can benefit from AR, as it allows them to visualize phenomena that would be difficult to understand through text or diagrams alone (Faridi et al., 2021). For example, in natural science education, AR has enabled students to interact with 3D models of molecules, cells, and ecosystems, which facilitates a deeper and more contextualized understanding (Karpudewan, 2024).

In addition to its application in specific disciplines, AR has also proven useful in fostering collaboration and teamwork. In educational environments where teamwork is essential, AR can facilitate communication and the exchange of ideas among students (Soboleva and Karavaev, 2020). For example, in design or simulation projects, AR allows multiple students to work together in a shared virtual environment, where they can interact with 3D models, discuss ideas, and adjust in real-time (Syed et al., 2022). This enhances collaboration and promotes the development of social and professional skills that are critical in the world of work.

Despite the benefits of AR, its adoption in higher education has not been without challenges. Among the main obstacles are the excessive cost of implementation, the need to train teachers in the use of new technologies, and the lack of conclusive studies on its long-term effectiveness. However, as technology advances and becomes more accessible, these challenges are likely to diminish. Educational institutions that have adopted AR have reported improvements in the academic performance of their students, suggesting that this technology has great potential to transform higher education in the future (AlNajdi, 2022).

Given the growing interest in augmented reality within the context of higher education, a comprehensive diagnosis of the current state of scientific knowledge at this intersection is essential. Although numerous studies have been published exploring AR applications in education, the literature lacks a bibliometric analysis that provides a comprehensive and detailed overview of the research trends, the most influential authors, the most productive institutions, and the emerging topics in this field.

Bibliometric analysis is a powerful tool for measuring scientific output, identifying patterns, and assessing the influence of research in each area (Donthu et al., 2021). By applying bibliometric analysis to the literature on AR and higher education, it is possible to gain a deeper understanding of how research in this field has evolved, which topics have gained more relevance, and which institutions and authors are leading innovation. In addition, bibliometric analysis can help identify research gaps, which in turn can direct future research to areas that need more attention (Goyal et al., 2021).

In short, the need to conduct this analysis lies in the need to understand how AR is being used in higher education, what its most promising applications are, and what impact it is having on teaching and learning. In addition, this analysis can provide a solid foundation for future research by identifying the areas that have been most studied and those that still require more attention. In this way, it is hoped that this study will not only contribute to scientific knowledge about AR in higher education, but also serve as a guide for researchers, educators, and policy makers seeking to integrate emerging technologies in education.

1. METHODOLOGY

The present investigation was based on a systematic review of the literature, using the Scopus database as the main source of information. Scopus was selected because of its broad coverage and rigorous indexing of high-quality scientific publications (Borre et al., 2023). The search was conducted in August 2024, employing a combination of key terms relevant to exploring the integration of augmented reality in higher education. The initial search terms were "augmented reality" and "higher education." In order to broaden the coverage and capture a more complete view of the topic, additional terms such as "immersive technologies," "educational innovation," "digital learning," "digital competencies," and "educational technology" were included. In addition, a set of keywords related to the application of augmented reality in educational settings was used to refine the search.

For the management and analysis of the bibliometric data obtained from Scopus, the software R and VOS VIEWER (Ramírez et al., 2023) were used. In addition, a descriptive documentary approach was adopted, which allowed for characterizing the scientific production around the study, through this approach, the main research trends, the most prolific authors, the most active institutions and the institutions with the greatest impact in the field were identified (Grazziotin et al., 2022; Gordo-Molina et al., 2022).

Table 1 ***List of terms used in the bibliometric analysis.***

Key term	Description
Augmented reality	Technology that superimposes digital elements on the real environment.
Higher education	Educational level that includes universities and technical colleges.
Immersive technologies	Technologies that create immersive experiences, such as virtual reality.
Educational innovation	Introduction of new ideas and methods in teaching.
Digital learning	Learning process that uses digital technologies.
Digital competencies	Skills needed to use digital technologies effectively.
Educational technology	Use of technological tools to improve teaching and learning.

