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Global Trends and Research Focus on Augmented Reality for Enhancing Critical Thinking: A Bibliometric Analysis

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Abstract: Learning media is a process through which learners acquire knowledge, understanding, and skills in science. Augmented Reality (AR) is a digital technology that integrates manipulable digital images into real-world environments in real time, revolutionizing dynamic learning. Research indicates that mobile-based AR learning media enhance students' material comprehension and stimulate critical thinking. Critical thinking involves analyzing, evaluating, and logically concluding information, which is a vital skill for informed decision making. Recent studies from 2015 to 2024 highlight the rapid growth of AR research across various disciplines, including Physics Education. To analyze these studies, a bibliometric method was employed, focusing on articles published between 2015 and 2024 in the Scopus database. This analysis identified research trends related to AR's impact on critical thinking. This study used descriptive bibliometric analysis to evaluate publications on AR and critical thinking. Results revealed a peak in publication trends in 2022 and citation trends in 2020. Taiwan led in research output. Key research areas include AR, VR, and students' critical thinking. Emerging themes such as STEM, artificial intelligence, nursing education, and game-based learning new research directions. These findings provide a reference for future research on AR in enhancing critical thinking, with potential data sources.

Keywords: augmented reality, critical thinking, learning media

Tren Global dan Fokus Penelitian *Augmented Reality* untuk Meningkatkan Berpikir Kritis: Analisis Bibliometrik

Abstrak: Media pembelajaran berperan penting dalam membantu peserta didik memperoleh pengetahuan dan keterampilan di bidang sains. *Augmented Reality* (AR) merupakan teknologi digital yang memadukan objek virtual yang dapat dimanipulasi ke dalam lingkungan nyata secara *real time*, sehingga menciptakan pengalaman belajar yang lebih interaktif dan dinamis. Berbagai penelitian menunjukkan bahwa media pembelajaran berbasis AR, khususnya pada perangkat *mobile*, mampu meningkatkan pemahaman materi serta mendorong kemampuan berpikir kritis. Berpikir kritis mencakup kemampuan menganalisis, mengevaluasi, dan menarik kesimpulan logis dari informasi, yang penting untuk pengambilan keputusan yang tepat. Studi terkini pada periode 2015–2024 mengungkapkan peningkatan pesat dalam penelitian AR di berbagai bidang, termasuk pendidikan fisika. Penelitian ini menerapkan metode bibliometrik untuk menganalisis artikel mengenai AR dan berpikir kritis yang dipublikasikan di basis data Scopus pada periode 2015–2024. Analisis bibliometrik deskriptif digunakan untuk menelusuri tren publikasi, sitasi, dan fokus penelitian. Hasilnya menunjukkan bahwa puncak publikasi terjadi pada tahun 2022, sedangkan puncak sitasi terjadi pada tahun 2020. Taiwan menjadi negara dengan kontribusi terbesar. Bidang penelitian yang dominan meliputi AR, VR, dan berpikir kritis peserta didik. Tema baru, seperti STEM, kecerdasan buatan, pendidikan keperawatan, serta pembelajaran berbasis gim, mengindikasikan arah pengembangan penelitian di masa depan. Temuan ini menjadi rujukan penting bagi penelitian selanjutnya mengenai penerapan AR untuk meningkatkan kemampuan berpikir kritis.

Kata kunci: augmented reality, berpikir kritis, media pembelajaran

INTRODUCTION

Learning media are tools educators use to help students acquire knowledge, understanding, and skills, particularly in science. These media serve as a conduit for information from educators to learners (Zuniari et al., 2022). Among the many forms of learning media, Augmented Reality (AR) stands out as one that can be effectively applied in educational environments. AR is a digital innovation that enables users to interact with and manipulate virtual objects in a controlled visual space (Catal & Tekinerdogan, 2019). AR integrates digital images into real-world spaces in real-time. This technology revolutionises learning by enabling interaction with the surrounding environment. Research has shown that developing mobile-based learning media for Android, mainly focusing on cameras and photography tools using AR, has received positive student feedback. It has been found to enhance student understanding of the material and stimulate critical thinking skills (AL-Hileh & Alhusamia, 2023). Critical thinking involves the capacity to logically and rationally analyse, evaluate, and draw conclusions from information (Aliftika et al., 2021). It is an essential skill for learners because it allows them to assess the world around them and make well-informed decisions critically (Al-Gerafi et al., 2023; Caratozzolo et al., 2021).

Research on AR learning media has increased in the last five years, from 2015 to 2024. This surge in AR research has led to numerous discoveries across various fields, including computer science, engineering, social sciences, physics, arts, and technology (Sriwitaya et al., 2023). As well as in Physics Education (Wibowo, 2023). In recent years, computer science has seen a substantial increase in AR research (Cabiria, 2012; Hidayat et al., 2021). However, this growth is not limited to computer science; significant advancements have also been made in social sciences and engineering, and there has been a notable rise in AR research focused on physics education. This trend of expanding AR research in education has been paralleled by increased attention to AR applications in physics learning. Therefore, it is essential to use statistical methods to analyse these research findings, which will help to determine the primary focus areas and uncover new insights within this body of work.

