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Virtual, augmented, and mixed reality in the University environment: an analysis of scientific production

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Abstract

Augmented, virtual, and mixed reality offer digital alternatives for implementing innovative educational processes, significantly expanding opportunities in university education due to the available resources and the psycho-evolutionary development of students. This study aimed to analyze the scientific production on this topic in Scopus using bibliometric techniques. Following the PRISMA statement, the final sample comprised 1,257 articles published between 2014 and 2023, utilizing various bibliometric analyses. The results indicate a surge in production over the last five years, with most articles indexed in the areas of social sciences, engineering, and medicine, aligning with the subject matter of the journals with the highest number of publications. While the United States and China are the most prolific countries, the leading authors and institutions are predominantly from Spain. In addition to meta-analyses and systematic reviews, the most cited articles focus on the use of augmented and virtual reality in health sciences within universities. Makransky and Akçayir (bibliographic coupling) are highlighted as the most influential authors, along with the duo Cabero and Barroso in the field of educational sciences (co-citation). Emerging research areas (co-occurrence) are oriented towards factors affecting learning processes with these digital resources, such as motivation and anxiety management. In conclusion, further research is needed to explore the potential of these resources for university training due to their positive effects on learning.

Keywords: Augmented reality, Virtual reality, Mixed reality, University, Scientific production

1 Preface

With their continuous evolution, technologies offer an ever-increasing range of digital resources for teaching and learning processes. Due to their interactivity, dynamism, and the heightened interest they generate among students, there is a growing commitment to integrating emerging technologies into active teaching methodologies, which facilitate more meaningful knowledge acquisition (Chaljub et al., 2022). Notably, technologies related to the metaverse stand out, where virtual spaces created through the convergence of various technological resources (Aguilar et al., 2022) allow users to interact

with each other and digital objects similarly to the real world, blurring the lines between reality and virtuality. This enhances immersion, navigation, and interaction between users (Cabero et al., 2022). Within the metaverse, technologies such as Augmented Reality (AR) and Virtual Reality (VR) have played a crucial role in its design, development, and implementation.

Augmented Reality (AR) is a technology that integrates digital information with the real world in real-time (Rohrbach et al., 2021), overlaying images, videos, or other elements onto the physical environment (Reyes-Ruiz, 2022). This provides an enriched and contextualized perspective with significant potential for educational development (Cabero-Almenara & Barroso-Osuna, 2016). Virtual Reality (VR), in contrast, replaces physical reality with virtual elements (Rauschnabel et al., 2022), creating a new reality that may be difficult or impossible to experience in the real world (Moro et al., 2017). This allows students to explore abstract concepts, engage in simulated practice, and participate in immersive and contextualized learning activities (Berg & Lavance, 2017). Mixed Reality (MR) combines both AR and VR to design a hybrid virtual environment.

While it is true that the use of VR and AR may require additional cognitive effort from learners, as they have to shift their focus between real and virtual content (Buchner et al., 2021; Maradei et al., 2023), the positive effects on motivation (Aroca and Llorente, 2023; Redondo et al., 2020), cognitive processes (Huertas-Abril et al., 2021; López et al., 2019), and academic performance (Gómez et al., 2022) have a significantly higher impact on the learning process (Bursali & Yilmaz, 2019; Fombona & Vázquez, 2017; Lai et al., 2019).

Despite the increased prominence of VR and AR in education, the lack of digital competencies among teachers to use these resources and create learning situations incorporating VR and AR is a significant issue (Barroso et al., 2019). While AR resources are generally more accessible for teachers compared to VR-based resources (Alalwan et al., 2020), implementing both requires explicit training on their creation and proper use, as highlighted by Delgado et al. (2023). This training is essential for achieving a better understanding of the educational applications of these immersive technologies (Marques & Pombo, 2021).

The recent development of VR and AR technologies is driven by their benefits for users and contextual factors that have led to a strong commitment to these resources. Their impact on students with Specific Educational Needs (SEN) is particularly noteworthy. For students with ASD, studies by López et al. (2024) and Zhang et al. (2022) highlight that the balanced integration of AR and VR in training processes enhances motivation, attention, communication, autonomy, and learning outcomes. Additionally, Amat et al. (2021) found that interactive AR and VR activities improve students' autonomy and attention. For students with dyslexia, Ausín et al. (2023) emphasized that using AR in a playful manner was beneficial, highlighting the quality of texts, the narrative of the game, and the sequencing of activities. One factor that significantly increased the use of virtual and augmented reality was the COVID-19 pandemic, which forced training processes to adapt to online contexts amidst lockdowns and restrictions (Infante-Moro et al., 2022). Numerous studies were conducted during this pandemic (Eldokhny & Drwish, 2021; Laurens-Arredondo, 2022; Saleem et al., 2023). As a result, the applicability of these resources expanded across all educational levels,

with a particular emphasis on higher education. There has been extensive development in health sciences, including their use in laboratory work (Akçayir et al., 2016; Makransky et al., 2019a), medical education (Cabero-Almenara et al., 2017, 2018), biology (Romero et al., 2023), and as a resource for therapeutic processes (Fan et al., 2023; Ghasempeyvandi & Torkan, 2023; Liu et al., 2022).