Source: author using R software based on information from Scopus (2024).

The bibliometric search was conducted for a period of 22 years, from 2002 to 2024. This interval was selected due to limitations of the Scopus platform, which did not allow the inclusion of previous years. Therefore, the

analysis focused on publications corresponding to these dates, providing an updated and relevant view of the integration of augmented reality in higher education.

A total of 1,159 publications related to the topic were identified in the database, all of which were included in the analysis. According to the type of documents, the majority are articles, which constitute 44.2%, followed by conference papers, which represent 36.2%. Other types of documents, such as editorials, books and book chapters comprise the remaining 19.6%. The publications found in the Scopus database include detailed information, such as date of publication, authors, title, abstract, journal and keywords, among other key aspects.

All these data were organized and managed in R Studio for subsequent analysis; the following analyses were carried out: documents by type, documents by year, documents by year by source, documents by author, documents by affiliation, documents by country/territory, documents by subject area, documents by funding sponsor, among others such as, for example, language in which they were published and stage of publication.

2. RESULTS.

The study of peer-reviewed publications provides a detailed perspective on the progress, evolution, and emerging trends in a scientific discipline, allowing a thorough understanding of its development and future direction.

Bibliometric productivity law

Lotka's Law states that most scientific publications are made by a minority of highly productive authors, while most authors publish very few papers (Rathika et al., 2020).

Table 2 shows that two authors wrote and published 6 documents, 4 authors each published 4 documents on the subject, and the maximum is 62 authors who each published 3 documents. It can be seen that we do not have complete information on the number of authors and their publications, since there is only a record of 266 documents with their authors.

Table 2 ***Lotka's Law***

Documents written	N. of Authors	Proportion of Authors
6	2	0.025
5	4	0.05
4	12	0.15
3	62	0.775

Source: author using R software based on information from Scopus (2024).

Bibliometric indicators

The results of the bibliometric analysis, visualized in Figure 1, show the importance of certain institutions in research funding. Monterrey Institute of Technology (ITESM) and the National Science Foundation emerge as the main actors, demonstrating their commitment to the advancement of knowledge in this field.

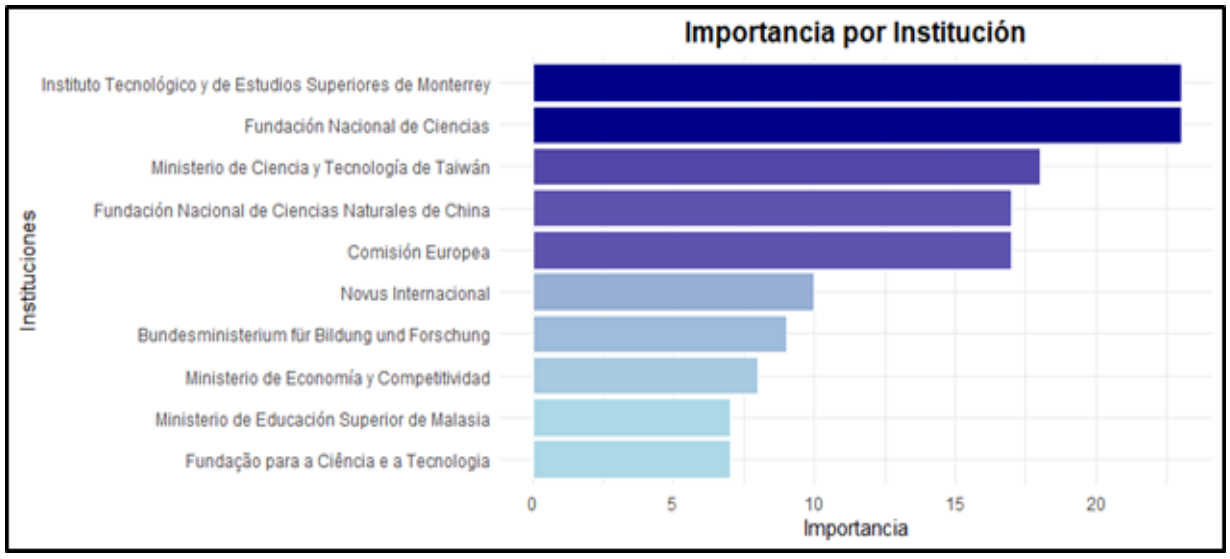


Figure 1. ***Most relevant institutions, source: author based on information from Scopus (2024).***