AR has been recognised as a valuable learning tool for its ability to create immersive, interactive experiences that elevate students' comprehension of abstract concepts. This system visualises complex phenomena, simplifying their computation and accessibility support this notion (Saidin et al., 2024), emphasising the success of AR in enhancing critical thinking skills through higher-order cognitive processes such as evaluating, analysing, and problem-solving. Such a set of processes is essential in education, particularly in the STEM fields, which often requires a profound ability to engage with logical reason and complex problems. In addition, AR fosters creative and critical thinking by interacting with digital objects in real time, leading to a deeper understanding and more robust argument development (Buditjahjanto & Irfansyah, 2023; Faridi et al., 2021). Such a combination of interactive engagement enables learners to collaborate with digital simulations and the ongoing situation encompassing learning disciplines and their practices. Recent literature confirms that the use of AR in science and physics education has grown rapidly, particularly in topics that require strong spatial representation skills such as rotational dynamics and the equilibrium of rigid bodies (Allo et al., 2025).

One approach for analysing research is bibliometric analysis. This method involves studying and evaluating the scientific literature. Bibliometric analysis generally investigates the most prolific countries, regions, institutions, journals, and authors in a particular research domain. It further examines factors such as publication volume and quality, collaboration networks, citation trends, co-occurrence patterns, and other

characteristics of scientific output. Through this approach, researchers can gain insights into the overall structure and emerging trends within a specific scientific field (Chusni et al., 2022; Dasari et al., 2024). Articles published between 2019 and 2023 were reviewed using Scopus to conduct research on “Augmented Reality” and “critical thinking” through a literature study. There has been no analysis using a bibliometric approach of Scopus data to examine how AR can improve critical thinking. The researchers chose the Scopus database for its comprehensive interdisciplinary coverage and reputation as a credible database often used for high-quality articles (Nisa et al., 2024). This study identifies research trends on AR's role in improving critical thinking.

METHOD

This study utilises a descriptive approach based on bibliometric analysis. Publications concerning the use of AR to enhance critical thinking, sourced from the Scopus database, were analysed using this method (Nisa et al., 2024). The stages of bibliometric research are: research question design, data collection, research limitations, visualisation using a VOS viewer, and data interpretation. Figure 1 presents the bibliometric analysis flow chart.

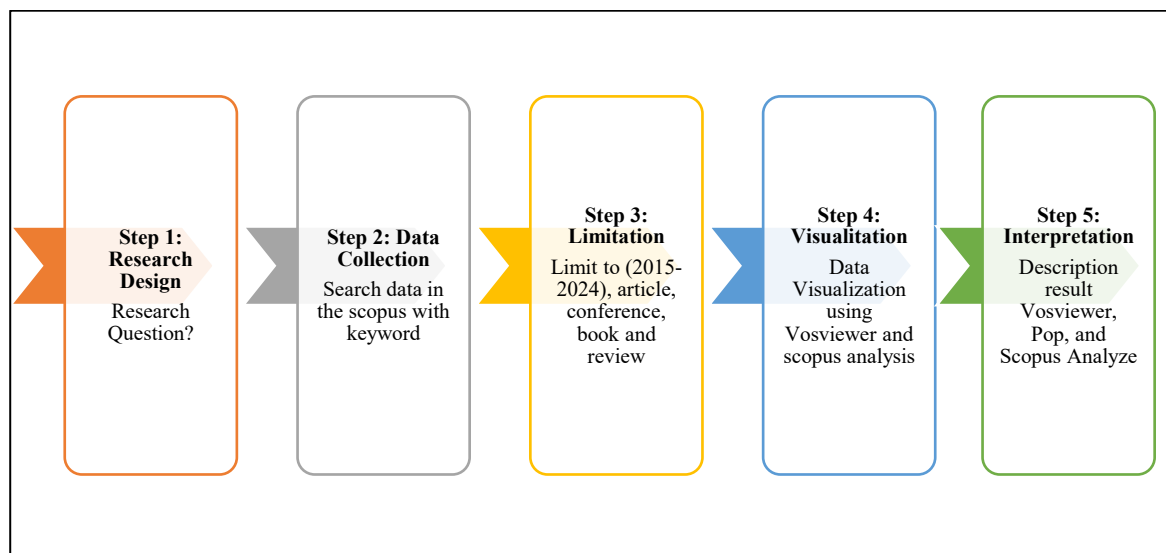


Figure 1. Bibliometric Analysis Flow Chart (Šūmakaris et al., 2020)

Research Question

The integration of AR technology into education has emerged as a significant focus of research in recent years. Research shows that interactive AR experiences can improve learners' deep understanding and knowledge retention. AR-based learning media has great potential to encourage learners to analyse information, evaluate evidence, and make informed decisions in learning (Maas & Hughes, 2020); Rizki et al., 2024; Suryanti et al., 2020). However, there remains a research gap regarding the influence of AR on critical thinking in an educational context. This literature review aims to explore current research on the following:

- 1) What are the publication trends by country and influential authors with the highest research citations?
- 2) Journals that publish AR articles on improving critical thinking skills?
- 3) What are the emerging research trends and innovative contributions of AR applications in enhancing critical thinking?