The relevance of these topics is evident in the numerous analyses of research output conducted in recent years. For augmented reality, studies have focused on early childhood education (Fernández & Duarte, 2023; Rivas et al., 2021), higher education (Mukhtarkyzy et al., 2023; Utami et al., 2023), and education in general (Akçayir & Akçayir, 2017; Hincapie et al., 2021; Karakus et al., 2019). Virtual reality has been examined at the compulsory school and university levels (Cabero-Almenra et al., 2019a; Merchat et al., 2014; Pellas et al., 2021), as well as exclusively in higher education (Radianti et al., 2020; Rashid et al., 2021). The combination of both technologies, known as mixed reality, has also been studied to understand the evolution of their scientific output (Angulo et al., 2023; Stretton et al., 2018; Zhao et al., 2023). Although this field has been widely explored, there has not been a bibliometric analysis focusing exclusively on higher education over the past 10 years.

Therefore, given the importance of these digital resources in the educational process at university level, this study aimed to conduct a bibliometric analysis of the scientific production on virtual, augmented, and mixed reality in the international database Scopus.

To this end, several research questions were established:

1) What have been the evolution and main characteristics of the scientific production on virtual, augmented, and mixed reality?
2) Which authors have published the most influential works in this field of study?
3) What research trends have been emerging in this area?

2 Method

2.1 Approach

A bibliometric study was conducted to examine the status of research on virtual, augmented, and mixed reality. This meta-analysis of scientific production (Gonzalez et al., 2020; Khanra et al., 2020) established guidelines and criteria to analyze the evolution of publications in this field of knowledge. Various variables were considered, interpreting the findings both quantitatively and descriptively. This technique, derived from scient metrics, has been implemented in many scientific works (Gil-Fernández & Calderón-Garrido, 2023; Ruiz-Palmero et al., 2021; Segura-Robles et al., 2020).

2.2 Sample

From the various international databases, Scopus was selected for this study due to its rigorous indexing quality criteria and its broad coverage of different knowledge areas (Cívico-Ariza et al., 2022; Zhang et al., 2023). The search query used was “virtual reality” OR “augmented reality” OR “mixed reality” (within the title) AND “university”

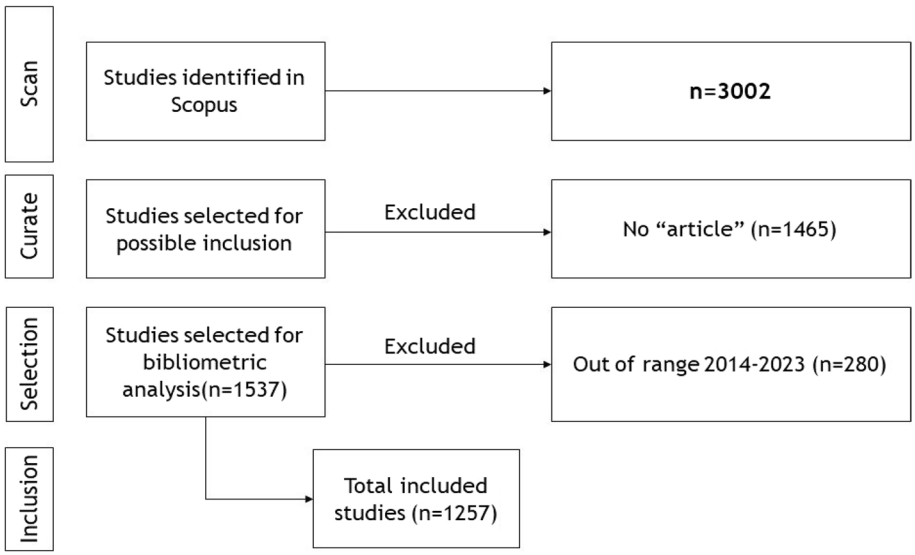

Fig. 1 Flowchart of the process for screening, curating, selecting, and including studies, based on the PRISMA statement

Table 1 Study variables and inclusion / exclusion criteria

Variables	Criteria of Inclusion/Exclusion
Year	All articles in range 2014–2023
Subject area	All subject areas with 80 or more articles
Author	All authors with 5 or more articles
Journal	All journal titles with 13 or more articles
Country	All countries with 40 or more articles
Institution	All institutions with 9 or more articles
Publications with most impact	All articles with 350 or more citations

Source: authors' own research

OR "higher education" (within the title, keywords, and abstract). This search returned a total of 3,002 documents as of March 23, 2024.

2.3 Screening procedure

To the 3,002 documents returned by the search, several screening criteria were applied, following the PRISMA statement as a reference (Fig. 1). During the curation process, all non-article documents were excluded, reducing the sample to 1,537 documents. In the selection process, only articles published within the past 10 years (2014–2023) were considered, excluding those published earlier or later. The final sample, after various screenings, comprised 1,257 articles in the following languages: English (1,151; 91.57%), Spanish (52; 4.13%), Chinese (33; 2.62%), Russian (8; 0.64%), French (6; 0.48%), German (5; 0.40%), and Portuguese (2; 0.16%). This dataset was exported as comma-separated values (.csv) for further analysis.

