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Bibliometric Review on the Application of Holograms in Immersive Environments in the Context of University Teaching, 2013-2023

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Abstract. Higher education institutions are making use of augmented reality and virtual reality to generate immersive environments and improve student understanding. However, other technologies, such as holograms, allow for immersion in more realistic scenarios, helping to reduce certain negative effects associated with the prolonged use of so-called mixed realities. Therefore, it is important to use bibliometric indicators to analyze the scientific production regarding the application of holograms in immersive environments in the context of university

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teaching, in order to identify gaps and trending topics that will contribute to guiding future research. The study followed a quantitative, descriptive approach to analyze studies extracted from the Scopus database. The results obtained show a growing trend in scientific production between the years 2020 and 2023, with 73.81% of reviewed publications being concentrated in that period; this is significantly higher than that which had been produced in previous years. Furthermore, the trending topics identified included Integrating Holograms in Mixed Reality for Immersive Learning and Applying Holograms for Spatial Understanding in Engineering. Thus, it can be concluded that the application of holograms in certain specialties of university education remains limited, indicating that there is a gap in thematic areas that must be covered and addressed in future studies; for example, the application of holograms in social sciences and humanities subjects, the integration of holographic technology into the curricular plan in mathematics and science subjects and the use of digital holography in medical education.

Keywords: holograms; immersive environments; learning; university; bibliometric review

1. Introduction

The phenomenon of digital transformation has given rise to the accentuated management of technologies with the aim of optimizing the teaching-learning process (Barráez-Herrera, 2022); in particular, that corresponding to the creation of immersive, multisensory 3D ecosystems (Galea, 2023). The flexibility and adaptability of these technologies have revolutionized both teaching and learning (Zambrano et al., 2023). Therefore, there is a growing need to rethink educational models in order to provide students with creative, problem solving, and technical-scientific skills (Ortiz, 2023; Gutiérrez, 2022). Thus, the concept of the virtual environment is highlighted, providing an interactive graphic database that is explorable and viewable in real time, represented in the form of three-dimensional images capable of provoking a sensation of immersion (Solórzano & Rueda, 2023; Acero, 2018). In the field of virtual environments, immersion can be achieved through visual representation and interaction with narratives made possible through digital technologies (Carrizo, 2021; Torres & Rodríguez, 2019). Immersive learning consists of activities that allow users to immerse themselves in an artificially constructed world called a virtual environment, which resembles reality (Ayala et al., 2020).

Extended reality is a comprehensive term used to describe environments that combine both physical and virtual dimensions or provide fully immersive virtual experiences, with the most commonly used technologies being augmented reality and virtual reality (Bojórquez, 2022; Cuan, 2023). Mixed reality allows for a combination of the real world and the virtual world within a digital environment, making it easier for the user – in this case the student – to interact with the content dynamically in real time (Marín-Díaz, et al., 2022; González et al., 2022). The environment is one in which people can interact in cyberspace through avatars or icons, which are practically identical, logical, non-physical representations of themselves, in the form of holograms (Coromoto, 2023; Olmos, 2022). However,

the ecosystem of mixed realities differs significantly in terms of their processing capabilities and interaction modality; therefore, interoperability becomes a barrier that can hinder the widescale adoption of platforms and experiences, especially if the intention is to integrate holographic communications within it (Arevalillo-Herráez et al., 2022).

The further development of the technique used to produce and project holograms has created remarkable potential for their use as a teaching medium (León et al., 2018; Arrollo & Tulcanaza, 2022). A hologram is the result of the holography process (Ortega et al., 2022), which is associated with the capture of reality that, when luminously projected onto a transparent object, generates a three-dimensional effect (Ochoa, 2018; Gonzáles, 2023); the same one is directly related to augmented reality, since it tries to recreate an object in a real environment (Morales, 2022). It is a representation of an object or person far away from us that is superimposed on our reality (Aretio, 2019). Thus, holograms allow students to carry out scientific experiments or practices that are considered risky, expensive or very difficult in real life, by using simulations, which provide a facsimile of the actual experience (Ríos-Castillo et al., 2022).

In a strictly educational context, holograms can be used to emulate the physical presence of the teacher in the physical space inhabited by the students, in order to generate a closer approach and more fluid communication (Sarobe et al., 2023). The hologram can be considered as a teaching medium since it represents a collaboration between the teacher and the student in the content formation process (Ruiz et al., 2021). It also contributes to enhancing the intrinsic motivation of students, thereby rendering them more predisposed towards learning (Orcos et al., 2018). This is due to the students feeling that the element being studied is really present, and that it is not simply a representation (Zúñiga et al., 2020). It should be noted that the hologram has various didactic functions such as cognitive, communicative, informative, motivating and integrative, all functions involved in the comprehensive development of the student (Beteta-Serrano et al., 2021). Therefore, there is an urgent need to develop the discussion of pedagogical models based on the experiential, and to incorporate the use of holograms as part of the teacher's didactic strategies (Ariñes, 2019).

