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WHERE DO WE GO NOW SINCE 2002? A BIBLIOMETRIC ANALYSIS OF AUGMENTED REALITY-RELATED STUDIES IN EDUCATION AND TRAINING

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Abstract: *Augmented reality (AR) has emerged as a transformative technology in education and training, demonstrating significant potential to enhance learner performance. Since 2002, it has garnered substantial academic interest and expanded publication opportunities. However, a comprehensive review of AR-related research in educational contexts has yet to be conducted. To address this gap, the current study employs VOS Viewer and Bibliometrix R-package software to perform a bibliometric analysis of the scientific literature concerning AR in education and training. This analysis focuses on several key aspects: (1) prominent authors and countries; (2) productive journals; (3) most cited articles; (4) co-authorship among countries; (5) trending topics; (6) thematic map and; (7) co-occurrence analysis of keywords. The researchers sourced publications from the Scopus database from 2002 onward, revealing that AR remains an active study area with a growing body of literature dedicated to its application in education and training. This bibliometric review aims to guide future research directions by offering a thorough overview of the current landscape of AR in education and training settings.*

Keywords: *Augmented Reality, Bibliometric Analysis, Education, Training*

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Introduction

Technological advancements have significantly transformed human life in recent decades. Over the last 50 years, various technologies have been integrated to enhance knowledge, skills, and capabilities through educational and training initiatives. One notable advancement is AR technology (Mendoza-Ramírez et al., 2023). AR tools overlay virtual objects onto the real world, enhancing reality rather than replacing it (Devagiri et al., 2022). This technology has been widely adopted across numerous disciplines, including computer science, engineering, medicine, social sciences, mathematics, decision sciences, physics and astronomy, psychology, health professions, and business management; however, its most promising applications are found in education and training.

Research indicates that learners appreciate the experiential engagement offered by AR applications (Okimoto et al., 2015; Vrellis et al., 2020), which can enhance their understanding and retention of knowledge (Bacca et al., 2018; Radu, 2014; Sun et al., 2022). Furthermore, studies have shown that AR positively influences student competencies and cognitive skills, fostering creativity, autonomy, critical thinking, and independent thought (Bower et al., 2014; Garzón et al., 2019). Additionally, AR impacts emotional outcomes by addressing complex issues related to learners' attitudes (Chang et al., 2013). While some research highlights AR's benefits for learning motivation and skills acquisition (Ibáñez et al., 2014; Turan et al., 2018), other studies report mixed results regarding its effectiveness (Chang et al., 2022). Challenges associated with learning through AR include usability concerns, technical difficulties, and issues with technology acceptance (Akçayır & Akçayır, 2017; Chang et al., 2013; Lucas et al., 2020).

The growing interest in AR within education and training reveals a significant gap in our comprehensive understanding of the knowledge accumulated from scholarly articles on this subject. There is also ambiguity surrounding the new contexts in which AR has emerged in educational research and areas that remain unexplored. Despite the increase in literature on AR applications in education, comprehensive academic reviews addressing its implications are limited. Notable exceptions like Hincapie et al. (2021) and Min and Yu (2023) primarily focus on AR's role in language learning and educational applications.

These studies utilized the Scopus database to narrow down to 213 articles for detailed analysis. Reviews of emerging fields are vital as they provide researchers with an overarching view of research composition and classification (Donthu et al., 2021). A careful review of existing literature along with systematic synthesis is essential for identifying research gaps and limitations while proposing future research directions.

To meet these needs, this study employs bibliometric techniques that utilize various quantitative tools to analyze extensive literature data sets (Donthu et al., 2021). The bibliometric evaluation aims to assess the current state of research on AR in education and training by identifying key topics and scholarly foundations where AR's applicability is explored. This will provide a framework for future inquiries. To the authors' knowledge, this represents the first bibliometric analysis specifically focused on AR within educational contexts. The study intends to address several research questions using bibliometric analysis techniques.

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RQ1. What are the research development pattern until 2024 in AR-related research in education and training?
RQ2. Which are the most-cited documents and the most contributing authors, countries and journals in AR-related research in education training?
RQ3. What thematic structure is evident in AR-related education and training articles?
RQ4. Which are the future research areas in AR in education and training?

Literature Review

This section discusses the significance of AR in the fields of education and training.

Augmented Reality

AR can be considered as a placing of virtual things in the actual world, which can be viewed as a technological advancement or a virtual reality subsidiary (Azuma, 1997). In other words, adding virtual objects is what makes AR like picture, animation, sound, graphics, etc (Talan, 2021) which computer-generated images into the real world while simultaneously merging them (Delello, 2014; Pérez-López & Contero, 2013). In its most basic form, it is a setting where computer-generated data is overlaid on the user's vision of a real-world scenario (Machado & Vilela, 2020). Through the use of AR, a person can carry out their tasks while simultaneously receiving visual input from additional computer-generated or modelled data (Wang et al., 2023).