2.4 Analysis

For analyzing the evolution and characteristics of scientific production, various variables were considered (Table 1), which detail the inclusion and exclusion criteria applied.

Bibliometric techniques were used to analyze the relationships between the articles in the sample, with VOSviewer software employed for visualizing these connections. We examined bibliographic coupling to identify the most influential publications based on shared citations with related research. Co-citation analysis was used to reveal how frequently different articles are cited together. Additionally, we analyzed keyword sets to highlight the descriptors and key terms that define the content of the analyzed articles.

3 Results

To achieve the objectives of this work, this section is organized around the various bibliometric techniques employed. It begins with an analysis of the scientific production and is followed by examinations of bibliographic coupling, co-citation, and co-occurrence.

3.1 Analysis of scientific production

Using the 1,257 articles in the sample as a reference, the analysis is conducted based on the various variables considered.

3.1.1 Year

Examining the last 10 complete years of the study period (2014–2023), a progressive increase in the number of articles is evident from 2017 onward, with several notable quantitative jumps (Fig. 2). In the first four years, the number remains steady at a total of 123 articles, representing 9.79% of the total. However, from 2017 to 2018, the sample nearly doubles from 40 to 78 articles. This trend continues between 2018 and 2020, where the count rises from 78 to 153, and between 2020 and 2023, it grows from 153 to 317. Thus, exponential growth is observed in the last six years, with the sample approximately doubling every two years, culminating in a peak of 317 articles in 2023, which accounts for 25.22% of the total sample.

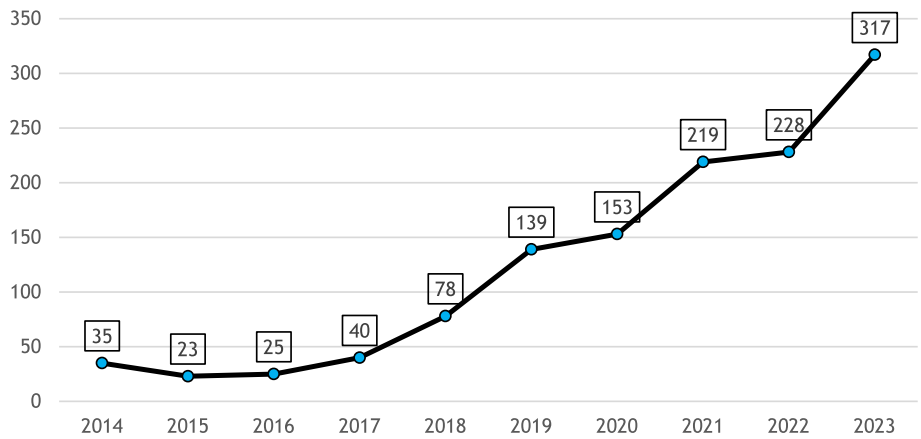

Fig. 2 Articles published by year

Table 2 Subject area

Subject area	Article
Social Sciences	589
Computer Science	432
Medicine	284
Engineering	256
Psychology	101
Arts and Humanities	81

Source: authors' own research

Table 3 Most prolific authors at Scopus

Author	Article	Country	Affiliation	Cites Scopus	Documents Scopus	H-index Scopus
Cabero	13	Spain	University of Seville	2724	147	27
Vergara	10	Spain	Catholic University of Ávila	1388	148	22
Fernández-Arias	9	Spain	Catholic University of Ávila	406	43	12
Antón-Sancho	9	Spain	Catholic University of Ávila	298	47	10
Vázquez-Cano	7	Spain	National University of Distance Education	2059	119	23
López-Meneses	6	Spain	Pablo de Olavide University	1383	84	22
Makransky	5	Denmark	University of Copenhagen	4441	80	30
Del Maestro	5	Canada	McGill University	8287	188	53
Barroso	5	Spain	University of Sevilla	974	42	17

Source: authors' own research

3.1.2 Knowledge area

To analyze this variable, a threshold of 80 or more articles per area was set. It is important to note that for indexing purposes, an article can be classified into multiple subject areas based on its content (multi-classification criterion). Consequently, the total number of articles across all subject areas exceeds the overall number of analyzed articles (1257), as illustrated in Table 2.

It is noteworthy that the social sciences, particularly due to their connection to education, had the highest number of indexed articles (589). Other significant areas include computer science (432) and engineering (256), reflecting the technological applications of virtual and mixed reality. Medicine, with 284 articles, ranks third, highlighting its importance in higher education training processes and its potential for non-tangible experimentation in the health field.

3.1.3 Authors

The analysis focused on the most prolific authors, defined as those who had published at least five articles (Table 3). Additional indicators were included to provide context for their research work beyond the study's focus, such as their city of affiliation, total citations in Scopus, total documents published in Scopus, and the H-index in Scopus.