Consequently, the purpose of this article is to identify the trends in scientific production on research regarding the application of holograms in immersive environments in the context of university teaching. This will be achieved through the bibliometric analysis of publications indexed in the Scopus database during the period between 2013 and 2023. This review article adopts a quantitative analysis, through which it seeks to describe thematic areas that are being addressed in the field of knowledge relating to the use of hologram technology in the teaching process in higher education institutions. Thus, this study seeks to contribute significant insights regarding the current knowledge of emerging topics as well as understudied topics, providing guidance and enabling decisions to be made concerning the topics that should be addressed regarding this field of study. Furthermore, this study represents a basis of knowledge as a foundation of research for the future development of systematic review or meta-analysis

studies, providing information on the number of publications in different areas of the field of study. In this sense, and in order to achieve the aforementioned objective, the following research questions (RQ) have been defined.

- RQ1: What has been the trend of scientific production and what types of publications are being developed on the application of holograms in immersive environments in the context of university teaching?
- RQ2: What are the bibliographic sources with the greatest number of publications and which studies are the most cited regarding the application of holograms in immersive environments in the context of university teaching?
- RQ3: What is the trend of published topics on the application of holograms in immersive environments in the context of university teaching?

2. Methodology

2.1 Analysis of data

This bibliometric review study has been developed following a quantitative approach, with bibliographic data being analyzed to identify trends in scientific production through descriptive statistical methods, evaluating annual scientific production, frequency of publication production by type of bibliographic source, as well as bibliographic sources with the greatest number of publications and with the highest impact index, word trends and bigrams used to a greater extent in titles, keywords and summaries of publications on the application of holograms in immersive environments in the context of university teaching. According to Mamani-Jilaja et al. (2023), such a study is developed under a quantitative and descriptive approach because real numerical data is used, which will be subjected to a statistical analysis to describe a problem that has been posed.

Another aspect worth noting is that the publications were extracted from the Scopus database because it is a repository of large volumes of publications regarding studies on hologram technology and its application in educational environments; furthermore, all publications have been subjected to peer evaluation and a rigorous selection process for indexing in this database. As Aranibar (2022) points out, the Scopus database houses research that has been evaluated with rigor and severity from various scientific journals.

In relation to data analysis and processing, the software tools Bibliometrix and VOSviewer were used. This is because they provide management and reporting environments that easily allow for the creation of bibliometric tables and graphs on files generated from different databases. In this regard, Gutiérrez and Gómez-Rudy (2024) point out that the Bibliometrix and VOSviewer software allows for generating graphic results related to bibliometric networks from data files in formats extracted from various repositories such as Scopus.

2.2 Inclusion and exclusion criteria

The inclusion and exclusion criteria defined for the development of this bibliometric review study were established with the purpose of reducing bias in the selection of publications regarding the application of holograms in immersive environments in the context of university teaching. These criteria ensured that the

selected publications focused on the context of the study; that is, the publications focused strictly on the field of higher education rather than the initial, primary or secondary levels. Another aspect considered was the time frame; in this case, it was considered convenient to work with studies that had been published within the last 10 years, to prevent the inclusion of publications that describe outdated applications of the current context in which higher education is developed. Table 1 shows the inclusion and exclusion criteria considered for the selection of scientific publications.

Table 1: Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Scientific publications that focused on the application of holograms in immersive environments in the field of higher education	Scientific publications that focused on the application of holograms in immersive environments in the field of initial, primary or secondary education.
Scientific publications developed during the years 2013 to 2023	Scientific publications developed prior to 2013
Scientific publications for which bibliometric indicators are available	Scientific publications for which bibliometric indicators are restricted
Publications defined as scientific articles, conference papers, conference reviews, books, book chapters and review articles	Publications defined as letters to the editor, patents, or scientific newsletters