The functions of AR may be varied. For example, it can be used in traditional or online settings of the classroom. In a traditional classroom setting, AR can find applications in science classes. Students can utilize AR-enabled apps or devices to see and engage with virtual elements. For instance, they can dissect a virtual organism or explore the Solar System using AR. In online teaching, AR applications enable students to scan images in their textbooks using their mobile devices. These applications then superimpose additional interactive content, like 3D models or videos, enhancing the learning experience with more engagement and visual aids (Tiwari et al., 2023).

Augmented Reality in Education and Training

While literature related to AR in education and training is still growing (Carless & Boud, 2018; Yu & Liu, 2021), based on previous discussions, it can be argued that AR in education and training plays a crucial role in the current education and training paradigm which encourages student agency and independence in learning (Sutton, 2012). According to existing literature, there are several practical implications of AR in teaching and education:

Education

- *Promotes active engagement.* The interactive delivery of information can encourage students to be more active and engaged in their learning (Pahmi et al., 2023). Incorporating AR in lessons can satisfy the learning needs of the current generation who are digital natives who are familiar with technology.
- *Immersive learning experience.* The vivid simulations of the real world enable students to experience realistic interactions with objects and situations that could have not been possible in the traditional classroom (Al-Ansi et al., 2023).

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- *Concretizes abstract concepts.* A tool to facilitate students' understanding through visual representations of important concepts including those related to STEM (Abualrob et al., 2023; Al-Ansi et al., 2023; Çetin & Türkan, 2022).
- *Inclusivity in education.* AR-based lessons have found to be able to facilitate the cognitive development and increase learning motivation of students with disabilities (Ahuja et al., 2022; Hashim et al., 2022; Lian et al., 2023).
- *Increases student motivation.* Interactive learning experience regardless in-class or remote learning lessons provided through AR have found to increase students' motivation in learning (Abualrob & Awaad, 2024; Ahuja et al., 2022; Çetin & Türkan, 2022).
- *Enhances online distance learning experience.* The inclusion of AR-based lessons in online distance learning provides students a three-dimensional view of their learning compared to common online learning platforms such as Google Meet, Zoom and Google Classrooms (Batool, 2022). It also enables students to continue learning in an engaging and safe environment even during emergency remote learning (Çetin & Türkan, 2022).

Training

- *In-class vocational training at industry standards.* AR enhances classroom teaching and training of vocational skills including those for hazardous occupations by providing realistic scenarios of the industry. This also ensures training and learning can be carried out in a safe environment (Bologna et al., 2020; Chiang et al., 2022).
- *Enhances training of spatial ability.* Spatial ability is an intrinsic skill in technical-related fields such as design, engineering, mathematics, and architecture. AR allows students to move and view an object or model from different perspectives compared to 2-D teaching materials therefore enhancing their spatial ability (Han et al., 2022; Zhou et al., 2022).
- *Time and cost-effective.* By using AR, trainers are able to train a large number of students without having to purchase or create physical models or objects which can be costly and time-consuming (d'Aiello et al., 2023). Trainees can also learn how to operate expensive industrial equipment in a risk-free environment (Bologna et al., 2020).
- *Familiarizes students with future workplace environments.* Exposure to AR in technical and vocational training helps students become familiar with this technology which is increasingly used in the industry (Bacca et al., 2018; Bricard & Lavric, 2022; Gasteiger et al., 2022).
- *Reduces cognitive workload.* Visualizations through 3-D imagery enable students to understand concepts, processes and procedures easily (Bricard & Lavric, 2022; Gasteiger et al., 2022). Furthermore, students/trainees can increase their skills through repeated practice which is made possible through AR (Gasteiger et al., 2022).
- *Reduces errors.* AR-based training immerses trainers in a learning environment that imitates real work scenarios. Training in such an environment can help them to reduce accidents and errors during training (Bricard & Lavric, 2022; Gasteiger et al., 2022).

Methodology

The current research utilized bibliometric analysis to examine publication trends regarding AR in education and training within the Scopus database. This method has gained popularity as an innovative approach to research evaluation among scholars in both social sciences and technology fields (Ellegaard & Wallin, 2015; Khan & Muktar, 2020). Bibliometric analysis enables the quantitative mapping of bibliometric components of published works (Danvila-del-Valle et al., 2019; Donthu et al., 2021). The benefits of bibliometric studies include: (1) offering

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a detailed overview of a research area, (2) identifying and emphasizing knowledge gaps, (3) allowing researchers to suggest potential future research directions, and (4) providing opportunities for scholars to contribute to their fields. Furthermore, this analysis can assist practitioners and policymakers in developing strategies to enhance practices in specific domains (Forliano et al., 2021).

Choosing The Approach for Analysis

The first phase of this research involved selecting an appropriate database to achieve the study's objectives. Widely used databases for sourcing bibliographic data include Google Scholar, Scopus, and Web of Science (WoS). Although some researchers prefer to combine multiple databases for bibliometric studies, this research followed the recommendation of Donthu et al. (2021) to use a single database in order to reduce redundant efforts and avoid potential errors. For this study, data were sourced from Scopus as of September 30, 2024. Scopus was chosen because it is recognized as one of the leading global databases (Ahmi & Mohd Nasir, 2019; Khan & Muktar, 2020).