Julio Cabero from the University of Seville is the most prolific author on the subject, with 13 articles. He is also the third most cited author and ranks third in terms of total publications in Scopus within the sample. He is followed by the research team from the

Catholic University of Avila, consisting of Vergara (10 articles), Fernández-Arias (9 articles), and Antón-Sancho (nine articles), who publish jointly. While they are prolific in this field, they do not rank among the top in other indicators of their overall scientific production in Scopus. Notably, Spanish authors dominate, including former professors from UNED, Pablo de Olavide University, and the University of Seville. Among the most prolific authors, only two are from outside Spain (both with five articles), and they have the best research metrics: Makransky (4,441 citations, H-index 30) and Del Maestro (8,287 citations, H-index 53).

3.1.4 Journal

By setting the threshold at 13 or more articles, 12 journals meet the inclusion criteria (see Table 4).

These journals can be categorized by their primary subject matter. In the realm of educational technology, Education and Information Technologies has the highest number of articles (23), while Computers and Education has the fewest (13). Both are key journals in this field, along with four others of note: Interactive Learning Environments, Virtual Reality, International Journal of Emerging Technologies in Learning, and International Journal of Interactive Mobile Technologies. There is also one general education journal, Education Sciences by MDPI. In the health field, Journal of Surgical Education and BMJ Open are included, reflecting the high number of articles indexed in medicine. Journals related to the environment and education include Sustainability and Journal of Chemical Education. Additionally, Applied Sciences is a general science journal represented in this set. These findings underscore the significant presence of specialized journals that address virtual and augmented reality within the context of higher education.

In addition to examining the most prolific journals according to the established inclusion criteria, the dispersion of research output was analyzed using Bradford's Law (1934). This law illustrates the uneven distribution of publications on a research topic, where the majority of publications are concentrated in a small number of journals, while the remaining publications are spread across a large number of less specialized journals. Bradford's Law helps identify journals that specialize in the subject under study

Table 4 Journals indexed in Scopus with the highest number of publications

Journal title	Article
Education and Information Technologies	23
Education Sciences	21
Interactive Learning Environments	20
Virtual Reality	19
Applied Sciences	19
Sustainability	17
Journal of Chemical Education	16
International Journal of Emerging Technologies in Learning	16
International Journal of Interactive Mobile Technologies	15
Journal of Surgical Education	14
BMJ Open	14
Computer and Education	13

Source: authors' own research

Table 5 Dispersion of scientific production by areas

Zone	No. of journals	% of journals	Article	% of article
Core	42	6.03	418	33.33
Zone 2	235	33.72	419	33.33
Zone 3	420	60.25	420	33.33

Source: authors' own research

Table 6 Countries with more articles in Scopus

Country	Article
United States	197
China	168
Spain	118
United Kingdom	80
Taiwan	62
Australia	62
Germany	47
Malaysia	44
Italy	40

Source: authors' own research

by dividing the sample into three zones based on specialization: core, zone 2, and zone 3, ranging from highest to lowest specialization. As detailed in Table 5, the sample is divided into these zones. The data reveal that 42 journals (6.03% of the total) focus specifically on virtual and augmented reality, with the 12 previously mentioned being the most prominent. Another 235 journals (33.72% of the total) are specialized in the topic. Finally, 420 journals (60.25%) have a low level of specialization in this field.

3.1.5 Countries

For countries, only those with a scientific production of 40 or more articles were included, as detailed below (Table 6).

The results indicate that all continents except Africa are represented among the most prolific countries. Notably, the United States leads with 197 articles, accounting for 15.67% of the total sample, while Australia has 62 articles. Asia, including China, Taiwan, and Malaysia, contributes 21.8% of the total, and Europe, represented by Spain, the United Kingdom, Germany, and Italy, accounts for 22.67% of the total. Together, the three most prolific countries—United States, China, and Spain—comprise 38.42% of the total number of publications on the subject.

3.1.6 Institutions

For institutional affiliation, we focused on institutions that had produced nine or more articles on the subject (see Table 7).

The University of Seville is the most prolific institution, with 24 articles. In second place is Tecnológico de Monterrey (Mexico), which, despite not having any of the top authors or meeting the production criteria for Mexico, still ranks highly. Conversely,

Table 7 Institutions with more articles in Scopus

Institution	Article
University of Seville	24
Monterrey Tech	11
National Taiwan University of Science and Technology	11
University of Cordoba	10
Catholic University of Avila	10
McGill University	9
University of Hong Kong	9
National University of Distance Education	9
University of Pablo de Olavide	9

Source: authors' own research

institutions like the National Taiwan University of Science and Technology and the University of Hong Kong, from Taiwan and China respectively, are prominent in the list of most prolific countries. McGill University, with nine articles, is notable as it includes Del Maestro, one of the leading authors on the topic. Spain again stands out, with its universities representing 4.93% of the total number of articles from the most prolific institutions in the country.

3.1.7 Publications with the greatest impact

This variable will be analyzed based on the number of citations, using a criterion that includes articles with more than 350 total citations (see Table 8). Among the most cited articles, Professor Akçayir from the University of Alberta (Canada) has two papers in the top rankings (1st and 7th most cited). Additionally, the journal Computers and Education, one of the top 12 most prolific journals, is represented twice in the list (second and third most cited articles).

