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Augmented reality as an educational tool in higher education: A literature survey

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ABSTRACT

Augmented Reality (AR) represents a promising technological advancement that this paper explores as a potential new educational tool. The integration of augmented reality applications into mobile devices facilitates interactive learning experiences for users. This integration transforms traditional printed educational materials into dynamic, interactive resources, aiming to enhance learner engagement, motivation, and overall educational outcomes. However, comprehending research trends and decision-making in this rapidly evolving field presents significant challenges. To address these challenges, this paper employs Bibliometrics, a method involving statistical and quantitative analysis of publications. Although augmented reality holds significant potential for higher education, limited studies have focused on its application, and scant attention has been given to bibliometric visualization. To bridge this gap, the paper utilizes VOSViewer, a bibliometric visualization software incorporating advanced machine learning techniques. The objective is to delineate the evolving landscape of augmented reality research from 2002 to the present and identify key research categories. Following an overview of the software's functionality, artificial intelligence, and machine learning concepts, the study progresses to its practical stage. The research involves the retrieval of publications related to augmented reality from the Scopus bibliographic database, resulting in the identification of 730 relevant publications. After their retrieval, the paper conducts a comprehensive statistical analysis and employs VOSViewer for further processing. The culmination of the study involves the construction of bibliometric maps, visualizing keywords and terms extracted from the titles and abstracts of international scientific journal publications. The analysis of these maps yields valuable insights, observations, and conclusions, contributing to a better understanding of the current state and trends within the augmented reality research landscape. This approach facilitates informed decision-making and provides a foundation for future developments in the educational sector leveraging augmented reality technology conclusions.

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INTRODUCTION

Augmented Reality (AR) is an increasingly influential tool within a range of promising technologies. As Kipper and Rampolla (2013) noted, AR has evolved significantly over the decades, becoming a prominent feature in today's technological landscape. This technology finds applications across various sectors, including advertising, navigation, sightseeing, entertainment, gaming, and education (Milgram et al., 1994). Lee (2012) highlights that numerous major companies utilize AR for visualization, education, and other purposes, integrating it to enhance product advertising and customer service. In the realm of navigation, AR provides valuable, real-time information. For instance, apps like Yelp and NRU help users locate places to eat, drink, and shop by offering visual directions (Kipper and Rampolla, 2013). In sightseeing, AR has the potential to enrich user experiences by displaying fascinating digital information and animations about places, events, or characters. A notable example is the Museum of Modern Art in New York City, which, in 2010, used AR technology to allow visitors to view hidden exhibitions through a dedicated AR app for iPhones and Android phones. Today, specially designed AR apps are available for tourism, entertainment, and gaming, enhancing the user experience by integrating the physical and digital worlds in real-time. These applications demonstrate AR's versatility and its ability to provide users with unique, interactive experiences that go beyond traditional media. As AR technology continues to develop, its role in various industries is expected to expand, offering innovative solutions and improved services to consumers.

The entertainment industry generates billions of dollars annually, as highlighted by Kipper and Rampolla (2013). This immense financial success is driven by producers and entertainers who constantly strive to enhance the audience's experience and surpass their expectations (Watson et al., 2018). As new technologies continually emerge, the traditional concept of entertainment is being redefined and expanded. Among these advancements, augmented reality (AR) stands out for its potential to revolutionize the entertainment landscape. AR applications offer a unique, interactive experience by allowing users to engage with entertainment elements in ways previously unimaginable (Javornik, 2016 a&b; Poushneh, 2018; Bonetti, Warnaby, and Quinn, 2018).

Moreover, AR-enabled games have become widely accessible on both mobile devices and desktops, providing an immersive experience that blends digital and physical realities. This technological evolution is not confined to entertainment alone but extends to the realm of education as well. The proliferation of mobile devices and tablets, equipped with internet access, is transforming educational methodologies (Azuma, 1997; Azuma et al., 2001). These devices enable the integration of AR into educational settings, offering interactive and engaging learning experiences that go beyond traditional methods. As AR technology continues to develop, its impact on both entertainment and education is poised to grow, offering innovative ways to engage and educate audiences.

The integration of various technologies in educational environments has the potential to simplify complex information, motivate learners, and actively engage them in the learning process. For instance, students tend to interact more with digital smart boards compared to traditional blackboards, highlighting the effectiveness of modern tools in education (Klopfer and Sheldon, 2010; Milgram et al., 1994; Dacko, 2017). Among these innovations, augmented reality (AR) stands out for its ability to create highly interactive and engaging learning environments. AR empowers learners to take control of their education by interacting with digital objects within a real-world context.

As an advanced teaching tool, AR can be effectively utilized in classrooms to enhance the learning experience. Research has shown that AR technology can significantly boost student motivation and improve educational practices that emphasize realism (Lee, 2012). By making abstract concepts tangible and interactive, AR helps students understand and retain information more effectively. Balkun (2011) further underscores the importance of not only providing learners with access to digital media but also teaching them to use technology thoughtfully, creatively, and collaboratively.

Integrating augmented reality and other advanced technologies into educational environments aligns with the objective of utilizing cutting-edge learning strategies to enhance student engagement. These tools offer enriched learning experiences by providing access to information and materials that are otherwise difficult to obtain. AR offers

unique opportunities for experiential learning, where students can explore and manipulate digital content in ways that traditional methods cannot replicate. This approach fosters a more dynamic and immersive learning environment, ultimately leading to better educational outcomes. By leveraging AR and similar technologies, educators can create a more inclusive and stimulating educational experience that prepares students for a technologically advanced world.