On the other hand, Figure 2 shows a comparison of the production of scientific papers among the 10 countries with the most published papers. The United States leads significantly in this production, followed by Spain. The United Kingdom, China and Malaysia complete the group of the five countries with the highest number of documents. The rest of the countries, such as Germany, Mexico, India, Australia and Indonesia, have a similar production, although lower compared to the former.

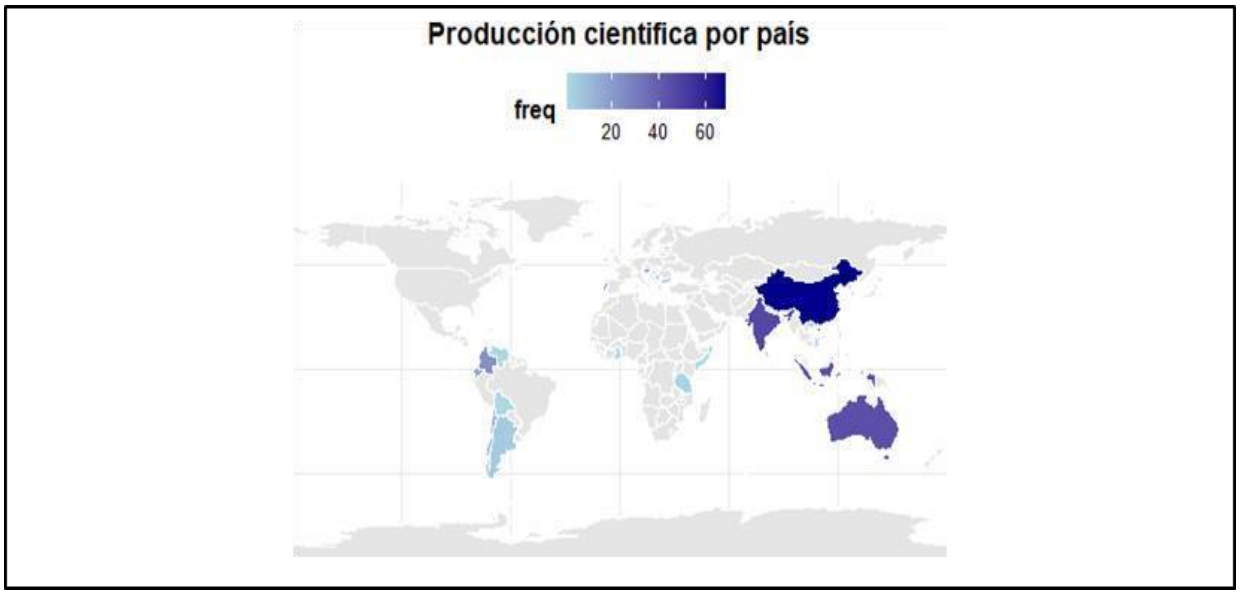


Figure 2. ***Scientific production by country, source: author based on information from Scopus (2024).***

This distribution suggests a concentration of scientific production in a few countries, with the United States standing out as the main producer. However, it is important to consider that this graph only shows a partial aspect of global scientific production and that other factors, such as the area of knowledge or the impact of publications, could influence the interpretation of these data.

Following this order of ideas, Figure 3 shows the institutions that have made the most contributions to the topic under study.