While we rank impact based on the total number of citations, citation intensity is assessed by the number of citations per year. This means that the rankings of the first and second most cited articles, as well as the third and fourth most cited articles, would change if we used citation intensity as the criterion.

The most cited article is by Akçayir and Akçayir (2017), which provides a systematic review of the literature on the impact of incorporating augmented reality into education, highlighting its benefits and the changes it brings to the teaching and learning process. In second place is the work by Radianti et al. (2020), another systematic review, but this one focuses on immersive virtual reality in higher education. Although this paper has the highest number of citations per year, it ranks second overall. The third most cited paper is a meta-analysis by Merchat et al. (2014), which examines the effectiveness of virtual reality for learning at both compulsory school stages and university. Such comprehensive reviews are often widely cited because they provide a broad overview of the topic, which is essential for researchers starting to explore the subject. The remaining papers concentrated on research related to the study's focus. For instance, Berg and Lavance (2017) explored the impact of virtual reality on product design and manufacturing. In another study, Makransky et al. (2019a) demonstrated that while the use of virtual reality increased attendance in the science laboratory, it did not significantly affect the learning

Table 8 Articles with more impact on Scopus

Autos	Year	Title	Source	Cited by	Average number of cited per year
Akçayır, M. & Akçayır, G	2017	Advantages and challenges associated with augmented reality for education: A systematic review of literature	Educational Research Review, 20, 1–11	1168	166.86
Radianti, J., Majchrzak, T.A., Fromm, J. & Wohlgenannt, I	2020	A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda	Computers and Education, 147, 103,778	1091	272.75
Merchant, Z., Goetz, E.T., Cifuentes, L., Keeney-Kennicutt, W. & Davis, T.J	2014	Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis	Computers and Education, 70, 29–40	970	97
Makransky, G., Terkildsen, T.S. & Mayer, R.E	2019	Adding immersive virtual reality to a science lab simulation causes more presence but less learning	Learning and Instruction, 60, 225–236	644	128.8
Berg, L.P. & Vance, J.M	2017	Industry use of virtual reality in product design and manufacturing: a survey	Virtual Reality, 21(1), 1–17	510	72.86
Moro, C., Štromberga, Z., Raikos, A. & Stirling, A	2017	The effectiveness of virtual and augmented reality in health sciences and medical anatomy	Anatomical Sciences Education, 10(6), 549–559	494	70.57
Akçayir, M., Akçayir, G., Pektaş, H.M. & Ocak, M.A	2016	Augmented reality in science laboratories: The effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories	Computers in Human Behavior, 57, 334–342	354	44.25

Source: authors' own research

process. Additionally, Akçayir et al. (2016) investigated the impact of augmented reality on students' laboratory skills and their attitudes towards these workspaces. Lastly, Moro et al. (2017) examined the effectiveness of both virtual and augmented reality in the health sciences, specifically in the field of medical anatomy.

3.2 Bibliographic coupling

The purpose of this technique is to assess the impact of an article based on the scientific literature reviewed, focusing on the degree of relationship and similarity with other publications in the sample. The key factor is the common references among the articles, analyzed through backward citation chaining. This method helps identify influential authors within the study's focus. We use authors as the unit of analysis, stipulating that each author must have at least one published article and reach a minimum of 100 citations.