Data Collection Stage

The source of literature used in this research is the Scopus database using the keywords "critical thinking" AND Augmented Reality". The use of keywords helps researchers select literature sources. The following inclusion and exclusion criteria are applied. The first search found 50,051 documents using the keyword "Augmented Reality" and then added the keyword "Critical Thinking".

Scope (Limitation)

Research publication documents were limited from January 2015 to May 19, 2024; all types of documents were used in articles, conference seminars, chapter books, review articles, and in English, so 150 papers were found. At this stage, the researcher analyses the results, abstract, research methods, findings, and discussion that explain the effect of AR-based learning media on improving critical thinking—the flow of research methods, according to Figure 1.

Data Analysis and Visualization

The data retrieved from the Scopus database are saved in two formats: CSV (Comma-Separated Values) and RIS (Research Information Systems). The CSV data are analyzed using VOSviewer, while the RIS data are processed through Harzing's Publish or Perish software. The study explores publication and citation trends in research utilizing AR to enhance critical thinking, categorized by publication year, country distribution, and patterns of international collaboration based on author affiliations. Using Publish or Perish, the analysis includes the calculation of h- and g-index values along with other citation indicators. Meanwhile, VOSviewer is employed to visualize the relationships among countries, the most frequently cited authors, and thematic networks of AR studies related to improving critical thinking—the central focus of this research (Abdelrahim, 2023; Dasari et al., 2024; Faridi et al., 2021).

Interpretation

The interpretations obtained agree with the research objectives, starting from publication trends, citation trends, publication distribution by country affiliation, and research innovation. After the results were displayed, a descriptive data analysis was conducted.

RESULTS AND DISCUSSIONS

Based on the bibliometric analysis, which incorporates publication trends, citation patterns, journal distribution, and country-level contributions, this study provides a comprehensive overview of the scholarly landscape on AR in science and physics education. The findings further highlight emerging research focuses and reveal the novelty of AR-based interventions in enhancing students' critical thinking skills.

Publication and Citation Trends

The trend of publications related to research on the effect of AR learning media on critical thinking can be seen in Figure 2.

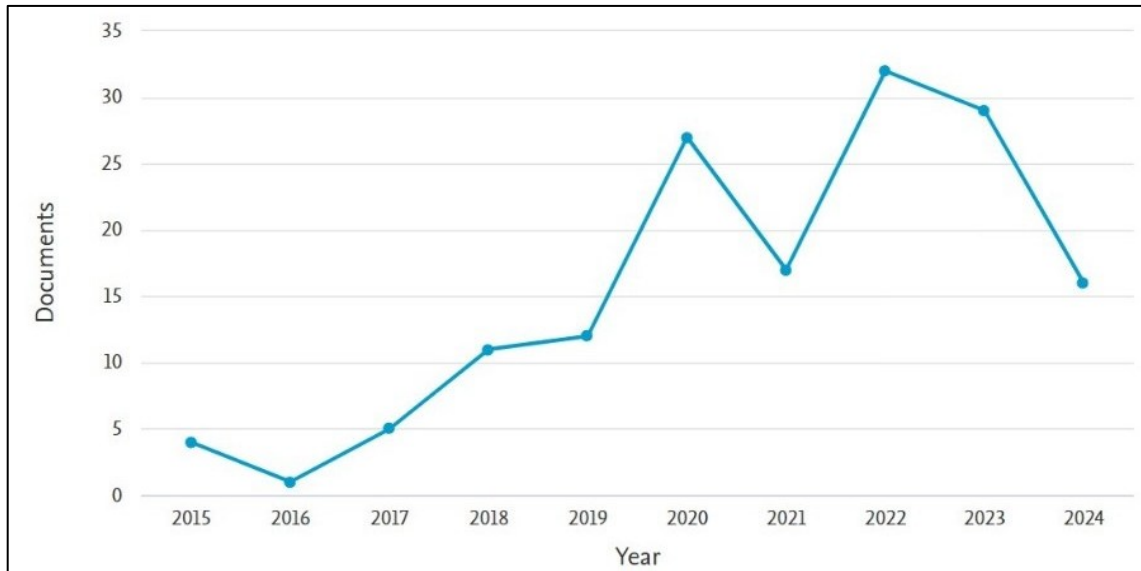


Figure 2. Publication Trend Chart 2015 – 2024

According to Figure 2, 2020, 2022, and 2023 were particularly productive regarding research publications on AR and critical thinking. While there was a slight decrease in publications in 2022, this trend was reversed in 2023 with a significant increase. In 2022, Scopus indexed 30 documents related to this topic, with an average citation value of 4.43 per publication. The citation trend is shown in Table 1.