The primary goal of this paper is to review and identify significant literature on the application of Augmented Reality (AR) technology in higher education. The research was conducted through a three-step process. Initially, relevant articles were meticulously selected. Following this, the gathered information was carefully extracted and interpreted. Finally, visualization tables and maps were created to illustrate the findings. The research framework is built upon the synthesis of information from existing literature. This review focuses exclusively on articles published between 2002 and November 2023. All selected articles are written in English, and a thorough examination of their abstracts, keywords, and titles was conducted to ensure relevance and accuracy.

The development of augmented reality technology is advancing rapidly, and its applications are expanding across numerous scientific fields. This, however, makes decision-making and understanding research trends and related AR literature initiatives particularly challenging. The solution is the application of Bibliometrics, the statistical and quantitative, i.e., publication analysis. Few such studies on the application of augmented reality in higher education can be found, and little attention has been paid to bibliometric visualization. Therefore, with the assistance of VOSViewer, a bibliometric visualization software that uses sophisticated machine learning techniques, an attempt is made to outline the field of knowledge and to identify the main categories of research in the period from 2002 to date.

The paper is organized as follows; the next section delves into a comprehensive literature review of Augmented Reality (AR) technology. Beginning with a conceptual overview, it traces the developmental stages, draws comparisons with Virtual Reality, and provides a succinct overview of AR devices. Subsequently, the chapter scrutinizes the role of augmented reality as an educational tool, elucidating its benefits and pinpointing the challenges inherent in its implementation. Moving to the next section, the research methodology is outlined, accompanied by a primer on the software and an elucidation of technical terms related to bibliometric maps. The chapter details the process of extracting map-relevant information, explores various map display methods, and introduces the kernel method, a key technique employed by VOSViewer software. Then, section four unveils the outcomes of the bibliometric analysis, describing the methodology behind bibliometric map production and listing the publications constituting the map database. A statistical analysis ensues, followed by the presentation of bibliometric maps, keywords, and terms, with comprehensive listings and various display options. Lastly, Conclusion encapsulates the paper's conclusions, highlighting aspects that will contribute to future research endeavors.

TRANSFORMATIVE IMPACT OF AUGMENTED REALITY IN EDUCATION

Educational technology is reshaping the dynamics of teaching and learning, ushering in a new era of enhanced classroom experiences. The integration of advanced technological tools as educational aids has become a hallmark of the contemporary educational environment, manifesting changes across short, medium, and long-term horizons. Augmented Reality (AR), initially perceived as a medium-term prospect in education, now stands at the forefront of innovative educational applications, demanding swift adoption by educators to harness its full potential. AR seamlessly integrates into mobile devices and tablets, providing an interactive dimension to user experiences (Lee, 2012). This technology elevates printed materials, transforming them into engaging and motivating resources that stimulate student interaction. AR applications exhibit the versatility to enrich various textual formats, including books, documents, textbooks, magazines, journals, newspapers, pamphlets, posters, Adobe Portable Document Format (PDF) documents, and digital photographs. The overarching objective is to convert static text into dynamic, interactive content, forging a seamless convergence between the physical and digital realms.

The definition of augmented reality is nuanced, influenced by its application and the domain it serves. Vogt and Shingles (2013) highlight AR's evolution from an emerging concept to an established technology, while Wu et

al. (2013) emphasize its technological aspect, defining it as a form of virtual reality with a transparent screen providing a clear view of the real world. A broader perspective, as suggested by Vogt and Shingles (2013), characterizes AR as the fusion of live images with virtual information layers encompassing 3D models, content, images, sounds, and videos. Crucially, AR distinguishes itself from virtual reality by adding virtual content to a real environment, instead of creating a predominantly virtual space.

Augmented Reality (AR) can be broadly categorized into two main types: location-based AR and image-based AR. Location-based AR leverages the spatial position and orientation of a device to deliver information pertinent to the user's specific location. This type of AR is particularly useful for navigation and geolocation services. On the other hand, image-based AR relies on sophisticated image recognition algorithms to overlay relevant digital content onto recognized physical patterns or images. This form of AR is commonly used in applications where interaction with specific objects or visual markers is required (Vogt and Shingles, 2013).

The transformative potential of AR extends to creating a new learning environment, enabling students to interact with the real world in novel ways (Lee, 2012). Through AR, images, objects, and physical locations come alive with interactive digital content such as videos, animations, and 3D scenes, elevating the learning experience. The ability for teachers and students to generate and share their AR content opens innovative and challenging avenues for learning (Koutromanos, Sofos, and Avraamidou, 2015). Today's tech-savvy students, accustomed to smart technology, are primed for the seamless integration of AR in the classroom. The applications of AR are diverse and extensive, with many freely available apps compatible with various materials, necessitating only an internet connection and a built-in camera for enhanced interaction. In recent years, augmented reality has garnered significant attention, underscoring its potential as a transformative force in education (Wu et al., 2013).

As educational institutions navigate this technological frontier, educators must swiftly adapt to the evolving landscape of AR to unlock its manifold benefits. This paper will explore the multifaceted impact of augmented reality on education, investigating its role in transforming pedagogical practices, enhancing student engagement, and addressing the challenges associated with its implementation. Through a detailed exploration of the literature, research methodologies, and practical applications, this study aims to provide a comprehensive understanding of the current state of augmented reality in education and its potential for shaping the future of learning.