2.3 Data extraction method from scientific publications

The method used to extract scientific publications is an adaptation based on the method validated by Harnal et al. (2023) in their bibliometric review study, which was developed taking into account the PRISMA method (Preferred Reporting Items for Systematic reviews and Meta-Analyses). In this method, four stages are defined that guarantee rigor and lead to the extraction of bibliographic data based on the inclusion and exclusion criteria defined for the study. The use of this method initially led to identifying the publications, which were generated by defining the following search equation for use in the Scopus database: ((TITLE-ABS-KEY (holograms) AND TITLE-ABS-KEY (education))). In this first phase, 278 publications were extracted. In the second "Screening" phase, the inclusion and exclusion criteria were applied, which sought to restrict the study to those publications that are aligned with the objective and the research questions. In this second phase, 196 publications were identified as a result of the inclusion criterion referring to the period in which the studies were published. Following this, when the other criteria were applied, 56 publications remained. In the third phase, eligible publications were identified following a review of the alignment of the study topic with the title and summaries of the publications selected in the previous phase. In this way, 42 publications were selected. The fourth phase, or data analysis phase, consists of extracting bibliometric data and analyzing it based on and in accordance with the research questions. Figure 1 shows the method used for data extraction.

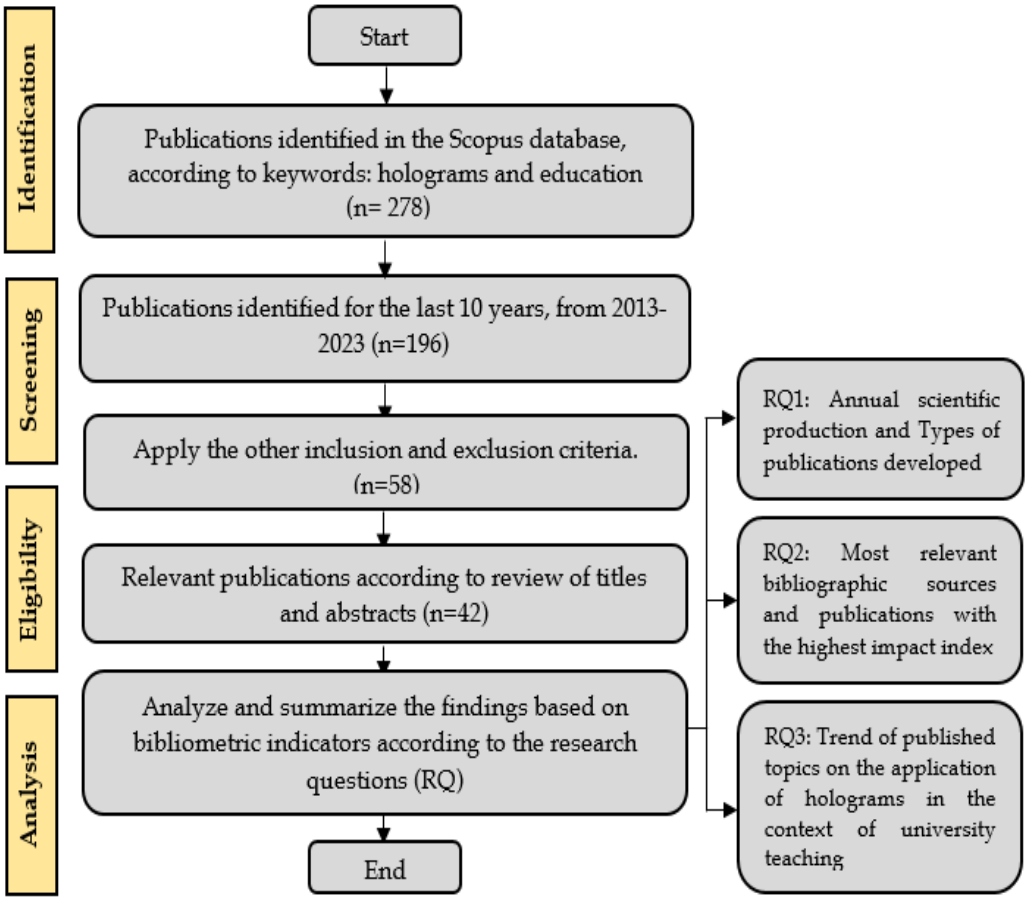

Figure 1. Method used for data extraction

3. Results

3.1 Trend of scientific production and types of publications developed on the application of holograms in immersive environments in the context of university teaching

In relation to the trend of scientific production regarding the application of holograms in immersive environments in the context of university teaching, it was identified that of a total of 42 publications produced between 2020 and 2023, a growing trend is evident in the production of studies which exceeds the annual average. That is, between the years 2013 and 2019, on average two studies were developed per year; however, between the years 2020 and 2023, this average increased significantly to eight studies per year. Figure 2 shows the annual distribution of scientific production, which identifies the percentage of publications between the years 2020 to 2023, representing 73.81%. This concentration of publications within this period is higher than the 26.19% that was generated between the years 2013 and 2019. These results clearly show that before the COVID-19 pandemic, and in an attempt to provide continuity to the university educational service, various researchers sought to contribute through various applications such as hologram technology to providing immersive environments

that, through virtual reality and augmented reality, allow for a better understanding of the theoretical concepts.