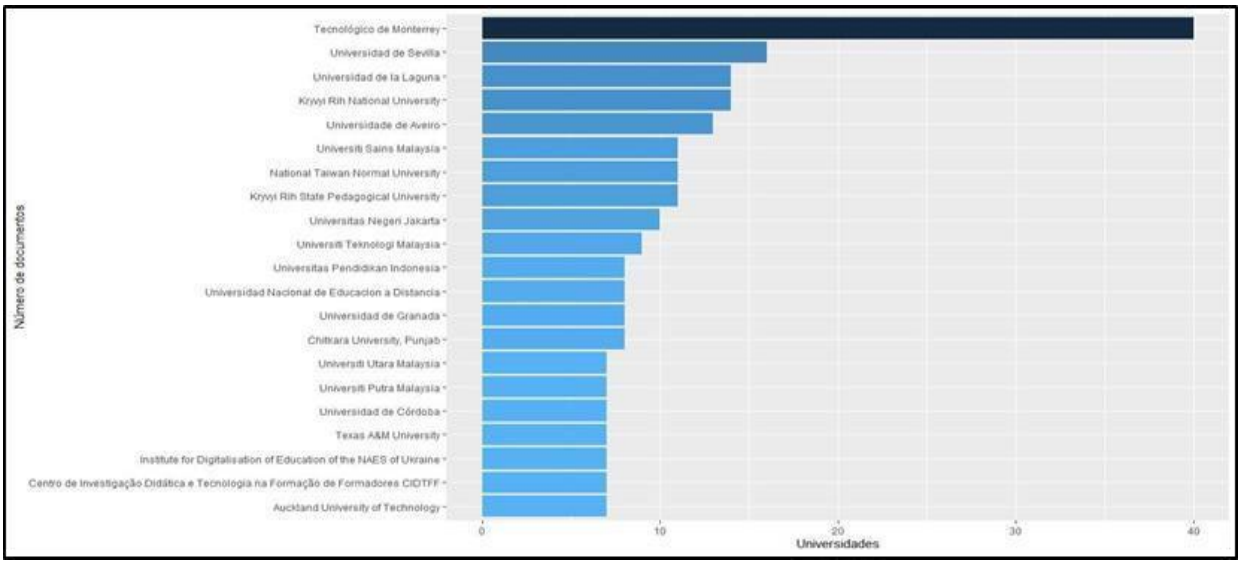


Figure 3. ***Most relevant affiliations, source: author based on information from Scopus (2024).***

The Monterrey Institute of Technology stands out significantly above the others, with a document production of 40 units, suggesting a high level of research activity and greater visibility at the international level. A group of universities, including the University of Seville, the University of La Laguna and the National University of Kryvyi Rih, are in the intermediate range of production, between 14 and 16 documents. This indicates relevant research activity, but less than that of Monterrey of Technologic; the distribution of document production among the rest of the universities is uniform, suggesting a similar level of research activity in these institutions.

To continue analyzing the evolution of scientific production throughout the period studied, we present the following graph showing the production of documents by year.