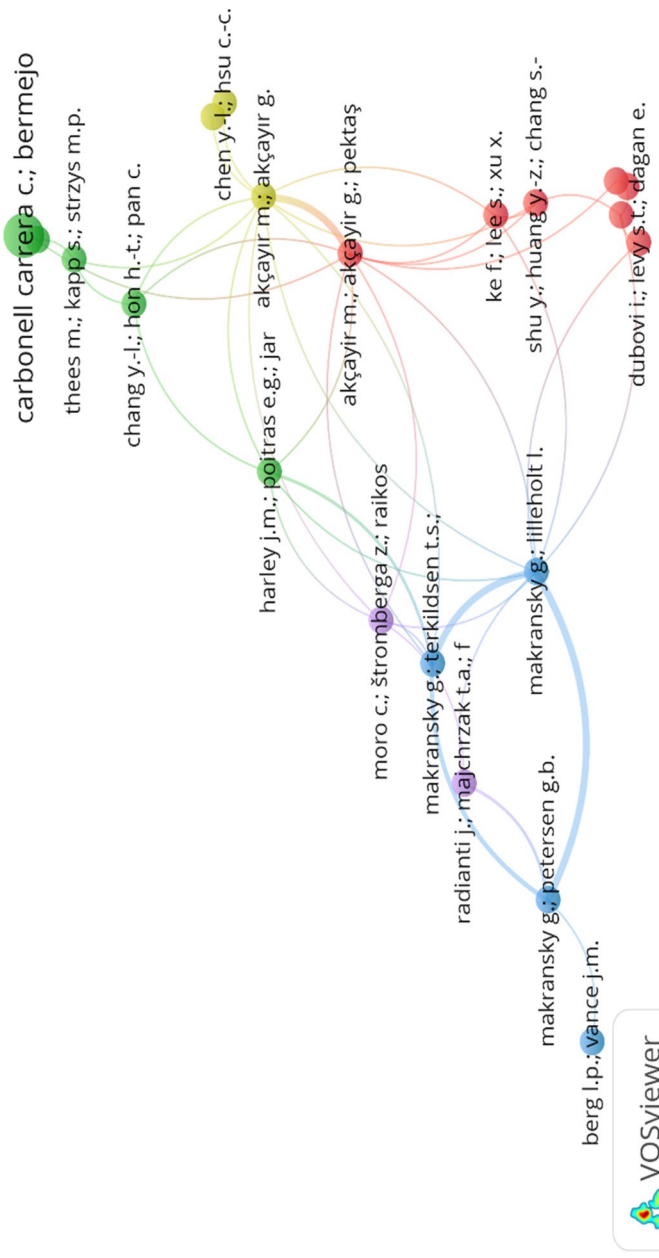

Fig. 3 Bibliographic coupling with "authors" as unit of analysis

The relationship nodes generated from the 21 items meeting these criteria formed five groups of authors, reflecting their interconnections (see Fig. 3).

In terms of coupling intensity, the blue cluster stands out, led by the team headed by Makransky (University of Copenhagen). This team achieved the highest coupling intensity (total link strength of 40–28) and has the fourth most cited work among those included in this analysis (Makransky et al., 2019a). Following the blue cluster in intensity are the yellow and red clusters, both influenced by the work of Prof. Akçayir (University of Alberta). Within the yellow cluster, Akçayir & Akçayir (2017) is notable for having the fourth highest intensity (total link strength of 26) and the most citations (1168). In the red cluster, the collaboration with Turkish researchers (Akçayir et al., 2016) ranks fifth in coupling intensity (total link strength of 25) and seventh in citations (354). It is important to note that papers from the purple and blue clusters, despite having high citation counts (e.g., Berg & Vance, 2017; Merchat et al., 2014; Moro et al., 2017; Radianti et al., 2020), exhibit very low coupling intensity (≤ 6 total link strength).

3.3 Co-citation and co-occurrence analysis

To identify the most relevant topics within the thematic focus of the investigation, two techniques were employed: co-citation analysis and co-occurrence analysis of keywords. Co-citation analysis examines how often different publications are cited together, while co-occurrence analysis of keywords looks at the frequency of word sets and the conceptual connections between them.

For co-citation analysis, a minimum of 90 citations was used as a criterion, which was met by 18 items (see Fig. 4). This analysis generated three sets of co-citations based on authors who are frequently cited together. Notable among these are the co-citation intensities of publications by Cabero (total link strength 1082) and Barroso (total link strength 888), both from the University of Seville, as well as Mayer (total link strength 849) and Makransky (total link strength 807), from the University of California and the University of Copenhagen, respectively.

Regarding the co-occurrence of descriptors, the analysis of a sample of 1,257 articles revealed that authors proposed 3,268 keywords, and the articles were indexed with 4,334 keywords, totaling 6,719 keywords. Among these, 54 keywords appeared together more than 30 times in the articles within the sample (see Fig. 5). This resulted in the creation of four co-occurrence clusters, based on the frequent joint appearance of these keywords.

The descriptors with the highest frequency include the Boolean terms “virtual reality” (728) and “augmented reality” (354). These are followed by terms related to the sample, such as “human” (333), “humans” (240), “female” (175), and “male” (164). Notably, terms associated with the educational process, like “learning” (114) and “teaching” (108), as well as research elements such as “questionnaire” (65), “controlled study” (157), and “human experiment” (74), are also prominent. Additionally, factors relevant to the study’s focus, such as “motivation” (37) and “anxiety” (43), are important, as well as the inclusion of these elements in educational plans through the “curriculum” (30). Elements related to educational technology and its development, such as “e-learning” (136), “computer simulation” (32), “technology” (38), and “immersive virtual reality” (37), are also highlighted.