In the realm of educational technology, Augmented Reality (AR) stands out as a transformative tool that seamlessly integrates virtual images with the real world, effectively bridging the gap between the tangible and the digital (Lee, 2012). This advanced technology has the potential to revolutionize teaching environments in diverse formats, serving multiple educational purposes and enhancing the overall learning experience.

A compelling example of AR's application in education is evident in the creation of "Cyberchase Shape Quest," an AR application developed by PBS Kids exclusively for tablets (available at: http://pbskids.org/cyberchase/). This application serves as an engaging math-focused game, targeting geometry, spatial thinking, and problem-solving skills. By employing a printable game board, students are prompted to point their tablet cameras at the board, causing materials and characters to materialize, effectively intertwining real-world and digital content. The fusion of a touchscreen interface with AR technology offers students a fully interactive visual experience, allowing them to touch, rotate, and examine geometric shapes from various perspectives, thereby deepening their comprehension of geometry vocabulary.

Vogt and Shingles (2013) introduced two specific manifestations of AR: augmented posters and augmented articles. Integrating AR into posters, articles, or plain text contributes to a more nuanced understanding of complex data presentations. These alternative visualization methods incorporate interactive 3D models, videos, and animations, facilitating improved communication and data interpretation. Notably, even PDF documents now have the capability to incorporate animated 3D models, whether in digital or print format (Vogt and Shingles, 2013). In essence, AR serves as a catalyst for transforming static text into a more interactive and dynamic format. The pivotal role of technology in enabling AR makes these applications seamlessly integrable into both formal and informal

educational settings, promoting interaction with physical materials and objects while establishing location awareness. AR applications exhibit diverse features, ranging from videos with accompanying audio to additional information accessible through active URLs or embedded animations. Some applications even integrate buttons for actions such as email communication or sharing information on social media platforms like Facebook or Twitter. This not only enhances the interactive experience but also facilitates easy sharing of results among learning groups, thereby improving the quality and effectiveness of communication (Vogt and Shingles, 2013).

The integration of AR with social media platforms has garnered considerable attention, with Vogt and Shingles (2013) asserting that AR provides the ability to instantly connect and share scientific data and publications through social media. Social media platforms emerge as powerful drivers for expanding the use of AR, amplifying its reach and impact. AR applications represent the next frontier of interfaces, offering a revolutionary approach to interacting with information (Santos et al., 2014). Beyond merely presenting images, animations, or videos, AR applications function as comprehensive tools. Educational researchers have recognized the myriad opportunities for teaching and learning facilitated by AR, emphasizing its potential to redefine the educational landscape (Wu et al., 2013). Implementing AR in the classroom elevates the teaching and learning process to a new echelon, empowering students to explore diverse topics and environments within the confines of the classroom (Wu et al., 2013). By seamlessly bridging the virtual and real worlds, AR creates an enhanced and augmented reality, as aptly described by Bower et al. (2014). Students, in turn, appreciate how AR technology enables their participation in activities that would otherwise be inaccessible, underscoring its ability to democratize and enrich the educational experience.

MATERIALS AND METHODS

The data for this research was sourced from existing literature, providing the foundational information for the study. This information was crucial in constructing the framework of the research. Additionally, bibliometric analysis was employed to quantify scientific research and conduct qualitative evaluations. Through this method, data related to scientific publications is recorded and processed, enabling the derivation of specific bibliometric indicators. These indicators help quantify researchers' contributions within their scientific fields. Furthermore, bibliometric analysis identifies the interaction between scientists and various research areas, offering insights into their broader scientific activities. This approach allows for a comprehensive understanding of any given scientific topic. It provides a macro-level view of researchers' activities and collaborations, revealing patterns and trends within the scientific community. The fields of computer science and library science frequently utilize bibliometric analysis to evaluate research output and impact. This method supports a holistic evaluation, facilitating a deeper understanding of scientific endeavors and their interconnectedness across different disciplines.

The objective of this study was to conduct a bibliometric analysis of literature related to augmented reality (AR), present the findings through bibliometric maps, and draw meaningful conclusions. The research utilized articles published in the "Scopus" database, chosen for its comprehensive features and user-friendly tools that streamline the bibliometric analysis process. Scopus, owned by Elsevier (The Netherlands), is a universally recognized and reliable electronic database. Its widespread use is attributed to its extensive coverage of peer-reviewed scientific literature and a substantial number of citations. The study leveraged this robust database to ensure the accuracy and depth of the analysis. Common bibliometric indicators employed in this analysis include metrics such as citation counts, h-index, and journal impact factors, which provide insights into the influence and reach of scientific publications within the AR research community. Through this method, the study aimed to map out the landscape of AR research, identify key trends, and evaluate the contributions of various researchers and institutions in the field.

This study was conducted through a systematic three-step process. Initially, relevant articles were meticulously identified. Following this, the extracted information was carefully analyzed and interpreted. In the final step, visualization tables and maps were created to represent the data. The research framework was constructed based on insights derived from a comprehensive review of existing literature, focusing on articles published between 2002 and November 2023. All selected articles were in English, and their abstracts, keywords, and titles were thoroughly reviewed. Publications containing the terms "Augmented Reality" and "Higher Education" in the title, keywords, or

abstract were identified, resulting in a database of 730 publications. The collected data included details such as authors' names, article titles, journal names, years of publication, countries, and keywords, all of which were recorded using Microsoft Excel. The primary goal was to identify journal articles within the database that specifically addressed the intersection of augmented reality and higher education. To visualize the data, bibliometric maps were created using VOSviewer, a tool designed for constructing and viewing bibliometric networks. These maps provided a visual representation of the relationships and trends within the collected data, offering valuable insights into the research landscape of augmented reality in higher education. This systematic approach enabled a thorough analysis and a clear visualization of key findings and trends in the field.