Table 1. The Citation Trend

Tahun	TP	NCP	TC	C/H	H	G
2024	16	10	3	0,63	2	3
2023	27	96	15	3,56	6	8
2022	30	133	20	4,43	6	10
2021	17	146	15	0,88	6	11
2020	27	394	7	0,26	8	19
2019	12	249	11	0,92	7	12
2018	11	362	8	0,73	4	11
2017	5	59	4	0,8	3	5
2016	1	22	1	1	1	1
2015	4	200	3	0,75	2	4

Notes: TP=total publications, NCP=number of publications cited, TC=total citations, C/P=average citations per publication, H=h-index, G=g- index

As shown in Table 1, the year 2020 recorded the highest number of cited publications, reflecting outstanding research quality with an H-index of 8 and a G-index of 19. This suggests that 2020 was a particularly productive period for studies related to AR. The pandemic and COVID-19 occurred that year, so many technology-based learning topics were studied, including AR (Maas & Hughes, 2020; Dasari et al., 2024).

Citation Trends by Author Country of Origin

Publications related to AR and critical thinking have been researched in various countries (Cabiria, 2012). Source bibliography merge analysis can help identify essential journals of this research area and their interdisciplinary characteristics. Figure 3 illustrates the results of the source bibliography merge analysis conducted using VOSviewer, highlighting ten significant sources out of 150 documents, with a minimum of 19 citations.

Among these sources, Taiwan, Malaysia, and India are prominent. Publications from Taiwan have received widespread citations because of their availability of open access and high-quality content (Maas & Hughes, 2020).

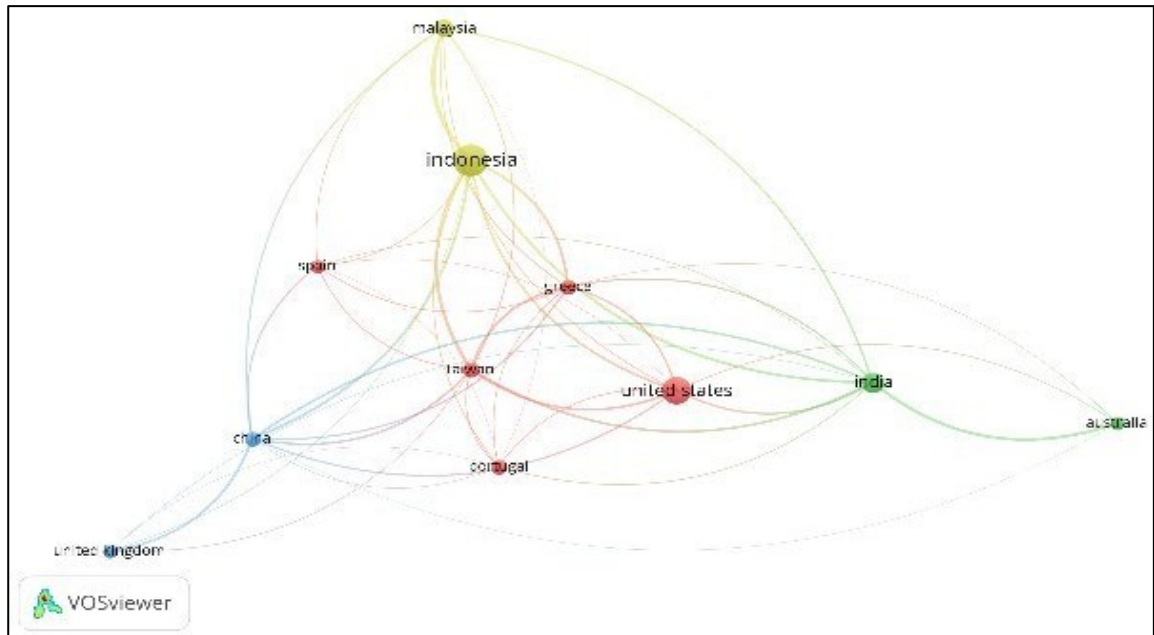


Figure 3. Distribution of Authors' Countries of Origin based on the HighestNumber of Citations

Figure 4 lists the top 11 countries based on the number of citations and documents in this field. The figure highlights the geographical distribution of research contributions and scientific impact, enabling a comparison between countries in terms of both research productivity and citation performance. This analysis helps identify the leading countries that have played a significant role in advancing knowledge and influencing the development of the field.