Scopus was also selected due to its vast index of scholarly works, providing broad coverage of peer-reviewed publications in disciplines such as science, technology, medicine, social sciences, and the arts and humanities. This extensive coverage allowed the researchers to gather a substantial number of documents related to AR in education and training from the last decade. As a result, all available papers up to the extraction date were included in the study.

Data analysis was conducted using both VOS Viewer software and the Bibliometrix R-package. Bibliometrix was used to generate citation and publication metrics, identifying the most influential authors, journals, and countries based on citation counts and publication frequency. A co-authorship analysis explored international collaborations by analyzing the countries of origin of the documents. Additionally, keyword analysis using Bibliometrix provided thematic mapping and insights into trending topics in the field. The thematic map highlighted current key themes and potential future research areas. Keyword co-occurrence analysis in VOS Viewer further demonstrated the relationships between keywords in the literature, enriching the understanding of the knowledge structure in this field. Both tools were essential in implementing these bibliometric techniques.

Data Collection

In their study, Harzing and Alakangas (2016) provide a thorough and detailed comparison of the three primary bibliometric databases: Google Scholar, Scopus, and Web of Science. Their findings indicate that Scopus generally offers a greater number of publications than Web of Science across all academic fields. Furthermore, Google Scholar surpasses both Web of Science and Scopus combined in terms of total papers available for each discipline. However, the authors advise caution regarding the reliance on the number of documents found in Google Scholar, as many may be duplicate entries with fewer than two citations unless careful manual cleaning and merging are performed for individual academic works. This observation underscores the reliability of Scopus as a database. Consequently, this research utilized Scopus to gather the necessary data. The systematic methodology for data collection is outlined in Table 1. Additionally, the study adopted keyword strategies based on Wei's (2019) research on AR and virtual reality (VR) to extract data from Scopus. No specific time frame was established for data extraction due to the rapidly evolving nature of AR as a subject.

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Scope of Search

This bibliometric analysis focuses exclusively on studies related to AR in the context of education and training. Only research that specifically addressed AR in these areas was considered, while studies outside this scope were excluded. This also involved excluding AR studies that were centred around specific industry contexts within education and training.

Results

This section discusses the outcomes of our bibliometric analysis.

Sample Characteristics

The sample comprises 213 articles published by 111 journals, authored by 155 individuals from 57 different countries, and spans 25 subject areas from 2002 to 2024.

Performance Analysis

Publication Trend

The total number of publications is illustrated in Figure 1, which depicts the trend in research on AR implementation in education and training from 2002 to 2024. The figure indicates that research related to AR in these fields began to develop significantly only after 2002.

Table 1: Search Procedure

Filtering Criteria	Excluded	Included
Database: Scopus		
Date of search: 30 September 2024		
Keywords: “augmented reality” OR “AR” AND “education AND “Training “in the article title, abstract and keyword		225
Published from: No time limit		225
Language: Documents in English only	9	216
Limit to: Documents with publication stage as “final”	3	213
Duplications		
Content screening: Articles in which the scope of the study (AR in education and training is discussed in “Titles, Abstracts, and Keywords” are only included		213

Note(s): This table shows the filtering criteria used to reach the final compilation of 213 studies

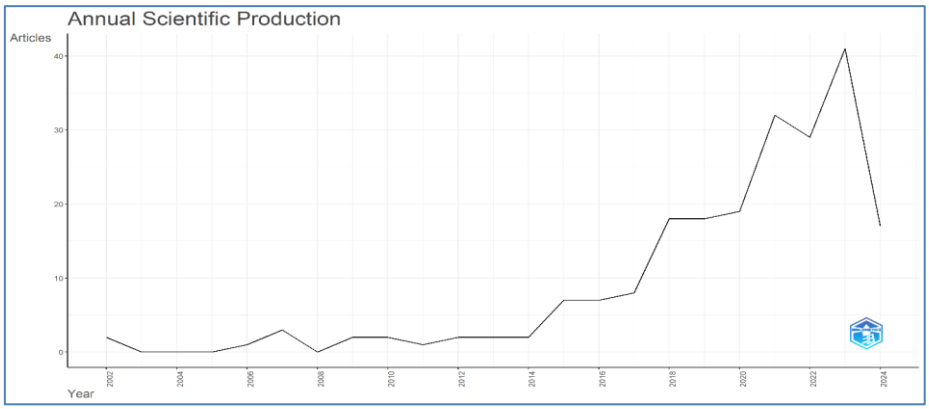

Figure 1: Total Number of Papers

Source: Bibliometric R-Package, Biblioshiny

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The publication trend for AR research in education and training shows that very few papers were produced from 2002 to 2017. It wasn't until 2018 that the annual publication count exceeded an average of ten. The highest volume of articles has emerged in the last three years, with 2023 being the most productive year, yielding 41 articles, followed by 32 in 2021 and 29 in 2022. Interestingly, despite being a year of recovery from the COVID-19 pandemic, 2023 saw the most significant output in this research area. As of now, with 2024 approaching its end, only 17 articles have been published, representing about 30% of the total publications from 2023. This indicates that research on AR in education and training is not progressing as rapidly in 2024.