RESULTS AND DISCUSSION

In this section, the results of the bibliometric analysis are presented. The following options were used to search the publications: (TITLE-ABS-KEY (augmented AND reality) AND TITLE-ABS-KEY (higher AND education)) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")) AND (LIMIT-TO (LANGUAGE , "English")), i.e. the relevant literature was searched with: Keywords: augmented AND reality and higher AND education, Publication type: journal articles and conference proceedings and Article language: English. The number of publications was 730 articles which were the sample of the survey. Statistical data were then extracted from the Scopus website and from the VOSviewer application with data concerning title, abstract and keywords.

Distribution of articles by year

The first year that the term "Augmented Reality" and its application in "Higher Education" appeared in the Scopus database was 2002. That year only one article was published. By 2016 the number of publications did not exceed 25. However, in the last 7 years the number of publications has increased significantly (Figure 1).

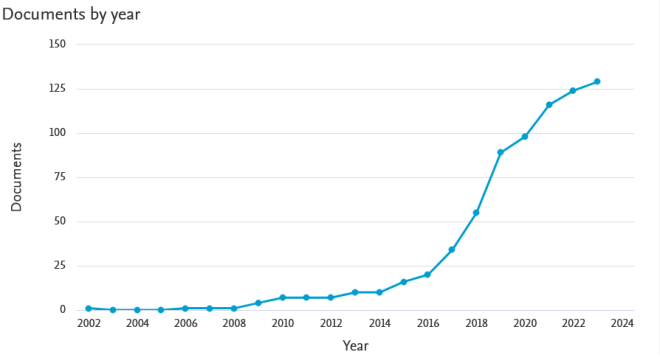

Fig. 1. Distribution of scientific articles by year - source: Scopus.

Distribution of articles by type

The sample consisted of approximately equivalent articles published in journals (388/ 53.2%) and conference proceedings (342/46.86%) (Figure 2).

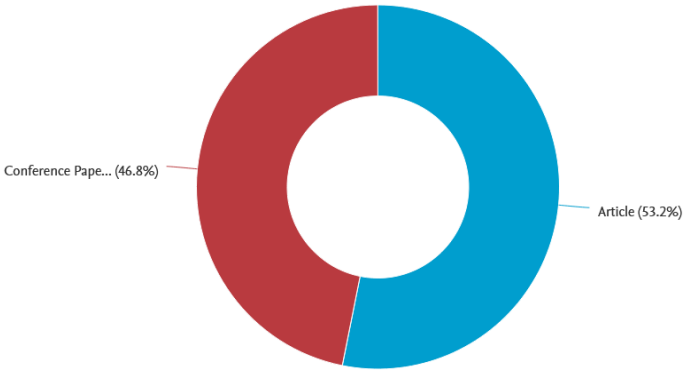

Fig. 2. Percentage of articles by type.

Authors' countries with publications on the implementation of AR in higher education

The 10 countries of authors who published research on the implementation of AR in higher education are presented in the figure below.

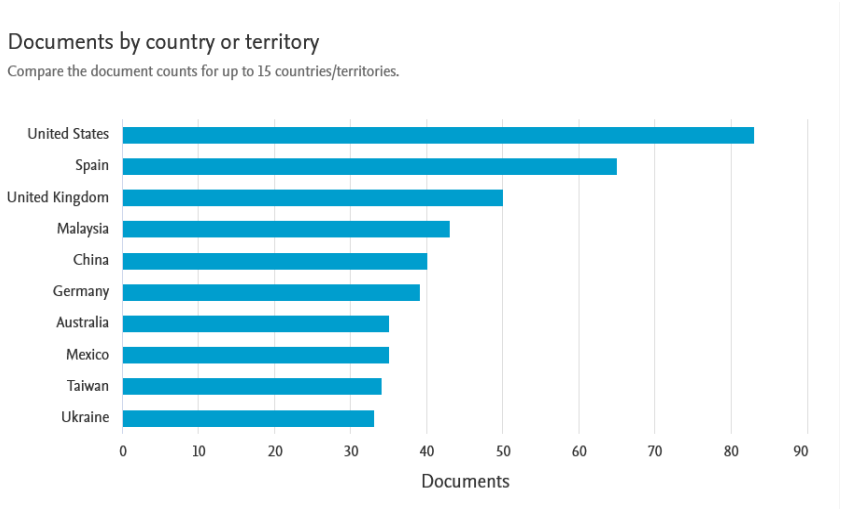

Fig. 3. Productivity of articles by country.

The most frequent keywords of the 730 articles

A bibliometric map was generated to analyze the keywords sourced from a comprehensive database comprising 730 articles. The chosen method of analysis employed co-occurrence, encompassing all keywords found across the publications as focal points within the map. This visual representation, rooted in bibliographic data, was crafted using VOSviewer software, selected for its capability to construct and depict bibliometric networks effectively. In constructing the map, the relevance of individual items is determined by their frequency of co-appearance in publications. To ensure meaningful representation, a minimum threshold of 10 occurrences per keyword was set, given the extensive dataset. Through visual inspection of the map, one can derive insights into semantic similarities between keywords and identify cohesive clusters. The spatial proximity of keywords within the map reflects their conceptual closeness, with closely positioned words indicating higher thematic relevance and similarity. Conversely, words positioned farther apart are less pertinent to the central themes explored in the research. The initial bibliometric map delineates clusters to which keywords from the 730 publications belong, offering a visual snapshot of their distribution and density across thematic domains. Figure 4 below illustrates the visualization of keyword density on the bibliometric map, providing a clear depiction of how keywords are distributed and clustered based on their co-occurrence patterns within the literature. This visual representation serves as a pivotal tool in understanding the structural composition and thematic focus of the scholarly landscape encompassed by the dataset.