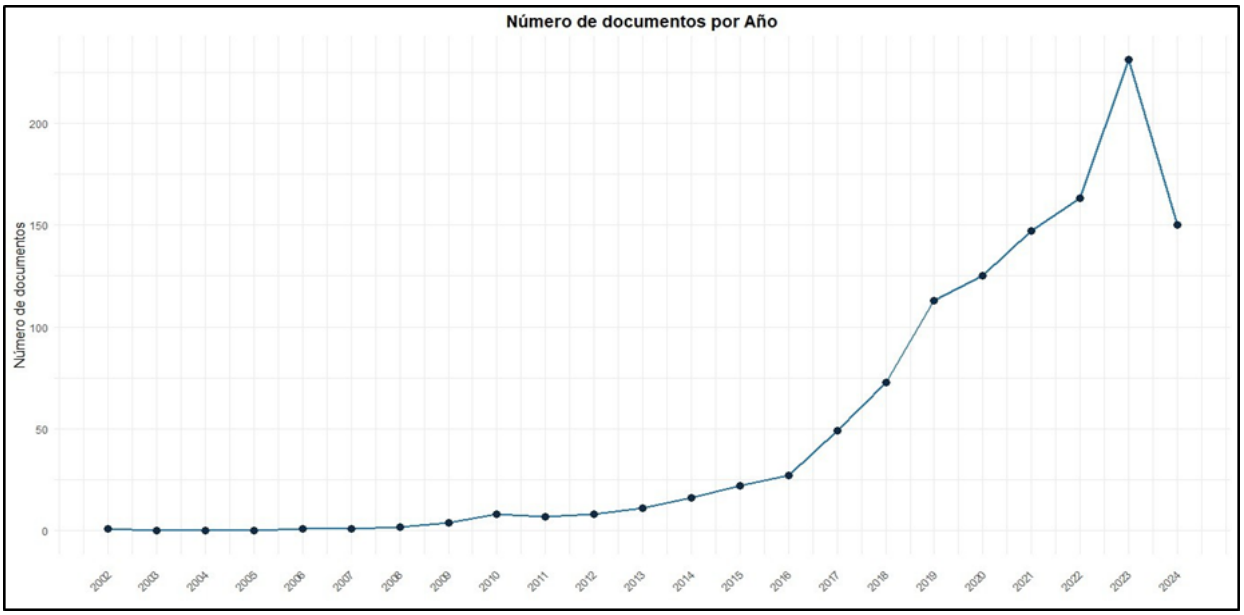


Figure 4. Documents by year, source: author based on information from Scopus (2024).

Analysis of the data provided on the number of publications in Scopus related to Augmented Reality and Higher Education between 2002 and 2024 reveals an exponential growth in academic interest and research in this

technological and pedagogical intersection. The graph below shows a significant increase in the number of publications over the years, especially from 2010 onwards. Around this year marks a turning point, initiating a phase of accelerated expansion.

The last five years (2019-2024) show a particularly pronounced growth. However, it is important to note that during the three years of the analysis (2003-2005), there were no publications in Scopus on this topic, which is evidence of an incipient interest in the subject. All this is due to the fact that augmented reality has evolved, and the academic community has recognized its potential to transform education. New avenues of research are opening in the design of effective learning experiences, impact evaluation and tool development.

Following the same order of ideas, Table 3 presents the 10 authors with the most published papers. The most active authors in the publication of papers on augmented reality and higher education have contributed an average of 4 to 6 papers. Cabero Almenara leads this group. The ranking of the 10 most prolific authors is presented below.

Table 3 ***Documents by author***

Author	**No. of documents**
Cabero-Almenara, J.	6
Castillo-Vergara, M.	4
Cochrane, T002E	4

Source: author using R software based on information from Scopus (2024).

Finally, Table 4 shows the ten articles related to the topic of study with the most citations.

Table 4 ***Most cited documents***

Author Title (in Spanish)	**Subpoenas**
Arrasyid et al. (2024)	
Design, development and evaluation of a mobile learning application for geography teaching.	1.316
Akçayır and Akçayır (2017).	Advantages and challenges
Shafique et al. (2020)	

Akçayır & Akçayır (2017)	associated with augmented reality for education: A systematic review of the literature.	1,283
Arrasyid et al. (2024)	Internet of things (IoT) for next-generation intelligent systems: a review of current challenges, future trends, and prospects for emerging 5G-IoT scenarios.	817
Kye et al. (2021)	Educational applications of the metaverse: possibilities and limitations	483
Bower et al. (2014)	Augmented Reality in education: cases, places and potentials	434
Ibáñez et al. (2014).	Experimenting with electromagnetism using augmented reality: Impact on student experience flow and educational effectiveness.	408
Chiang et al. (2014).	An augmented reality-based mobile learning system to enhance students' learning achievements and motivations in natural science inquiry activities.	402
Akçayır et al. (2016).	Augmented reality in science laboratories: The effects of augmented reality on undergraduate students' laboratory skills and attitudes toward science laboratories.	387
Martín-Gutiérrez (2015)	Augmented reality to promote collaborative and self- directed learning in higher education	296
Küçük et al. (2016).	Learning anatomy through mobile augmented reality: effects on performance and cognitive load.	267

Source: author using R software based on information from Scopus (2024).