Top Authors and Countries Of AR-Related Research in Education and Training

The most influential authors in AR research related to education, along with the countries that have produced the highest number of cited documents, are summarized in Table 2 based on citation metrics. Among the 155 authors who have published at least one paper, Potkonjak V. emerges as the leading figure in this field, amassing 610 citations. He is followed by Shi L. with 355 citations and Ayoub A. with 205 citations. Regarding the countries contributing to AR-related studies in education and training, the United States leads with 38 publications, while the United Kingdom has garnered the highest citation count at 1,368.

Table 2: Top Authors and Countries of AR Research in Education and Training

Author	TP	Author	TC	Countries	TP	Countries	TC
Nerdel C	3	Potkonjak V	610	United Kingdom	24	United Kingdom	1368
Ripsam M	3	Shi L	355	United States	38	United States	1283
Sidhu Ms	3	Ayoub A	205	Austria	8	Austria	723
Ahmed N	2	Jetter J	146	Australia	8	Australia	690
Ahn S	2	Siyaev A	139	Finland	6	Finland	651
Alhussian H	2	Uppot Rn	124	Serbia	1	Serbia	610
Alkawsi G	2	Soltani P	120	Germany	26	Germany	528
Amara K	2	Carruth Dw	107	South Korea	5	South Korea	234
Baashar Y	2	Bacca J	106	China	7	China	218
Bacca J	2	Petrigna L	105	Spain	9	Spain	216

Note(s): TP: Total Production, TC: Total Citation

Top Sources for AR-Related Research in Education and Training

Table 3 presents the leading publications in AR research within the education sector. The journals Computers and Education and Nature are the most significant sources, with citation counts of 730 and 355, respectively. In terms of publication volume, both Computers and Education and Procedia Manufacturing have published a total of two articles each.

A closer examination of Table 3 reveals that three out of the top ten journals focusing on AR-related research in education and training are specifically oriented towards this field. This finding highlights the diverse array of multidisciplinary journals willing to publish work on AR, which is promising and crucial for advancing research across various domains.

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Top Articles on AR-Related Research in Education and Training

Table 4 presents the top 10 most cited articles on AR-related research in education and training, ranked by the total number of citations. The article by Potkonjak V., published in Computers and Education in 2016, holds the highest citation count with 500 citations. This is followed by an article by Shi L., published in Nature in 2021, which has received 321 citations. Potkonjak V.'s study primarily explores the advantages, challenges, and technological methods involved in virtual labs for educational purposes. He found that AR enhances engagement by creating immersive learning environments and improves accessibility by providing flexible access to experiments that might be costly or dangerous. Additionally, the study reveals that AR-based virtual labs support skill development by allowing students to practice repeatedly in simulated environments without the limitations of physical equipment, thus bridging the gap between theory and practical application.

Petrigna et al.'s (2022) study highlights several advantages of using this suite of technology for both teaching and learning. AR shows significant potential, particularly in enhancing the learning experience by offering interactive and immersive environments, enabling trainees to visualize complex tasks. The study also demonstrates that AR can accelerate skill acquisition by providing visual and interactive representations of tasks, thereby reducing training time. However, successful implementation of AR technology requires careful planning to ensure effective integration into the curriculum, along with adequate training for both educators and learners to utilize the tools efficiently.

Science Mapping

Co-Authorship Analysis Of AR-Related Research in Education and Training Based on Countries

Figure 2 shows the co-authorship networks among researchers from different countries. This widely recognized approach provides insights into scientific collaboration patterns, emphasizing that researchers often work in multidisciplinary teams with diverse perspectives and skills to achieve common objectives. As such, co-authorship analysis is a valuable method for understanding collaboration trends and identifying leading contributors in the field (Fonseca et al., 2016).

In the figure, each country is represented by a labelled circle, where the size of the circle reflects the number of publications authored by researchers from that country. The lines connecting the circles represent co-authored documents, with the thickness of the lines indicating the number of shared papers between countries. The analysis shows that the United States has the most extensive co-authorship network, collaborating with 19 other nations, including strong partnerships with the United Kingdom, Germany, Malaysia, Canada, Spain, Portugal, Austria, Saudi Arabia, Singapore, and others.