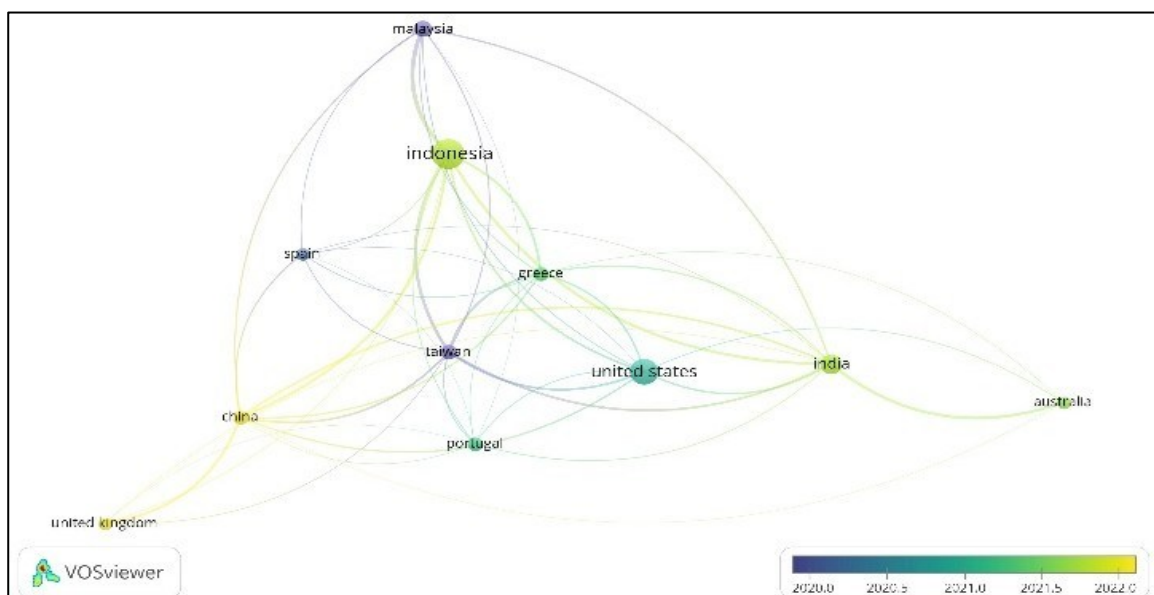


Figure 4. Distribution of Research Novelty Based on Bibliographic Analysis of a Country

Table 2. Distribution of Authors' Country of Origin based on the Highest Number of Citations

No	Country	Cluster	Documents	Citations	Total LinkStrength
1	Taiwan	1	7	425	194
2	Malaysia	4	8	230	147
3	India	2	12	144	201
4	Indonesia	4	28	137	282
5	United states	1	21	136	127
6	Australia	2	5	89	52
7	Spain	1	5	66	42
8	Portugal	1	6	59	34
9	China	3	5	49	179
10	United Kingdom	3	6	22	40
11	Greece	1	6	19	130

Figure 3 and Table 2 display the distribution of the countries of origin and authors with the highest number of citations in the AR and critical thinking field, as identified by VOSviewer. They highlight 11 countries, each with a minimum of six publications and at least 19 citations, out of the 43 countries in the VOS viewer dataset. Visualisation of research novelty, data analysis, abstracts, findings, and research results from several articles affiliated with the Taiwan region shows that research conducted based on quasi-experiments shows that using AR media in classroom learning can increase students' understanding and motivation. Therefore, these articles are widely cited by other researchers (Faridi et al., 2021; Rizki et al., 2024; Wibowo, 2023).

Most Influential Journal Trends

Of the 150 articles analysed using VOSviewer, those discussing AR in the context of critical thinking are likely to be published in several journals, as Table 3 shows.

Table 3. Most Influential Journal Trends

No	Source	Cluster	Documents	Citations	Total Link Strength	Category Quartile
1	Applied Sciences (Switzerland)	2	2	79	37	Q1
2	Computer Applications in Engineering	3	2	61	42	Q1
3	Education Sciences	2	2	32	13	Q1
4	Electronics (Switzerland)	3	2	27	24	Q1
5	Sustainability (Switzerland)	3	2	26	23	Q2
6	Journal of Physics Conference Series	1	12	22	48	Q1
7	Education and Information Technologies	1	2	21	21	Q1
8	AIP Conference Proceedings	2	9	16	17	-
9	Journal of Technology and Science Education	1	2	9	12	Q1
10	International Journal of Advanced Computer	1	2	6	13	Q3

Figure 5 visualises the analysis of publication sources. The figure presents the distribution of publications across different sources, highlighting the journals, conference proceedings, and other outlets that have contributed to the research area. This analysis provides insights into the primary channels of scholarly communication and helps identify the most influential publication venues within the field.