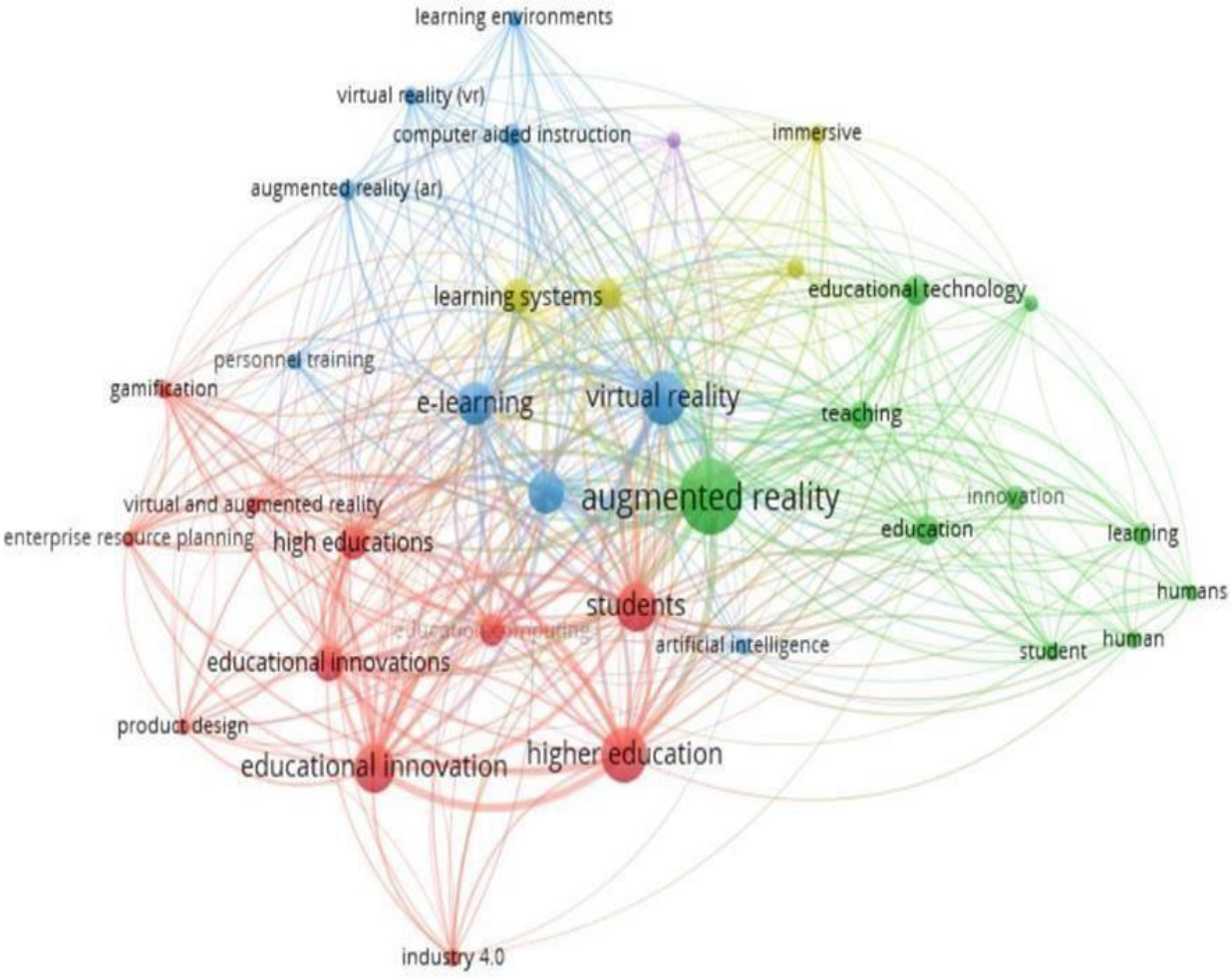
In first place, the most cited article is Arrasyid et al. (2024), entitled "Design, development and evaluation of a mobile learning application for teaching geography", with 1,316 citations. This work has been instrumental in the implementation of augmented reality in geography teaching, showing how this technology can enhance interaction and understanding of complex geographic concepts. It is followed by the article by Akçayır and Akçayır (2017) entitled Advantages and Challenges Associated with Augmented Reality for Education: A Systematic Literature Review, with 1,283 citations. This study provides a comprehensive overview of the