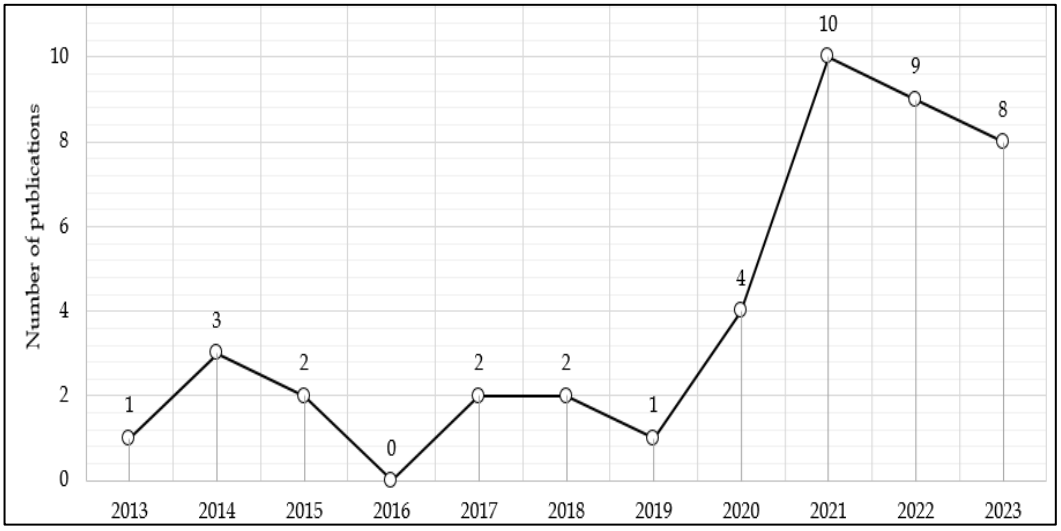

Figure 2. Annual distribution of scientific production

Similarly, in relation to the types of publications that were developed from 2013 to 2023 regarding the application of holograms in immersive environments in the context of university teaching, it was identified that of the 42 publications, 20 were scientific articles, 17 were conference papers, two were book chapters and three were review articles. Figure 3 shows the percentage distribution by type of publications, obtained from the Scopus data source, which clearly shows that there is a very significant gap between the production of "scientific articles" and "conference papers" with respect to the scientific production of "review articles" and "book chapters". This margin between the types of publications indicates the need to undertake more review studies that contribute to mapping the state of the art, and to establish the existing gaps in the thematic areas regarding the use of holograms in the field of university education.

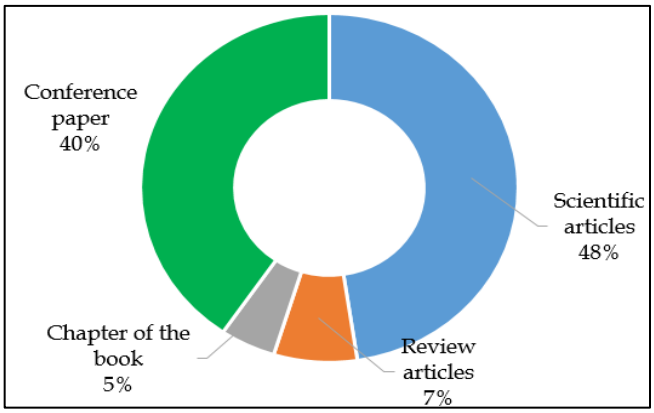

Figure 3. Percentage distribution by type of publications

3.2 Bibliographic sources with the greatest number of publications and most cited studies regarding the application of holograms in immersive environments in the context of university teaching

In relation to the most relevant bibliographic sources on the application of holograms in immersive environments in the context of university teaching, it was identified that the publications under analysis corresponded to 42 scientific sources, of which 20 were Journals, 15 were Conference Proceedings, 5 were Book series and 2 were Books. Thus, it was also identified that the two sources with the highest number of publications in the study period, from 2013 to 2023, were "Proceedings of SPIE - The International Society for Optical Engineering" and "Lecture Notes in Networks and Systems", with four and two publications, respectively. Table 2 shows the most relevant scientific sources on the topic under study, which highlights that the bibliographic source with the highest h-index, according to Scimago Journal Rank (SJR), was "Computers and Education" with a value of 215, located in quartile Q1.