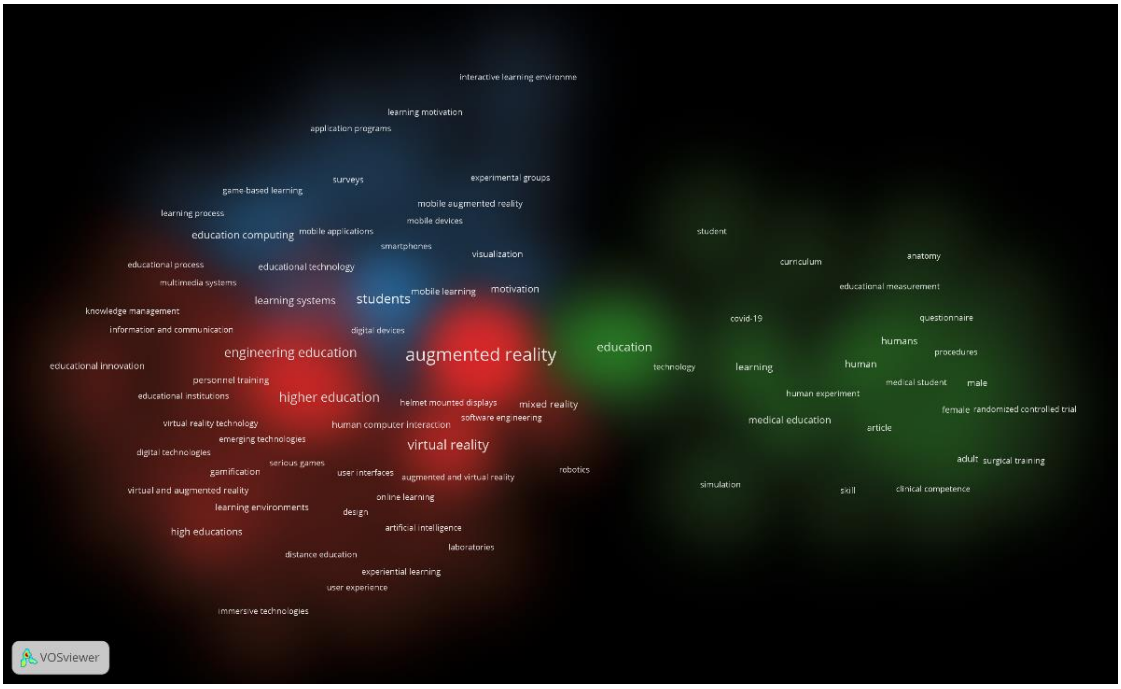

Fig. 4. The most frequent keyword clusters.

The keywords extracted from the articles were categorized into four distinct clusters. To assess the outcomes of this keyword clustering, Table 1 was compiled. The table features three columns: the first column displays the designated color representing each cluster, the second column lists the cluster name along with the count of articles included, and the third column details the keywords associated with each cluster. This structured presentation provides a comprehensive overview of how keywords are grouped according to their thematic similarities across the analyzed literature.

Table 1. All keywords for the clusters.

Color	Cluster	Key words (ascending alphabetical order)
	Cluster 1 Technology (45 items)	application programs, artificial intelligence, augmented and virtual realities, computer aided instruction, design, digital devices, digital technologies, distance education, e-learning, educational innovation, educational innovations, educational institutions, educational process, educational technology, emerging technologies, engineering education, experiential learning, extended reality, gamification, helmet mounted displays, high educations, higher education, higher education institutions, higher school, human computer interaction, immersive, immersive technologies, industry 4.0, information and communication technologies, interactive learning environments, internet of things, knowledge management, laboratories, learning environments, learning experiences, mixed reality, multimedia systems, online learning, personnel training, professional aspects, robotics, serious games, software engineering, systematic review, teachers, teaching and learning, user experience, user interfaces, virtual reality, virtual reality technology, visualization.
	Cluster 2 (Higher) Education (28 items)	adult, anatomy, article, clinical competence, comparative study, controlled study, covid-19, curriculum, education, educational measurement, female, human, human experiment, humans, learning, male, medical education, medical student, procedures, questionnaire, randomized controlled trial, simulation, skill, student, surgical training, teaching, technology, young adult.
	Cluster 3	3d modelling, application programs, augmented reality applications, augmented reality technology, curricula, education computing, experimental groups, game-

	Applications/ Tools (23 items)	based learning, interactive learning environment, learning motivation, learning process, learning systems, mobile applications, mobile augmented reality, mobile devices, mobile learning, motivation, smartphones, students, surveys, three dimensional computer graphics.
	Cluster 4 (3 items)	professional aspects, robotics, software engineering.

By observing the keywords (items) per cluster we can conceptually name AR Technology as the 1st cluster, AR Education as the 2nd cluster and AR Tools in Education as the 3rd cluster (the 4th cluster can be integrated into the previous ones). The results are considered as expected according to the literature survey.