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Table 3: Top Sources for AR Research in Education and Training

Rank	Source Title	No. of Citation	No. of Documents	Education and Training
1	Computers and Education	730	2	/
2	Nature	355	1	
3	BMC Oral Health	205	1	
4	Computers in Human Behavior	146	1	/
5	Sensors	139	1	
6	Radiology	124	1	
7	Procedia Manufacturing	123	2	
8	ICETA 2017- 15th IEEE International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management	107	1	
9	Procedia Computer Science	106	2	
10	Journal of Ambient Intelligence and Humanized Computing	105	1	/

Source: Scopus Database

Table 4: Top Articles on AR Research in Education and Training

Title	Author	Total Citation
Virtual Laboratories for Education in Science, Technology, and Engineering: A Review	Potkonjak et al. (2016)	500
Towards Real-Time Photorealistic 3D Holography with Deep Neural Networks	Shi et al. (2021)	321
The Application of Virtual Reality and Augmented Reality in Oral & Maxillofacial Surgery	Ayoub and Pulijala (2019)	312
Augmented Reality Tools for Industrial Applications: What Are Potential Key Performance Indicators and Who Benefits?	Jetter et al. (2018)	252
Towards Aircraft Maintenance Metaverse Using Speech Interactions with Virtual Objects in Mixed Reality	Siyaev and Jo (2021)	172
Advances in Virtual and Augmented Reality—Exploring the Role in Health-care Education	McCarthy and Uppot (2019)	168
Implementing Virtual and Augmented Reality Tools for Radiology Education and Training, Communication, And Clinical Care	Uppot et al. (2019)	116
Augmented Reality Tools for Sports Education and Training	Soltani and Morice (2020)	115
Virtual Reality for Education and Workforce Training	Carruth (2017)	113
Mobile Augmented Reality in Vocational Education and Training	Bacca et al. (2015)	99

Source: Scopus Database

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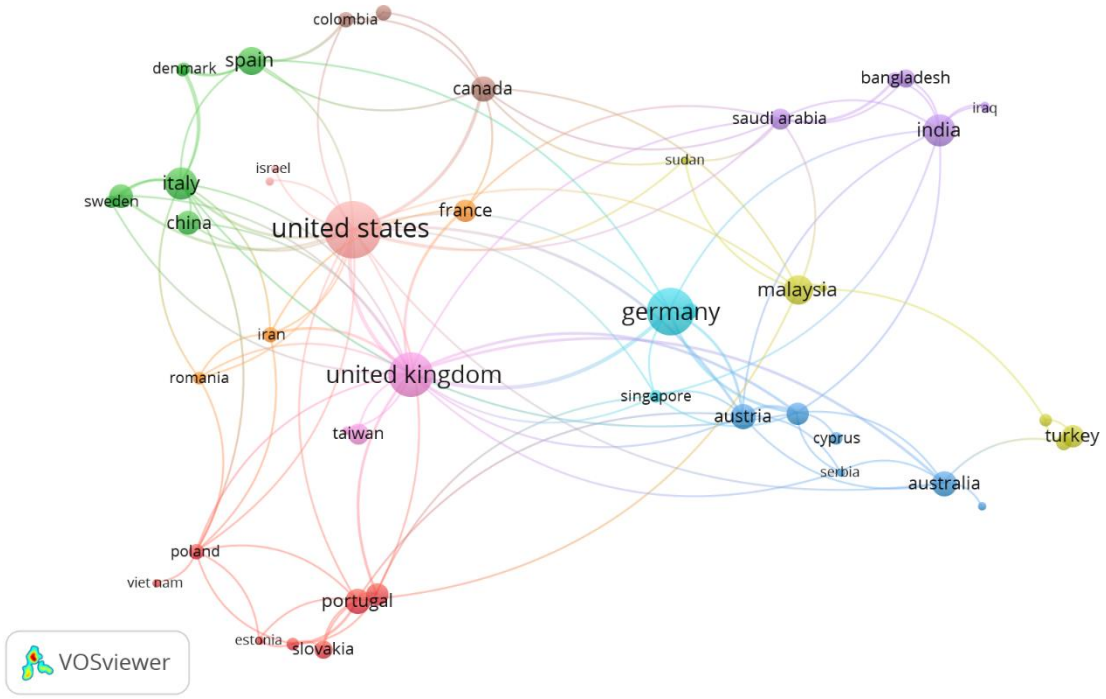

Figure 2: Co-Authorship Analysis Based on Countries

Source: VOS Viewer

Keyword Analysis

Trending Topics and Thematic Mapping

Analysing the keywords used in research papers is a key approach for identifying emerging themes and understanding authors' areas of focus on a given topic (Agbo et al., 2021). Figure 3 displays the trending topics in this field based on keyword usage by authors. For this study, the minimum word frequency was set at 5, with an annual word count of 3. The analysis reveals that recent research is predominantly focused on AR in education and training, particularly in the context of medical students, medical education, reviews, systematic reviews, humans, and mixed reality. Notably, the term "AR" started gaining significant traction in 2021, often appearing in conjunction with terms like "virtual reality," "humans," and "e-learning." Table 5 provides a list of the top 20 most frequently used keywords in AR-related research within education and training.

Furthermore, Figure 4 presents a thematic map of AR in education and training, which was generated using the Bibliometrix R-package. This thematic map aims to analyse the current state of research in the field and explore potential future directions for sustainable development. This analysis offers valuable insights for researchers and stakeholders, highlighting possible new areas of thematic research (Agbo et al., 2021). The density and centrality of the topics indicate how well-developed they are and their importance within the broader field. Each circle's size reflects the number of articles that include the respective term. The thematic map is divided into four quadrants, which are further explained in the following sections.