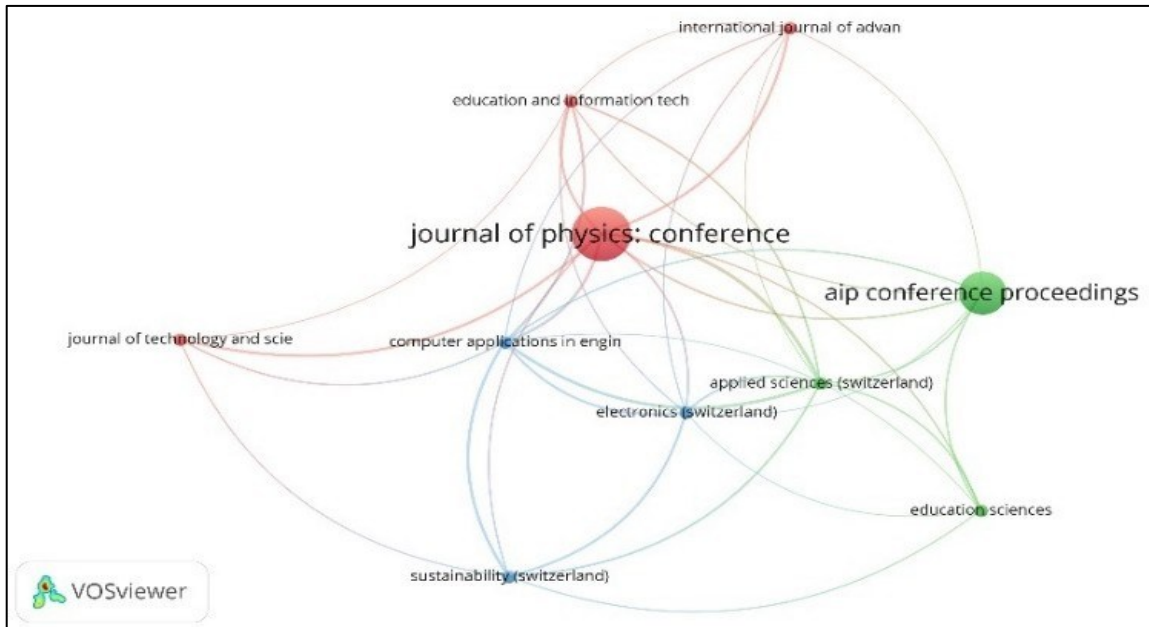


Figure 5. Bibliographic Relationship Analysis Mapping of Publication Sources

Table 3 lists the top 10 media sources, comprising eight journals and two conferences. These sources cover computer science, engineering, science, and physics research. Figure 5 reveals that the Journal of Physics Conference Series has the highest total link strength, 48. This indicates a promising avenue for researchers to submit their articles on the research theme of "Augmented Reality" Based on the literature review and analysis of Table 3, five journals are highly recommended for future research: Applied Sciences (Switzerland), Computer Applications in Engineering, Education Sciences, Electronics (Switzerland), and Sustainability (Switzerland). These quartile journals often feature experimental research on developing AR media to enhance critical thinking.

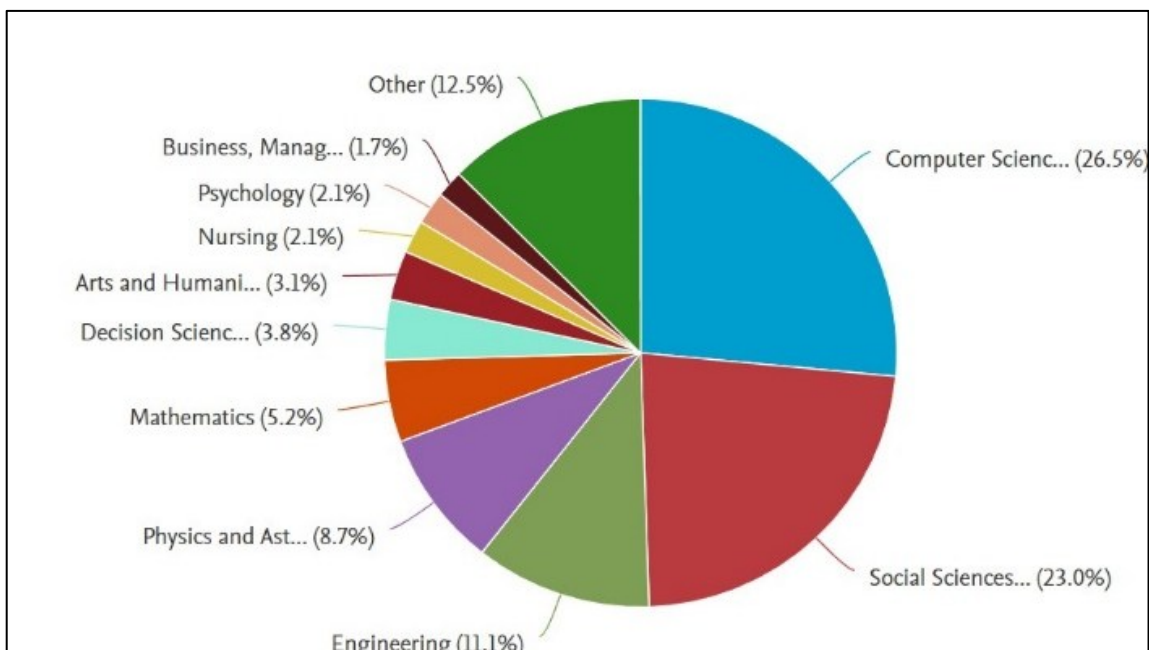


Figure 6. Publication of the AR in Critical Thinking Subject Area

Figure 6 presents the top ten subjects related to AR and critical thinking research. Computer Science dominates the field, accounting for 26.5% of the documents. The following five most prevalent subjects are Social Science (66 papers), Engineering (32 documents), Physics and Astronomy (25 documents), Mathematics (15 papers), and Quantitative Science (15 documents). This demonstrates the wide-ranging applicability of AR across various disciplines, particularly Computer Science, Engineering, Mathematics, Social Sciences, and Science.

Publication Trends by Name of Influential Authors

A more in-depth VOSviewer analysis was performed to identify influential authors in this field. The results of this analysis, which categorise publications by the most prolific authors, are summarised in Table 4.