Following the clustering of objects, the map was generated and showcased in all available formats within the software. Figure 5 illustrates the network visualization where colors denote the respective clusters to which the objects are assigned. The size of each object corresponds to its frequency of appearance across the literature encompassing 730 publications. This visual depiction offers insights into the distribution of thematic clusters and highlights the prominence of specific keywords based on their frequency of occurrence in the analyzed scholarly works.

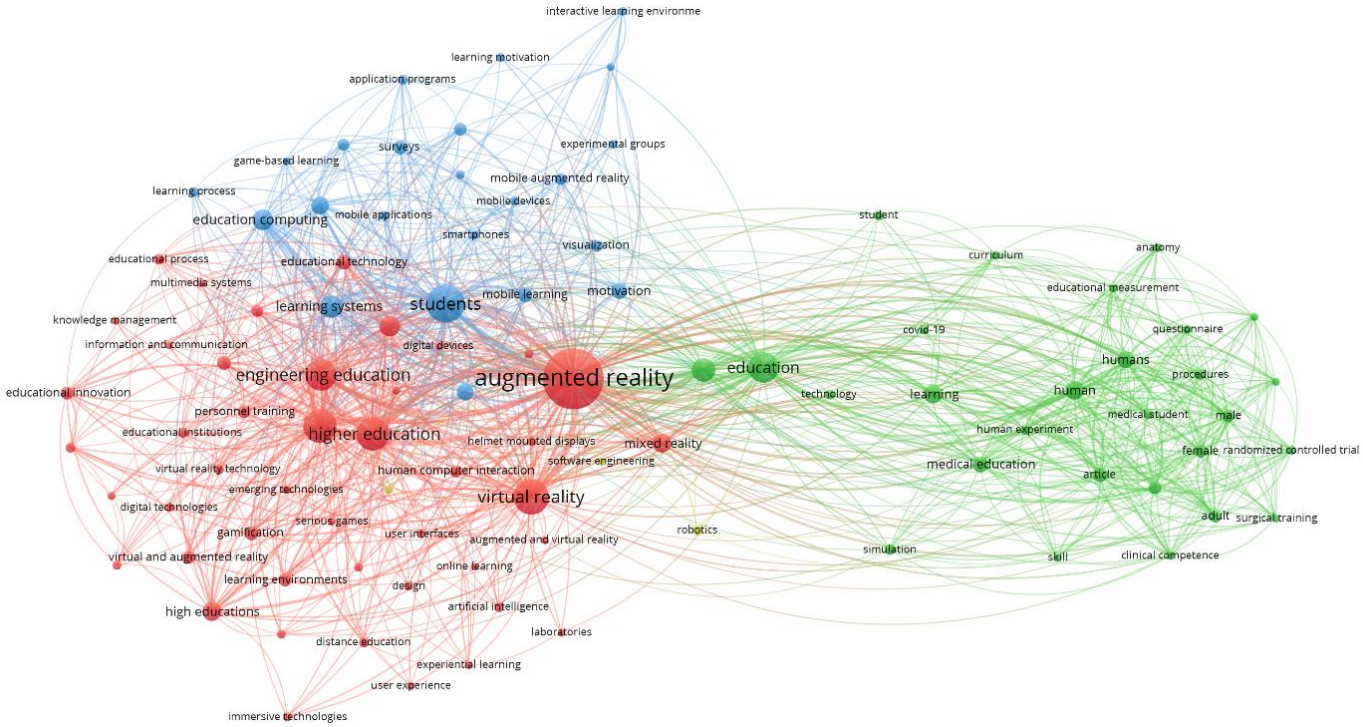

Fig. 5. The most frequent keywords of visualization networks.

This visualization presents an overlay of the bibliometric keyword map, utilizing a unique feature that integrates a scoring mechanism based on a common attribute—in this case, the year of publication for each keyword. This overlay capability allows for a nuanced analysis of how keywords are distributed over time within the map. In the object density view, the background is depicted in a deep blue hue. Areas illuminated in yellow indicate higher density and are determined by both the number of keywords present and their respective weights. The shading of an area tends towards a brighter yellow when keywords within it carry greater weight and when the concentration of keywords is higher. This visual representation offers a dynamic perspective on the temporal evolution of themes within the literature, showcasing areas where certain keywords have proliferated or gained prominence over specific periods. It serves as a valuable tool for identifying trends and patterns in scholarly discourse across the dataset, contributing to a deeper understanding of the temporal dynamics underlying the research landscape.

CONCLUSION AND RECOMMENDATION

The primary aim of this study was to systematically identify and analyze relevant literature pertaining to the application of Augmented Reality (AR) technology within the educational sphere, with a specific focus on higher education. To achieve this objective, a meticulous procedure was employed. Initially, pertinent articles were meticulously sourced and extracted from the Scopus database. Subsequently, information derived from these articles, along with data obtained through the utilization of VOSViewer software, was extracted, interpreted, and culminated in the creation of visualization tables and maps. The research framework's elements were comprehensively examined based on the amalgamation of existing literature, with a specific inclusion criterion of articles published between 2002 and November 2023, all of which were in English.

Based on the findings of this bibliometric analysis, several useful insights have emerged. Firstly, the analysis highlights the importance and usefulness of augmented reality (AR) as an educational tool in higher education. These results (cluster 1 in Table 1) are consistent with similar research and bibliometric analyses (Elnaqlah, Jamiat, and Madi, 2023; Akçayır et al., 2016), as well as case study/ application (clusters 2 and 3 in Table 1) research (Nordin, N., Nordin, M., and Omar, 2022; Södervik et al., 2021; Kwiatek et al., 2019). AR technology is increasingly recognized as a powerful educational tool in higher education due to its capacity to:

- Enhance learning experiences, engagement, motivation, collaboration, communication, knowledge retention, and understanding.
- Create immersive and active learning environments with interactive content.
- Support other educational tools and paradigms such as distance learning, gamification, virtual reality, and various real-world applications.
- Facilitate complex problem-solving.