benefits and obstacles of AR in education, making it a key reference for academics and practitioners seeking to integrate this technology into educational settings.

The third article, by Shafique et al. (2020), entitled Internet of Things (IoT) for next- generation smart systems: a review of current challenges, future trends and prospects for emerging 5G-IoT scenarios, has been cited 817 times. Although its focus is IoT, its relevance extends to the field of augmented reality due to the integration of these technologies in the creation of smart educational environments. Each of the articles found highlights technological innovation in immersive educational environments and the limitations that persist in the application of these technologies.

Analysis of relationships and co-occurrences

Finally, in the cluster analysis through VOS VIEWER, Figure 7 reveals the terms with the highest impact grouped by co-occurrence, where keywords such as: Virtual Reality, Augmented Reality, Learning, Education, Educational Innovation, among others, can be observed.



Terms associated with the study topic "Augmented reality and higher education"*, source: author based on information from Scopus (2024).*

3. CONCLUSIONS

The research presented here offers a comprehensive overview of the integration of augmented reality in higher education, revealing both its growing adoption and the main institutions and authors leading its development. Through a detailed bibliometric analysis, it has been possible to identify the emerging trends in the field and the most significant contributions at a global level, evidencing a growing interest in the intersection between immersive technology and pedagogy.

Analysis of publications between 2002 and 2024 shows a marked increase in scientific output from 2010 onwards, reflecting a growing acceptance and recognition of the potential of augmented reality in higher education. The last five years (2019- 2024) have experienced accelerated growth, suggesting that this technology is reaching maturity in educational research. However, the absence of publications in the first years analyzed (2003-2005) is evidence that interest in this technology is relatively recent and still in the process of consolidation.

The United States leads scientific production in this field, closely followed by Spain and the United Kingdom, indicating a strong concentration of research in developed countries. Monterrey Institute of Technology (ITESM) stands out as the institution with the highest production of papers, underscoring its commitment to the advancement of educational technology. These results indicate that the most relevant institutions not only drive research in this field but also serve as benchmarks for other organizations.

In terms of productivity, an uneven distribution is observed, where few authors are responsible for a large share of publications, in accordance with Lotka's Law. This suggests that augmented reality research in higher education is driven by a small core of highly productive experts, which may indicate a growing specialization in this area. In the analysis of the most cited articles, it stands out that the study by Arrasyid et al. (2024), entitled Design, development and evaluation of a mobile learning application for teaching geography, is the most cited with 1,316 references. This finding underscores the importance of augmented reality in specific areas of knowledge, such as geography, where immersive technology has proven to be highly effective in improving students' spatial and conceptual understanding.

In conclusion, augmented reality has established itself as a promising tool in higher education, with a growing impact on educational research. As new applications are developed and its effectiveness in learning environments is evaluated, its adoption is likely to expand further. Leading institutions and authors will continue to play a crucial role in this advancement, helping to guide the evolution of this technology in education. The study suggests that, although the field is still young, its trajectory points to a promising future, with profound implications for pedagogical innovation and digital learning in higher education.

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