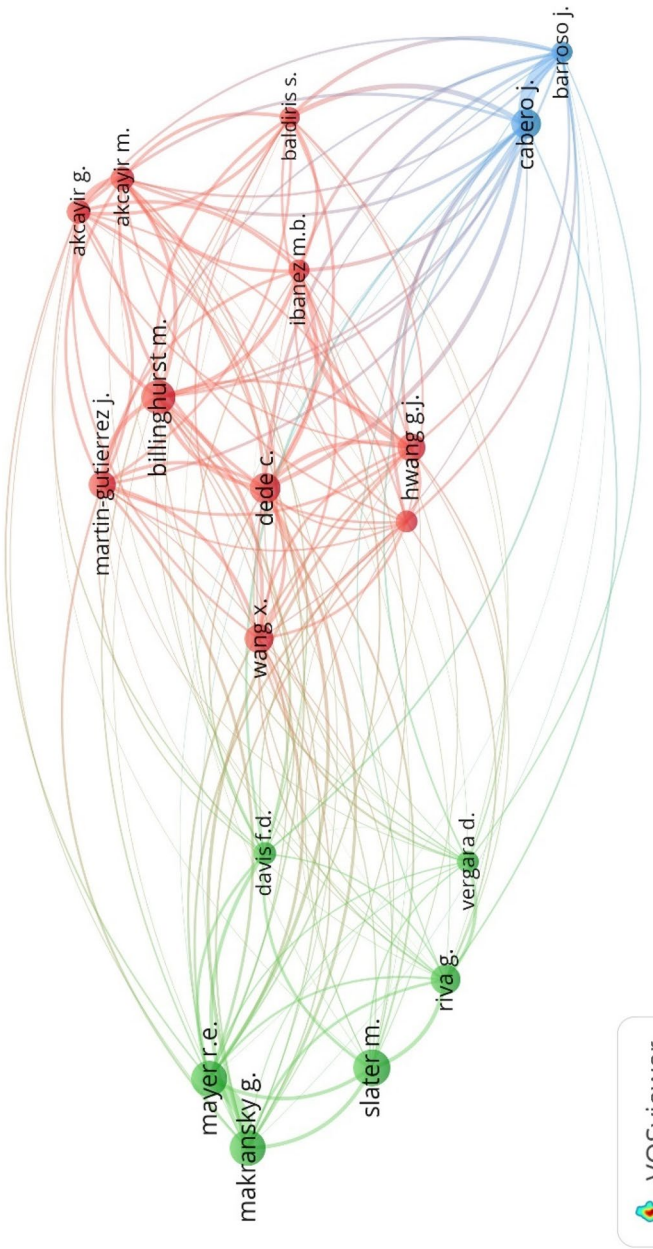

Fig. 4 Co-citation with "authors" as unit of analysis

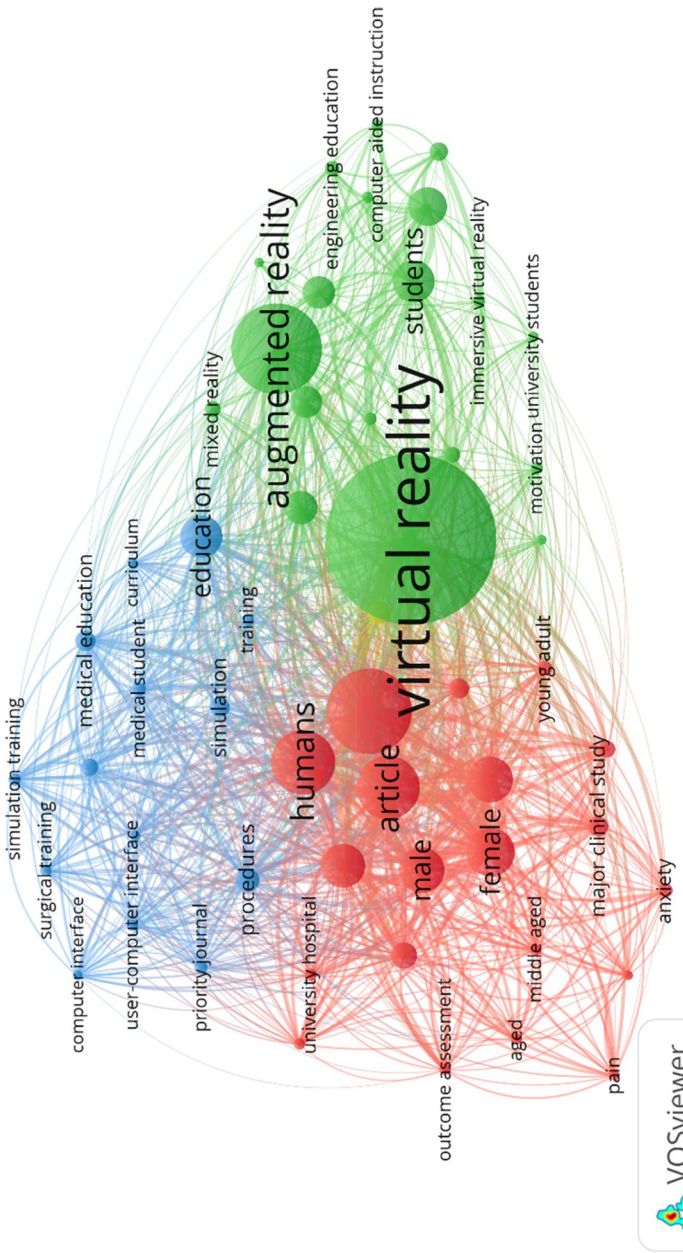

Fig. 5 Concurrence of keywords in scientific production

4 Discussion and conclusions

The bibliometric analysis of scientific production highlights the peak of virtual and augmented reality in the academic environment. These technologies are continually evolving, drawing in new researchers, and fostering collaborative efforts among scientists. This has led to numerous research avenues that are expected to be explored further in the future.