Table 4. Distribution of 10 Authors with The Most Citations

Author	Documents	Citations	Total Link Strength
Mantri, Archana	6	88	467
Singh, Gurjinder	3	67	368
Pares, Narcis	2	60	110
Schaper, Marie-Monique	2	60	110
Kumar, Amit	2	21	265
Hosseini, Samira	2	15	67
Bakri, Fauzi	2	14	56
Muliyati, Dewi	2	14	56
Kaur, Deepti Prit	2	13	184
Hidayat, Wahyu Nur	3	13	132

According to data obtained from the Scopus database, Mantri Archana has authored six publications focusing on the application of AR to enhance students' critical thinking skills. Among these, one of her most frequently cited studies is titled "A Framework Utilizing AR to Improve Critical Thinking Ability and Learning Gain of the Students in Physics." This study investigates the development of an AR-based learning environment to help students understand concepts such as magnetic fields, electric currents, electromagnetic waves, Maxwell's equations, and Fleming's rules for electromagnetism using a quasi-experimental design (Dutta et al., 2022; Gargish et al., 2020). The results reveal that learning supported by AR has a significant positive effect on students' critical thinking abilities and learning achievements, facilitating the visualization of abstract physics concepts and improving overall understanding.

Research Focus and Novelty of AR-related Research in Critical Thinking

Figure 7 illustrates how a VOSviewer analysis revealed a set of keywords associated with AR in the context of critical thinking.

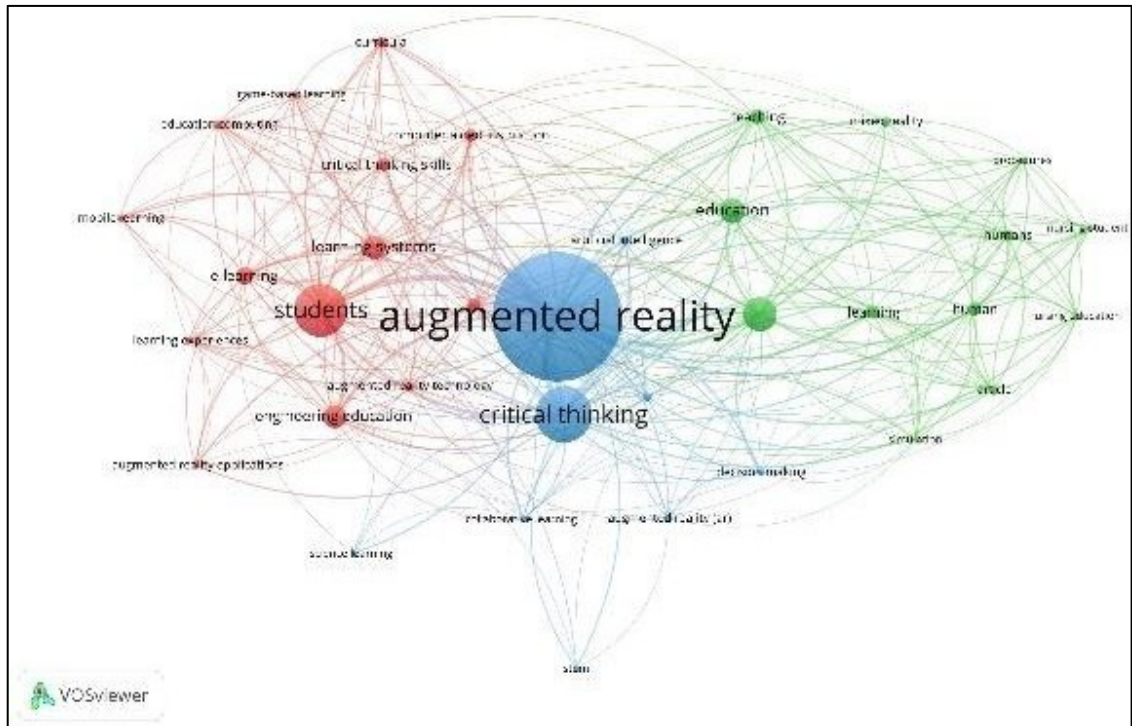


Figure 7. Network Co-Occurrence Visualisation Mapping of All Keywords

The keyword relationship used by the author can be seen in Figure 7. Co-occurrence network visualisation mapping. A total of 35 keywords were identified in the analysis. Research on the development of AR media to enhance critical thinking from 2015 to 2024 is categorized into three distinct clusters, represented by different colours. The blue cluster represents the largest group and constitutes the primary research focus, followed by the red and green clusters. The size of each circle corresponds to the frequency of keyword co-occurrence, where larger circles indicate higher occurrence values and stronger thematic prominence.

The first cluster, represented by red circles, comprises 14 keywords, with the largest circle indicating the primary research focus. Within this cluster, the keywords student and learning show the highest co-occurrence frequency, signifying that studies employing AR technology have predominantly centered on enhancing student learning experiences. The impact of AR-based learning media on enhancing critical thinking is the focus of this research. Several studies have shown that the use of AR-based learning media can improve students' critical thinking skills and increase their motivation in learning (AL-Hileh & Alhusamia, 2023; Aliftika et al., 2021; Cabiria, 2012; Caratozzolo et al., 2021; Chang & Hwang, 2018). Research conducted by Shao-Chen (2019), which discusses the AR-based flipped learning system, significantly improves student groups' learning achievement, motivation, critical thinking, and self-efficacy (Abdelrahim, 2023; Muliani et al., 2024).