Table 2: Most relevant sources according to number of publications, impact h-index and SJR quartile

Bibliographic source	h-Index	Total number of publications	Scimago SJR Quartile 2022
Proceedings of SPIE - The International Society for Optical Engineering	187	4	not yet assigned a quartile
Lecture Notes in Networks and Systems	27	2	Q4
2019 9th IEEE Integrated STEM Education Conference, ISEC 2019	7	1	not yet assigned a quartile
2022 Advances in Science and Engineering Technology International conferences, ASET 2022	-	1	-
Academic and Digital Libraries: Emerging Directions and Trends	-	1	-
Advances in Intelligent Systems and Computing	58	1	not yet assigned a quartile
AIP Conference Proceedings	80	1	not yet assigned a quartile
Anatomical Sciences Education	64	1	Q1
Annales Mathematicae et Informaticae	14	1	Q4
Computers and Education	215	1	Q1
Educational Media International	44	1	Q1
Fringe 2013 - 7th International Workshop on Advanced Optical Imaging and Metrology	8	1	not yet assigned a quartile

In relation to the 42 studies or publications under analysis, it was identified that 10 studies were cited more than seven times. On the other hand, 20 of the manuscripts have not been cited at all. The table shows the 10 most cited studies, of which the three with the highest number of citations are "Technologies for the future of learning: state of the art"; "The effect of auto-stereoscopic holograms on anatomical knowledge: a randomized trial" and "Future mixed reality educational spaces" with 51, 32 and 30 citations, respectively. These results reveal a base of studies or existing knowledge that supports the construction of new and innovative studies regarding the use of holograms in university education; this is

because the numbers of citations indicate that these studies remain significant for contemporary research.

Table 4. Studies with the highest numbers of citations

Scientific study	Total citations	Author
Technologies for the future of learning: state of the art	51	Hernandez-De-Menendez et al. (2020)
The effect of autostereoscopic holograms on anatomical knowledge: a randomized trial	32	Hackett & Proctor (2018)
Future mixed reality educational spaces	30	Campbell et al. (2017)
5G Joint Artificial Intelligence Technology in the Innovation and Reform of University English Education	23	Sun (2021)
The Effectiveness of an Augmented Reality Head-Mounted Display in Learning Skull Anatomy at a Community College	21	Duncan-Vaidya & Stevenson (2021)
The potentials and trends of holography in education: A scoping review	12	Yoo et al. (2022)
My Teacher is a Hologram: Measuring innovative STEM learning experiences	11	Paredes & Vasquez(2019)
Augmented Reality in Radiology for Education and Training - A Design Study	10	Raith et al. (2022)
On the Hologram of International Education	8	Mestenhauser et al. (2015)
Application of the technical - pedagogical resource 3D holographic LED-fan display in the classroom	8	Prado et al. (2020)

3.3 Trend of published topics on the application of holograms in immersive environments in the context of university teaching

In relation to the trend of published topics on the application of holograms in immersive environments in the context of university teaching, in a first analysis using the data processing tools provided by the Scopus database, it was possible to identify the percentage distribution of publications by area of study. Thus, it was determined that the three thematic areas with the greatest number of publications are concentrated in Computer Science studies, with 22.7%, Engineering, with 17.5%, and Social Sciences, with 17.5%. These results imply that research on the use of hologram technology in education is applied to a greater extent in these areas; that is, in engineering education, or in areas of social sciences, analyzing levels of satisfaction or acceptance of the use of this technology in the teaching and learning process. However, we can also identify the areas with much lower concentrations of publications that have been analyzed for this bibliometric review study, the most notable being the areas of medicine and arts and humanities, with 4.1% and 2.1%, respectively. Figure 4 shows the percentage distribution of publications by subject area, according to Scopus.