This study reveals that AR technology continues to evolve, and its potential to transform educational practices and outcomes in higher education is immense, making it a valuable tool for educators and students alike. This technology offers immersive and interactive learning experiences, personalized instruction, and access to opportunities that may not be feasible in traditional classroom settings. Although there are challenges to implementing AR, academic institutions should consider the benefits and explore ways to integrate it into their teaching practices.

Moreover, the findings of the annual search for articles on AR technology's application in higher education revealed a limited number of publications from 2002 to 2016. This trend underscores the initial lack of interest, not in the technology itself, but specifically in its adaptation to support higher education. A noteworthy surge in articles post-2016 indicates a paradigm shift, highlighting the considerable potential of AR applications in higher education, with a predominant focus on case studies and best practices. The core emphasis of the literature review revolved around the concepts of "Augmented Reality" and "Higher Education." The review showcased a balanced distribution of articles between journals (53.2%) and conference proceedings (46.86%). While unexpected, this distribution can be partially attributed to the exclusion of book chapters in the search process.

Two highly cited papers emerged: 1) "Advantages and challenges associated with augmented reality for education: a systematic review of the literature" by Akçayır M. and Akçayır G., and 2) "A systematic review of immersive virtual reality applications for higher education: design elements, lessons learned, and research agenda" by Radianti J., Majchrzak T.A., Fromm J., and Wohlgenannt I. Notably, the majority of top-cited articles were published in the journal Computers and Education. Geographically, the research map exhibited a concentration in countries like the USA, Spain, UK, Germany, Australia, and China, while unexpected contributors included Malaysia, Mexico, and Taiwan. Greece, however, displayed a relatively moderate to low research output.

The analysis of article keywords led to their categorization into four clusters. Cluster evaluation revealed that the first cluster focused on the technological aspects of AR itself, the second cluster related to the educational process and its key stakeholders, and the third cluster encompassed tools, technologies, and means of AR implementation in

higher education. The fourth cluster, with only three items, was deemed negligible and excluded from further consideration. This comprehensive examination sheds light on the multifaceted landscape of AR in higher education, providing insights into its growth, impact, and global research patterns.

A bibliometric map was generated to conduct a more in-depth study of the keywords within the database. The selected analysis method was co-occurrence, encompassing all keywords from the publications as map objects. This map, grounded in bibliographic data, encapsulates the keywords from 730 articles. The distances between circles reflect keyword relevance; the closer two keywords are, the more frequently they co-occur and, thus, are deemed more relevant. Links between items, depicted by curved lines, express the degree of relevance. According to the bibliometric map, the central keyword is 'augmented reality,' occupying the largest area and affirming the search's validity. Notably, 'engineering education,' a topic of significant interest, is the second-largest circle following augmented reality, with 'education' being approximately equivalent.

An intriguing inclusion is the phrase 'medical education,' indicating that the primary application fields are within the scientific realms of 'engineering' and 'medicine.' Examining the density illustration reveals blue-contoured areas with few or no objects, while illuminated yellow clusters denote areas with higher object density. The central keyword 'augmented reality' is surrounded by few objects but strongly illuminated, signifying its paramount weight and influence on the map. The next most highlighted keywords are 'students' and 'virtual reality,' suggesting extensive research or a probable comparison between the two technologies.

It is essential to acknowledge the study's limitations, confined solely to the Scopus database. Renowned databases like Science Direct, Springer, and Wiley were not considered. Additionally, only journal articles and conference proceedings were examined, excluding chapters in books, volumes, and reports. Furthermore, the analysis focused exclusively on English-published articles, neglecting those in other languages such as German, Chinese, or Spanish. Future research prospects involve expanding the bibliometric analysis to other databases and document types. Specific scientific areas, like engineering, medicine, and pharmaceuticals, could be scrutinized, along with an exploration of best practices.

REFERENCES

Akçayır, M., Akçayır, 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, *Computer Human Behavior*, 57, 334-342.

Azuma R. (1997). A survey of augmented reality, *Presence: Teleoperators and Virtual Environments*, 6(4), 355-385.

Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2001). Recent advances in augmented reality. *Computer Graphics and Applications IEEE*, 21(6), 34-47.

Balkun, M. (2011). Teaching with digital media: Widening the framework. *Transformations*, 22(1), 15-24.

Bonetti, F., Warnaby G., & Quinn, L. (2018). *Augmented Reality and Virtual Reality in Physical and Online Reatilng: A Review, Synthesis and Research Agenda, Augmented Reality and Virtual Reality*, pp.119-132, Springer International Publishing: Switzerland.

Bower, M., Howe, C., McCredie, N., Robinson, A., & Grover, D. (2014). Augmented reality in education cases, places and potentials. *Educational Media International*, 51(1), 1-15.

Buckingham, D. (2007). Media education goes digital: An introduction. Learning, *Media and Technology*, 32(2), 111-119.

Chiang, T. H. C., Yang, S. J. H., & Hwang, G.-J. (2014). An Augmented Reality-based Mobile Learning System to Improve Students' Learning Achievements and Motivations in Natural Science Inquiry Activities, *Education Technological Society*, 17(4), 352-365.