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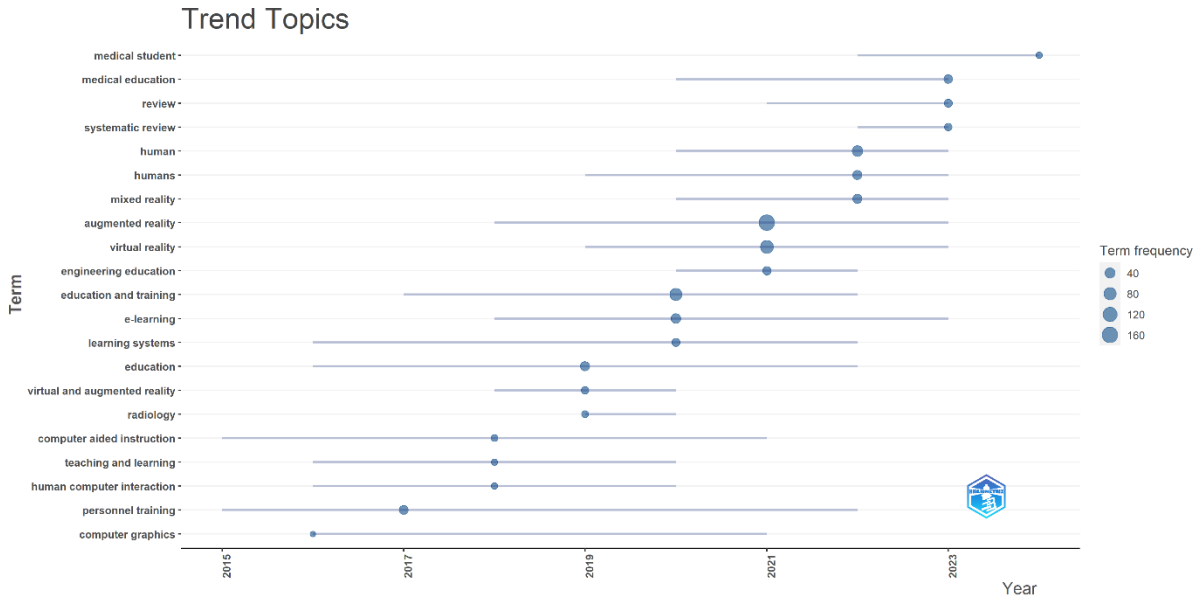

Figure 3: Trending Topics with The Use of Keywords

Source: Bibliometric R-Package, Biblioshiny

Table 5: Top Keywords

No.	Keywords	No. Of Documents	No.	Keywords	No. Of Documents
1	Augmented Reality	164	11	Engineering Education	17
2	Virtual Reality	91	12	Learning Systems	16
3	Education And Training	74	13	Review	16
4	Human	45	14	Virtual And Augmented Reality	11
5	E-Learning	34	15	Systematic Review	11
6	Humans	28	16	Computer Aided Instruction	9
7	Education	27	17	Radiology	9
8	Mixed Reality	26	18	Human Computer Interaction	6
9	Personnel Training	23	19	Teaching And Learning	6
10	Medical Education	20	20	Medical Student	6

(Source: Scopus Database)

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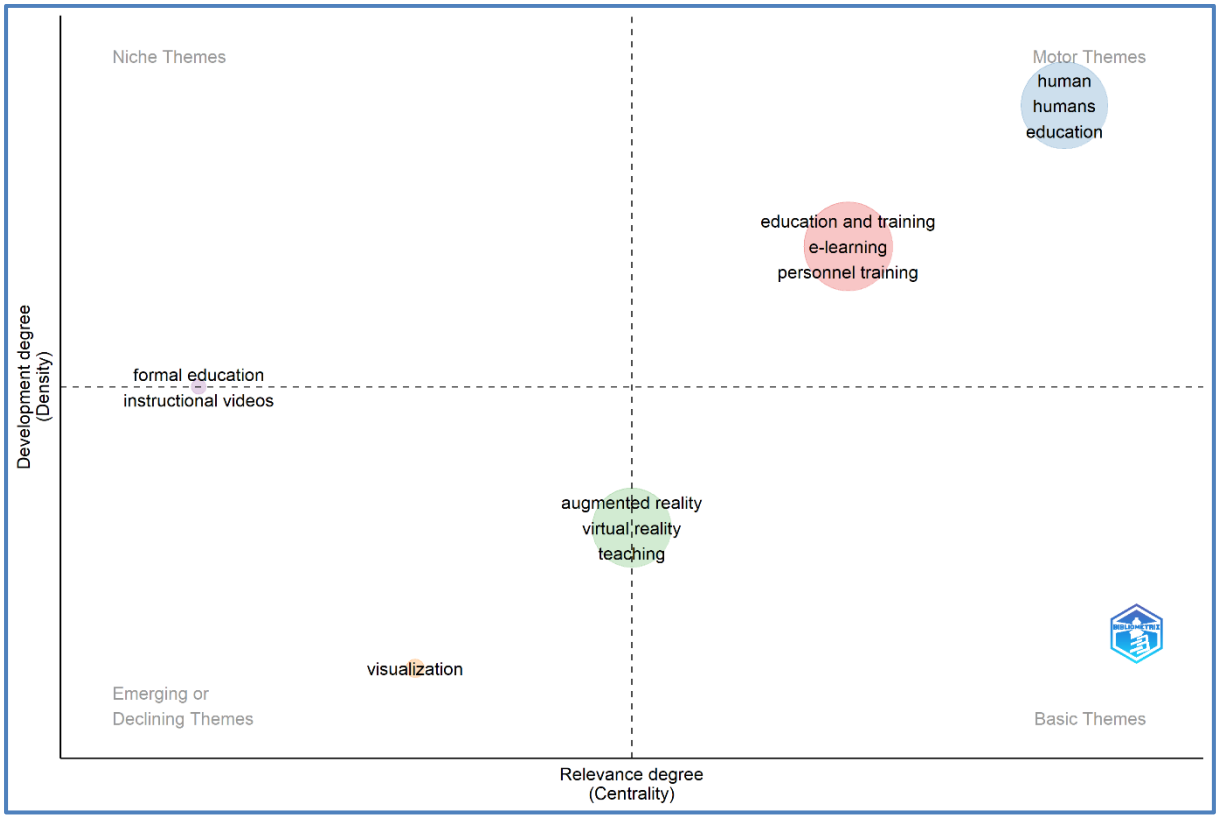