The results indicate that virtual and augmented reality have become increasingly established topics in the academic world, with a notable surge in research over the past five years, comprising 84.01% of the analyzed articles. Social sciences, engineering, and medicine are the primary fields with the highest number of related publications. Spanish researchers are particularly prominent among the leading authors, with established research teams such as those from the Catholic University of Avila (Vergara, Fernández-Arias, and Antón-Sancho) and collaborations between the universities of Seville (Sevilla [Cabero and Barroso] and Pablo de Olavide [López-Meneses]) and UNED (Vázquez-Cano). Notable exceptions include Makransky from Denmark and Del Maestro from Canada. The most prolific journals are those specialized in virtual and mixed reality, as described by Bradford's Law (1934). These journals predominantly cover the field of educational technology, though there is also notable representation from science and medicine, reflecting the indexing areas. The United States and China lead in research production, with Spain ranking third, largely because seven of the nine most prolific authors in this field are based there. Spanish universities, especially those in Seville, are also at the forefront of scientific production. An exception is the Tecnológico de Monterrey, which ranks highly despite Mexico not being among the top-producing countries and its authors not being among the most prolific. In terms of impact and relevance, the most cited articles extend beyond meta-analyses (e.g., Merchat et al., 2014) and systematic reviews (e.g., Akçayir & Akçayir, 2017; Radianti et al., 2020). They primarily focus on the use of augmented and virtual reality in the teaching of health sciences at the higher education level (e.g., Akçayir et al., 2016; Makransky et al., 2019a). This emphasis helps explain why the field of medicine is frequently indexed in these publications.

When considering the most influential authors cited in key studies on the topic, the work of Makransky and his team stands out. Their contributions include research on how virtual reality increases student attendance in science laboratories (Makransky et al., 2019a), the emotional impact of virtual reality on student learning (Makransky & Lilleholt, 2018), and the differences between using virtual reality at home as opposed to the classroom (Makransky et al., 2019b). Also noteworthy is the research by Akçayir, which focuses on the use of augmented reality in science laboratories (Akçayir et al., 2016), as well as the highly cited systematic review on augmented reality by Akçayir & Akçayir (2017).

In the co-citation analysis, the notable contributions of Cabero and Barroso are evident. Their work primarily focuses on the use of augmented reality with university students, covering areas such as educational sciences (2019b) and medicine (2017), as well as mixed reality for teaching mathematics to architecture students (2021). Similarly, Meyer and Makransky are highlighted for their research on the impact of virtual reality in laboratories and the differences between its application in the classroom versus at home (Makransky et al., 2019a, 2019b). Given that Boolean terms have

defined the core themes of research in this field, the teaching process—both face-to-face (Alfalah, 2018; Cooper et al., 2019; Marks & Thomas, 2022) and online (Baabdullah et al., 2022; Saidani et al., 2021; Saleem et al., 2023)—as well as learning with immersive technologies (Makransky & Petersen, 2019; Mystakidis et al., 2022; Shen et al., 2019), is a predominant focus among key studies. Additionally, two key themes related to the learning process stand out in the context of virtual and augmented reality, both of which increasingly impact cognitive abilities. First, motivation plays a crucial role in enhancing interest in learning. This has been observed with both virtual reality (Hu, 2023; Kapustina & Zikeeva, 2021; Lin & Wang, 2021) and augmented reality (Cabero-Almenara & Roig-Vila, 2019; Chin et al., 2019; Laurens-Arredondo, 2022; Lin & Wang, 2023). Second, there has been significant research into how training programs using virtual and augmented reality can address various types of anxiety (Barabanschikov & Selivanov, 2023; Ghasempeyvandi & Torkan, 2023; Selivanov et al., 2023; Tatlı & Karadağ, 2023; Xu et al., 2021). This research not only explores the potential benefits for learning but also examines variables that might have a negative impact and require careful management.

This study has helped identify key works and authors in the field, as well as established and emerging research trends. Moving forward, scientific progress in virtual and augmented reality should focus on consolidating new topics while building on existing evidence. Virtual and augmented reality are now well established within the realm of digital resources. To fully harness their potential, it is essential to invest in infrastructure, resources, training, and research.

One limitation of studying scientific production is the exclusion of publications from various databases, particularly major international ones like Web of Science, ERIC, or Scielo. While this may appear to be a limitation, it is important to note that the decision was made to avoid potential duplication of records and to ensure the quality of indexing criteria provided by Scopus, which helps ensure that the sample is representative of the study phenomenon. Additionally, changing the time frame of the sample could have affected the observed results. Narrowing the focus to only the most recent research might have highlighted current trends, while expanding the timeframe could have included foundational studies that influenced the field over the past decade.

Future research could enhance the analysis of scientific production by incorporating additional analytical techniques. Complementing this study with a systematic review that targets specific areas of university knowledge would be beneficial. For instance, focusing on the field of education could involve examining the impact of virtual and mixed reality on learning processes, including variables such as academic performance, motivation, and student attention levels. Additionally, investigating emerging topics could further consolidate our understanding of virtual and augmented reality in these areas.

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Authors' contributions
Conceptualization: ECM; Data curation: ACA; Formal analysis: ECM; Investigation: ECM and ACA; Methodology: ACA; Software: FDGG; Supervision: JRP; Validation: JRP and FDGG; Visualization: JRP and FDGG; Writing – original draft: ECM, and ACA; Writing – review & editing: JRP and FDGG.

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Declarations

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