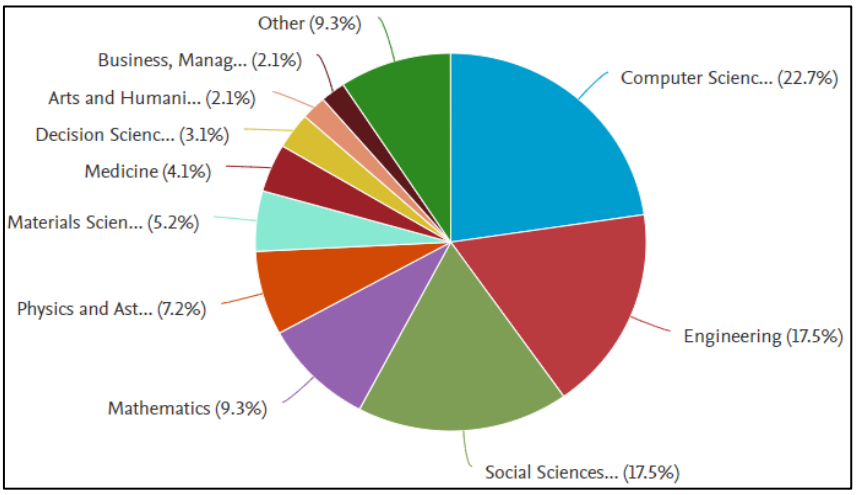

Figure 4. Percentage distribution of publications by subject area

After gaining an initial impression of the thematic areas addressed by the publications under analysis, the Bibliometrix software was used in order to identify the trends regarding the frequency of occurrence of the most used words in the titles of the publications, with the words "Holograms" and "students" having had an increasing trend between the years 2013 and 2023; both words occurred 14 times in the titles of the studies developed during the year 2023. Similarly, other words that have shown a lesser trend of growth during the time frame of study in this bibliometric review were "Engineering education" with eight occurrences, "education" with seven occurrences and "learning" with seven occurrences, in relation to the year 2023. Figure 5 shows the trend in the frequency of occurrence of words in the titles of the manuscripts.

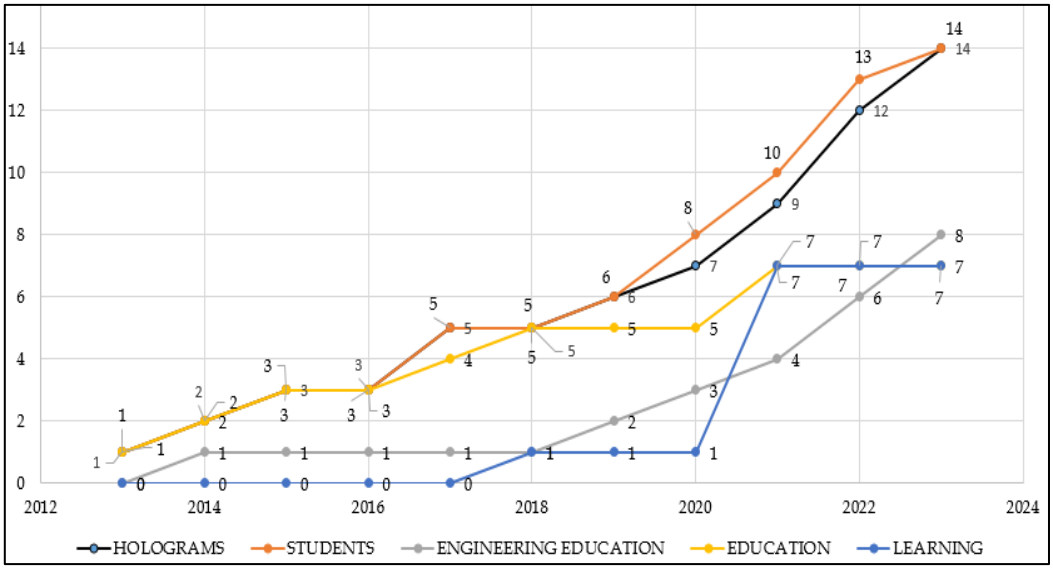

Figure 5. Trend of word occurrences in manuscript titles

Other analyses on the publications under study were performed using the VOSviewer software, making it possible to identify the co-occurrence networks between the keywords, identifying the ways in which they were associated with each other and highlighting the degree of frequency or repetition of these

associations through the size of the nodes. In this network it was possible to identify that the keywords with the greatest link strength were “holograms”, “education” and “students”, with values of 31, 32 and 35, respectively. It was also identified that the keywords presenting the least link strength were “engineering education”, “mixed reality”, and “augmented reality”, whose values were 19, 16 and 13, respectively. Figure 6 shows the co-occurrence network between keywords used in the publications under analysis. This demonstrates the interdisciplinarity of the topics that make use of hologram technology in immersive environments in higher education.