Figure 4: Thematic Map

Source: Bibliometric R-Package, Biblioshiny

1) The upper-right quadrant of the thematic map highlights the driving themes in AR research within education and training. This quadrant features six distinct clusters, interconnected through a substantial number of keywords, indicating that the primary themes in this area include human(s), education, education and training, e-learning, and personnel training.
2) The lower-right quadrant showcases the basic concepts in the field, consisting of three clusters centred on augmented reality, virtual reality, and teaching. Here, the concept of AR is well-structured and developed, particularly regarding its adoption among students facilitated by AR technology.
3) In The lower-left quadrant, themes that are either emerging or declining are represented. This quadrant contains two clusters focused on visualization and instructional videos. While AR as a visualization tool and its application in instructional videos are important areas for further study, they have not yet reached full development.
4) The upper-left quadrant depicts the niche themes being explored within AR in education and training. This quadrant includes a single cluster related to formal education. There is a need for increased efforts to enhance AR functionalities within formal educational settings to improve technical skills and adapt to an increasingly artificial intelligence-driven world.

Co-occurrence Analysis

Co-occurrence analysis, based on keywords, provides insights into the concepts emphasized in studies regarding the applicability of AR in education and training. Among the 645 keywords identified in the 213 articles, 33 met the threshold of occurring at least three times, as illustrated

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in Figure 5. This figure highlights that keywords such as AR, virtual reality, education, mixed reality, and training significantly impact the network. It reveals that authors have frequently studied AR in conjunction with virtual reality and simulation. This analysis underscores the interconnectedness of these concepts, suggesting a strong relationship between AR and other immersive technologies in educational contexts.