Chiu, L, DeJaegher, J., & Chao, J. (2015). The effects of augmented virtual science laboratories on middle school students' understanding of gas properties, *Computer Education*, 85, 59-73.

Dacko, S.G. (2017). Enabling smart retail settings via mobile augmented reality shopping apps. *Technological Forecasting and Social Change*, 124, 243-256.

Elnaqlah, A., Jamiat, N., & Madi, T. (2023). Augmented reality in higher education: a 10-year systematic literature review, *Journal of Theoretical and Applied Information Technology*, 101, 6495-6511.

Hsiao, H.-S., Chang, C.-S., Lin, C.-Y., & Wang, Y.-Z. (2016). Weather observers: a manipulative augmented reality system for weather simulations at home, in the classroom, and at a museum, *Interactive Learning Environment*, 24(1), 205-223.

Javornik, A. (2016a). Augmented reality: Research Agenda for Studying the Impact of its Media Characteristics on Consumer Behaviour. *Journal of Retailing and Consumer Services*, 30, 252-261.

Javornik, A. (2016b). It's an Illusion, but it looks Real! Consumer Affective, Cognitive and Behavioural Responses to Augmented Reality Applications. *Journal of Marketing Management*, 32(9), 987-1011.

Kipper, G. & Rampolla, J. (2013). *Augmented reality: An emerging technologies guide to AR*. Waltham, MA: Elsevier.

Klopfer, E. & Sheldon. J. (2010). Augmenting your own reality: student authoring of science-based augmented reality games. *New Directions for Youth Development*. 128 (2010), 85-94, 10.1002/yd.378

Koutromanos, G., Sofos, A., & Avraamidou, L. (2015). The use of augmented reality games in education: A review of the literature. *Educational Media International*, 1-19.

Kwiatek, C., Sharif, M., Li, S., Haas, C., & Walbridge, S. (2019). Impact of augmented reality and spatial cognition on assembly in construction, *Automation in Construction*, 102935.

Lee, K. (2012). Augmented reality in education and training. *TechTrends*, 56(2), 403-410.

Lin, H.-C. K. Chen, M. C., & Chang, C.-K. (2015). Assessing the effectiveness of learning solid geometry by using an augmented reality-assisted learning system, *Interactive Learning Environment*, 23(6), 799-810.

Medicherla, S. Chang, G., & Morreale, P. (2010). Visualization for increased understanding and learning using augmented reality, Proc. Int. Conf. Multimed. Inf. Retr. - MIR '10, 441–443.

Milgram, P. Takemura, H. Utsumi, A., & Kishino, F. (1994). Augmented reality: a class of displays on the reality–virtuality continuum *Proceedings the SPIE: Telemanipulator and Telepresence Technologies*. 2351(1994), 282-292.

Nordin, N., Nordin, N. R. M., & Omar, W. (2022). The efficacy of REV-OPOLY augmented reality board game in higher education, *International Journal of Emerging Technologies in Learning*, 17(7), 22-37. doi:10.3991/ijet.v17i07.26317.

Oda, O. Lister, L. White, S., & S. Feiner, S. (2008). Developing an Augmented Reality Racing Game, Proc. 2nd Int. Conf. intelligence. *Technology Interaction Entertainment*, 1-8.

Poushneh, A. (2018). Augmented reality in retail: A trade-off between user's control of access to personal information and augmentation quality. *Journal of Retailing and Consumer Services*, 41, 169-176.

Radu, I. (2014). Augmented reality in education: a meta-review and cross-media analysis, *Personal and Ubiquitous Computing*, 1-11.

Sääski, J, Salonen, T, Liinasuo, M, Pakkanen, J, Vanhatalo, M., & Riitahuhta, A. (2008). Augmented reality efficiency in manufacturing industry: a case study. In L Roosimölder (ed.), Proceedings of NordDesign 2008, August 21-23, 2008, Tallinn University of Technology, Tallinn, Estonia. Tallinn University of Technology, 99-109.

Santos, M. E. C., Chen, A., Taketomi, T., Yamamoto, G., Miyazaki, J., & Kato, H., (2014). Augmented reality learning experiences: Survey of prototype design and evaluation. *IEEE Transactions on Learning Technologies*, 7(1), 38-56.

Södervik, I., Katajavuori, N., Kapp, K., Laurén, P., Aejmelaeus M., & Sivén M. (2021). Fostering performance in hands-on laboratory work with the use of mobile augmented reality (AR) glasses, *Education Science*, 11(12), 816. doi:10.3390/educsci11120816.

Spector, J. M. & Denton, T. X., (2016). Smart learning environments: Concepts and issues. *Society for Information Technology & Teacher Education International Conference*, Savannah, GA.

Van Krevelen, D.W.F. & Poelman, R. (2010). A Survey of Augmented Reality Technologies, Applications and Limitations. *International Journal of Virtual Reality*, 9, 1-20.

Vogt, F. P. A. & Shingles, L. J. (2013). Augmented reality in astrophysics. *Astrophysics and Space Science*, 347(1), 47-60.

Wojciechowski R., & Cellary, W. (2013). Evaluation of learners' attitude toward learning in ARIES augmented reality environments, *Computer Education*, 68, 570-585.

Wu, H., Lee, S., Chang, H., & Liang, J. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, 62, 41-49.

Zhang, J., Sung, Y.-T., Hou, H.-T., & Chang, K.-E. (2014). The development and evaluation of an augmented reality-based armillary sphere for astronomical observation instruction, *Computer Education*, 73, 178-188.