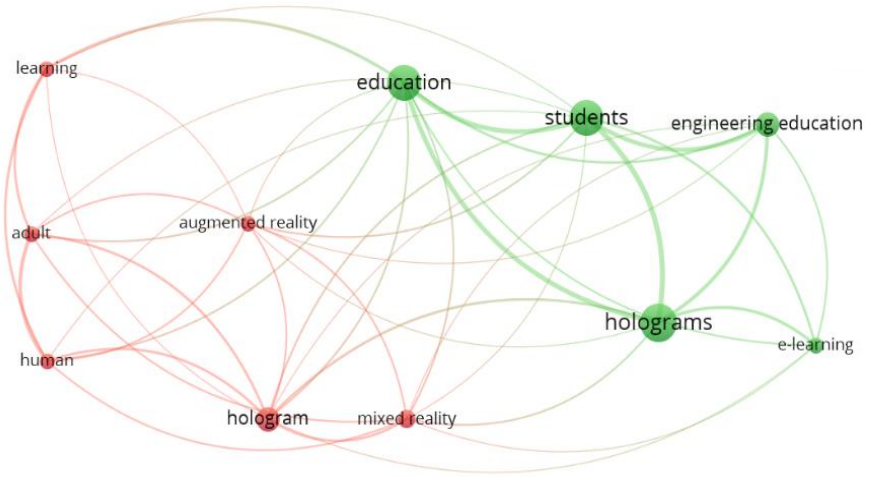

Figure 6. Co-occurrence network obtained from the keywords of the publications

Another aspect to take into account in the analysis of co-occurrence among the keywords in the publications studied is that shown in Figure 7, which illustrates the temporal aspect defined by the horizontal bar in which the colors represent gradients ranging from blue to yellow, indicating that the keywords with the greatest link strength in 2019 were “holograms”, “education”, “students”, “e-learning”. On the other hand, in 2021, the keywords with the greatest strength of association were “hologram”, “augmented reality” and “mixed reality”.

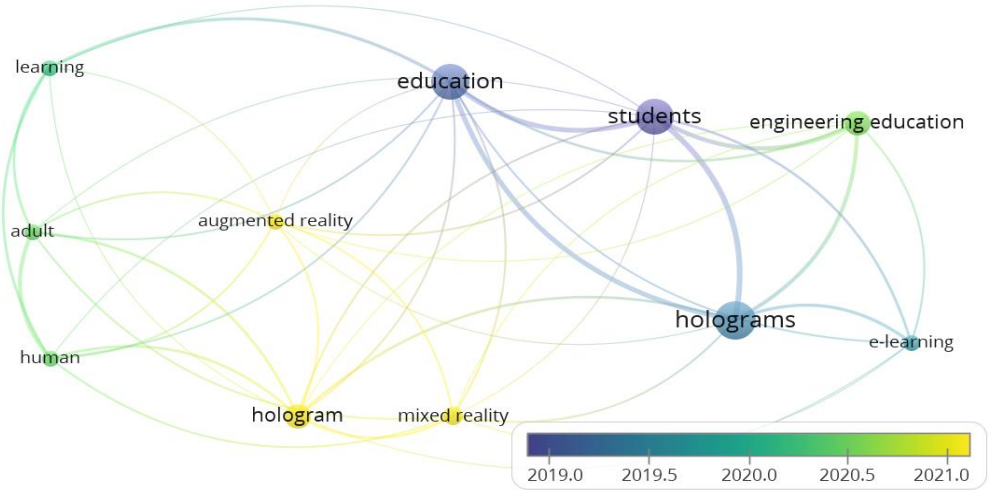

Figure 7. Co-occurrence trend between keywords

4. Discussion

A growing trend of scientific production on the application of holograms in immersive environments within the context of university teaching is evident between 2020 and 2023, with the production of studies reaching an average greater than seven manuscripts per year, consisting of 73.81% of the publications in that period, significantly higher than that which was produced between 2013 and 2019. In their study of trends in the applications of holograms in education between the years 2011 and 2021, Yoo et al. (2022) identified a total of thirty-one publications, noting that there has been an increasing trend of scientific interest regarding this field of study in recent years. Furthermore, Barkhaya and Halim (2016), in their study reviewing the use of holograms in education between 2005 and 2015, managed to identify only 10 publications. Despite being carried out over different periods of time, these two investigations concur with the growing trend of manuscripts being produced in recent years, particularly since 2020. This suggests that one of the reasons for this increasing trend has been the need to find alternative means of achieving the continuity of university educational services; thus, many new studies sought to demonstrate the importance of the application of hologram technology in immersive environments as well as the ways in which these contribute to improving learning and provide a better understanding of the theoretical concepts. In this regard, Haleem et al. (2020) point out that hologram technology currently represents a disruptive innovation that has contributed significantly to various fields including medicine, education, engineering, graphic design and art; its use became even more relevant in the context of virtual teaching due to the pandemic.