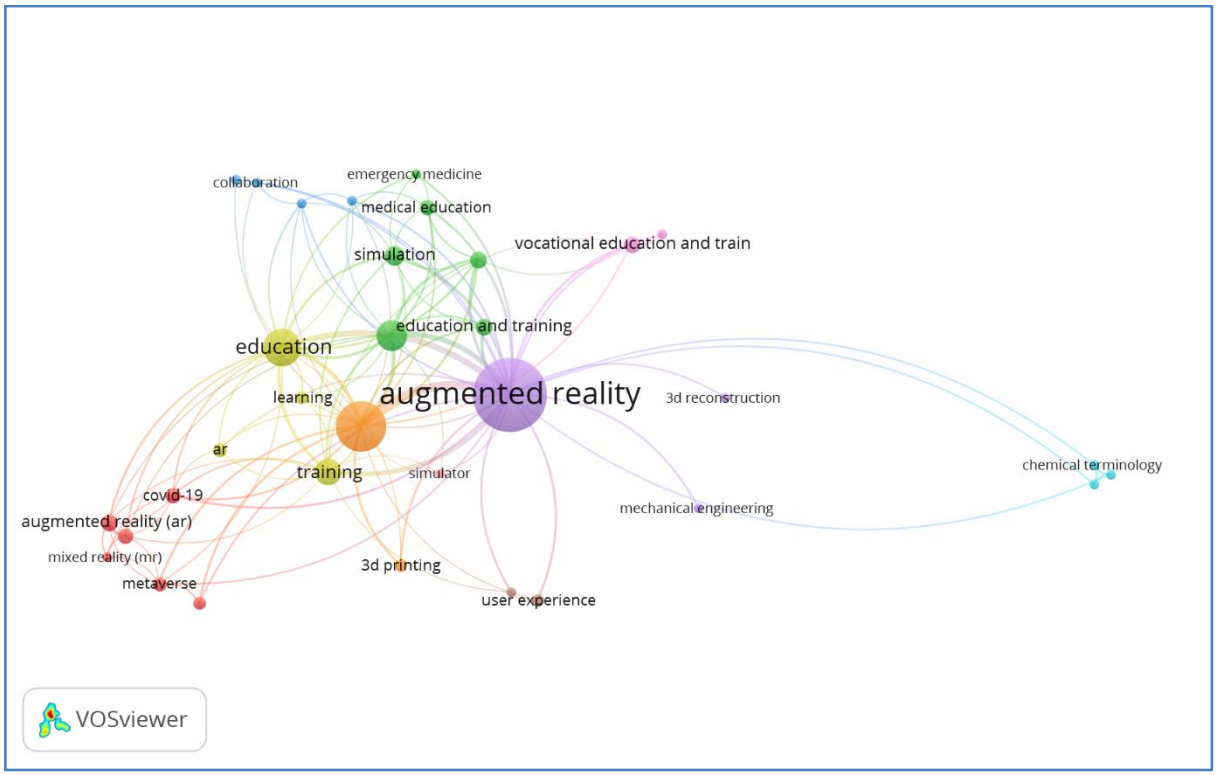

Figure 5: Co-occurrence Analysis of Keywords

Source: VOS Viewer

Discussions and Conclusions

The current study enhances our understanding of the present state of AR research in education by compiling all publications in this area up to September 30, 2024. Although AR was first conceptualized 53 years ago in 1968, significant research progress has only been observed since 2002. Notably, this study is the first bibliometric analysis focusing on AR-related research in education and training, marking a key contribution to the literature. The findings indicate a growing trend in scholarly publications on this topic, with the first article by Fruend, J. appearing in 2002. Interest in AR research has notably increased since 2017, with a clear upward trajectory beginning in 2018, albeit at a moderate pace.

While numerous articles have been published across various countries, global attention to AR in education and training remains uneven. The United States leads with 38 publications, followed by Germany and the United Kingdom. Among the top ten publications, three papers have collectively received 1,170 citations out of a total of 2,017 citations. In total, 155 authors have contributed to this field, with Potkonjak V., Shi L., and Ayoub A. being the most cited. The study also identifies the top ten journals that have accumulated over 2,168 citations. Furthermore, among the 57 countries with co-authorship links, the United States has the most extensive connections, collaborating with 19 other nations. Keyword analysis reveals that

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recent studies are increasingly focusing on topics such as AR, virtual reality, education and training, humans, and e-learning.

Suggestions for Future Research

The following existing gaps and needs in AR research were derived from past studies. These can guide future researchers to expand understandings and find solutions on the use of AR in education and training.

- More research on how AR can facilitate training and teaching in the medical field (d'Aiello et al., 2023).
- Conduct studies on different disciplines or courses that require students' understanding of abstract concepts (Çetin & Türkan, 2022) and complex information (tom Dieck et al., 2024).
- Identifying the solutions to the technical problems related to AR (Akçayır & Akçayır, 2017).
- Expanding the application of AR in learning for various student demographics such as lifelong learners and special need students (Wu et al., 2013).
- More investigation on the effects of AR-based learning and training on students' cognitive workload should be conducted. This can be explored about the task/topic, age, gender and user interface (Akçayır & Akçayır, 2017).
- Investigating the relationship between visual complexity of user interface and the visual perception on students (Lian et al., 2023).
- Providing detailed explanation of the materials and processes involved in designing AR-based teaching and training applications (Akçayır & Akçayır, 2017).
- Considering pedagogical aspects when developing and designing AR products to maximise the achievements of learning outcomes (Zhou et al., 2022).

Theoretical Implications

This bibliometric analysis addresses critical questions that researchers should consider when exploring AR applications in education and training. The study serves as a valuable resource for academics seeking to identify and understand emerging trends in this field, as well as the relevant literature. It highlights the significance of AR in education and can be instrumental in developing future educational products. As the first study to utilize a bibliometric approach to fill this knowledge gap, it identifies key documents, journals, and, importantly, future research areas within this domain. The findings provide a foundation for further investigations into AR in education and training, suggesting ample opportunities for additional research. Despite the evident need for such studies to enhance the education and training sector as a whole, there remains a scarcity of research focused on specific sub-sectors within this field.

The analysis underscores how AR can transform educational experiences by integrating digital elements into real-world settings, thereby enhancing engagement and learning outcomes. This is particularly relevant as various industries are increasingly adopting AR technologies for training purposes. The study's insights can guide researchers and industry professionals in leveraging AR to improve educational practices and address existing gaps in the literature.

Limitations and Future Research Directions

Although this paper makes valuable contributions, there are certain limitations that must be recognized. One limitation is the reliance on a single database for data collection. While the

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authors argue that Scopus includes a substantial number of relevant papers, using multiple databases would offer a more holistic understanding of the topic. Additionally, the study's focus on English-language publications excludes research published in other languages, which could limit the scope of the findings.

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