The second cluster consists of 12 keywords, each with a green circle: article, education, humans, learning, mixed reality, nursing education, nursing student, procedures, simulation, teaching, and virtual reality. The largest green circle indicates the research focus. In the second research focus, the keyword with the largest circle is Virtual Reality.

The third cluster is keywords with blue circles consisting of 9 items: artificial intelligence, AR, collaborative learning, critical thinking, decision making, problem-solving, science learning, and STEM. The dominant blue circle signifies the primary focus of the third cluster, with AR emerging as the most frequently occurring keyword, reflecting

its pivotal position in this research domain. This shows that using AR media in learning affects students' learning outcomes in understanding concepts, abstracts, and motivation (Muliani et al., 2024; Faridi et al., 2021; Rizki et al., 2024; Hayek et al., 2023). A subsequent analysis was conducted to identify research novelties based on the overlay visualisation results from VOSviewer, as presented in Figure 8.

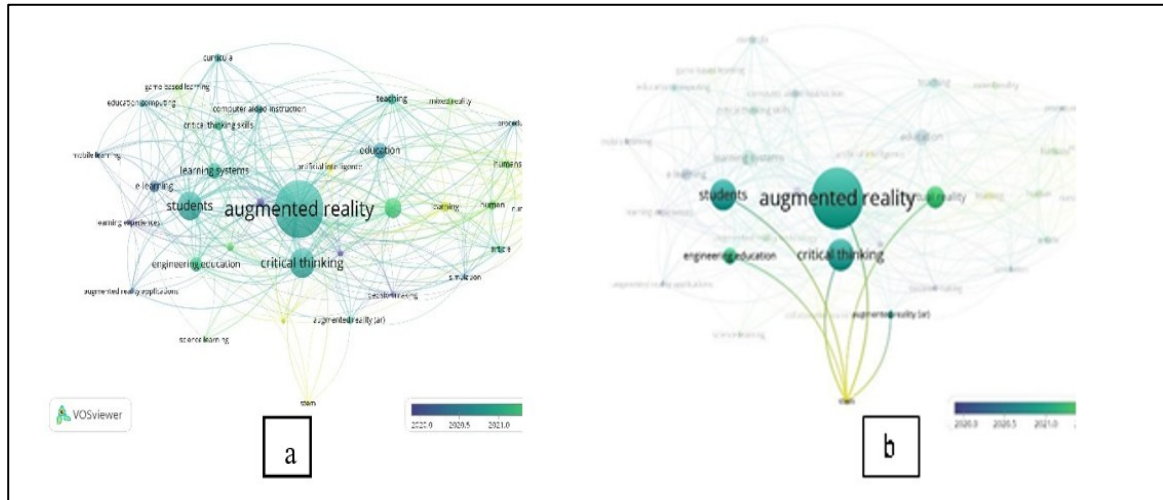


Figure 8. Overlay Visualization (Research Novelty), a). All Keywords, b). STEM Overlay Visualization

The novelty of research on using AR media to enhance critical thinking from 2015 to 2024 can be discerned from the keyword associations in Figure 8a. The overlay visualisation highlights two primary categories: research focus keywords and emerging themes. Yellow circles indicate emerging themes like STEM, artificial intelligence, nursing education, and game-based learning. These keywords have only recently been used with AR and critical thinking research. These emerging research themes can serve as valuable references for future researchers exploring topics aligned with their respective fields. As depicted in Figure 8b, the STEM keywords have yet to connect to game-based learning, computing education, mobile learning, or nursing education. This suggests that the relationship between these keywords could be a promising avenue for further research on using AR media to enhance critical thinking (Faridi et al., 2021; Faridi et al., 2021).

CONCLUSION AND SUGGESTIONS

Based on the findings and discussions presented above, it can be concluded that AR media has contributed to enhancing critical thinking from 2015 to 2024. The peak in publication trends occurred in 2022, with 30 documents. Meanwhile, the highest citation trends were observed in 2020, with an NCP value of 349, an h-index of 8, and a g-index of 19. Taiwan emerges as the leading country in research on the influence of AR-based learning technology media in enhancing critical thinking. AR research has extensive applications across various fields, including computer science, engineering, mathematics, social sciences, and science. The research focus is delineated into three main areas: 1) AR, 2) VR, and 3) Critical thinking and students. Emerging themes in this domain include STEM, artificial intelligence, nursing education, and game-based learning. These new research themes can serve as valuable references for future researchers exploring topics within their respective fields. The research focus discussed in this paper can serve as a valuable reference for future researchers pursuing themes aligned with their respective

fields. The relationships between these keywords, a novelty in research related to AR technology-based learning media for enhancing critical thinking, are conducive to further exploration. Researchers can also enrich their investigations by exploring additional data sources beyond Scopus, such as PubMed, Open Alex, and others.

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