The most relevant bibliographic sources on the application of holograms in immersive environments in the context of university teaching were identified as the two sources with the highest number of publications in the study period, from 2013 to 2023. These were "Proceedings of SPIE - The International Society for Optical Engineering" and "Lecture Notes in Networks and Systems", with four and two publications, respectively. In this regard, it is evident that there is not a high concentration of publications by any scientific journal or bibliographic source, leading us to establish that the field of knowledge requires greater attention, and a greater number of investigations is needed to contribute to the literature on university education. In their review of the use of holographic technology in education, Barkhaya and Halim (2016) point out that although there are applications in different areas of the educational field, this technology remains in its initial phase. Similarly, Ninković and Adamov (2023), in their study on the perception of the usability of hologram technology in higher education institutions, point out that there has yet been limited scientific production; although it is true that in recent years there has been a growing tendency towards a greater number of studies, it remains significantly lower, for example, than its application to the natural sciences, despite its high potential for use in the field of education. Aligned with this view, Katsioloudis and Jones (2018) point out that holographic technology allows for creating ideal three-dimensional virtual environments for learning, known as augmented reality, which manage to immerse the student in an artificial scenario that improves the learning experiences.

In relation to the trends of the topics published on the application of holograms in immersive environments in the context of university teaching, it was possible to identify the following words as having a higher frequency of occurrence in the titles of the publications and, in turn, a higher co-occurrence among them: "holograms", "education", "students", "engineering education", "mixed reality" and "augmented reality". Thus, it is established that the trending topics are "Integration of holograms in mixed reality for immersive learning" and "Application of holograms for spatial understanding in engineering". In their review study on the use of holography in education, Ramachandiran et al. (2019) conclude that technological progress is evident in the use of this technology in the educational field, particularly in engineering learning, because it facilitates the student to gain a better understanding of three-dimensional models, which guarantees the improvement of the teaching-learning process. Similarly, Turk and Seckin-Kapucu (2021), in their study on the use of holographic technology in the learning of science subjects, point out that this technology contributes significantly to students' understanding of topics such as the solar system. However, they further recommend that this technology could also be useful in other subject areas, such as mathematics. In the same vein, Elmarash et al. (2021) reviewed the use of holographic technology in education and established that this technology optimizes the visualization of complex concepts and assists students in their learning by ensuring that they understand complex concepts in subject areas such as engineering.

5. Conclusion

In relation to the trend regarding scientific production and types of publications that have been developed on the application of holograms in immersive environments within the context of university teaching, from an analysis of the manuscripts from the Scopus database, a growing trend was identified in the production of studies between 2020 and 2023, reaching an average of more than seven manuscripts per year, representing 73.81% of the publications in that period; this was significantly higher than that which was produced from 2013 to 2019. In addition to the total number of publications reviewed, it was found that 48% were scientific articles, 40 were conference papers, 7% were review articles and 5% were book chapters. Similarly, in relation to the most relevant bibliographic sources, it was possible to identify that the two sources with the highest numbers of publications between the years 2013 and 2023 were "Proceedings of SPIE - The International Society for Optical Engineering" and "Lecture Notes in Networks and Systems", with four and two publications, respectively. This reveals that there is not a high concentration of publications by any scientific journal, so it is possible to establish that this field of knowledge requires greater attention. Finally, in relation to the trends of the topics that have been published on the application of holograms in immersive environments within the context of university teaching, it was identified that the topics covered by the studies are linked to the "Integration of holograms in mixed reality for immersive learning", and the "Application of holograms for spatial understanding in engineering. Therefore, these findings lead us to conclude that there is a gap in thematic areas that must be urgently addressed in future studies,

such as "Application of holograms in social sciences and humanities subjects", "Integration of holographic technology to the curricular plan in mathematics and science subjects" and "Use of digital holography in medical education."

6. Limitations of the research

This review study on the application of holographic technology in immersive environments within higher education was strictly focused on the analysis of bibliometric indicators regarding scientific production in the Scopus database; therefore, it did not address related aspects concerning the ways in which the implementation can be developed, nor the implementation of this technology within the classroom. It is necessary to specify that the study was limited to publications in which holographic technology was used, so words such as components, infrastructure, implementation and installation of holographic technology were not considered in the publication search equation. Therefore, it is recommended that future research should focus on systematic review studies as well as meta-analyses regarding these unaddressed topics, based on the knowledge obtained in this study.

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