JIPF (JURNAL ILMU PENDIDIKAN FISIKA)
p-ISSN: 2477-5959 | e-ISSN: 2477-8451 *Vol. 9 No. 3, September 2024, Page 438-452*

Research Trends of Augmented Reality in Physics Education based on Scopus Database in Thirteen Years (2010-2023): A Bibliometric Approach

Siti Nurjanah [1*)], Muhammad Iqbal [2], Jumriani Sultan [3], Sholihin [4], Nur Ulyasari [5], Salman Rashid [6]
Yogyakarta State University, Indonesia[1,2,3], Tanjungpura University, Indonesia[4,5], University of Turbat, Pakistan[6]
[*)]Corresponding E-mail: siti960pasca.2023@student.uny.ac.id

Received: February 29th, 2024. Revised: August 7th, 2024. Accepted: August 8th, 2016

Keywords :
Augmented Reality; Physics Education; Bibliometric; Biblioshiny; RStudio

ABSTRACT
This research is useful for mapping the development of AR research in physics learning. This research is a bibliometric study to analyze scientific publications related to the implementation of Augmented Reality (AR) in physics learning. Data obtained from the Scopus database by applying certain inclusion criterias, resulting in 55 relevant publications from 2010 to 2023. Data analysis is done using Rstudio application with biblioshiny package. The analysis is done to extract a variety of bibliometric information such as publication trends, authors and influential countries, keywords, themes, and research trends. The analysis shows a significant increase in publications since 2017, with Germany and Indonesia as the most research countries. The integration of AR into learning methods like PBL is found to be the most dissected. Inter-country and inter-affiliate research collaboration on this topic still needs to be enhanced. Existing research is largely focused on the potential of augmented reality to enhance students' interest, motivation, and understanding of physical concepts through interactive and realistic visualizations. These findings could inform the direction of future research to produce significant innovations in improving the quality of physics learning.

INTRODUCTION

Augmented Reality (AR) research and development has grown rapidly in recent years [1] [2]. At first, AR technology was more focused on military solutions and advanced technology that required large investments [3]. Over time, the potential of AR has begun to attract the attention of educational researchers [4]. As a result, research findings about the benefits of AR in learning are beginning to emerge. The use of AR has been found to facilitate students with a more efficient and different

learning experience [5]. AR can also enhance the opportunity of learners to become more skilled and knowledgeable [6]. Using AR in learning can create a fun, enthusiastic, and immersive learning environment. Research conducted by Chang and Hwang showed that the application of AR has positive benefits to educational outcomes such as learning achievement, attitudes, motivation and cognitive burden [7]. In addition, the use of these learning alternatives can also improve the level of mathematical communication and critical thinking skills [8] and 21st century skills [9]. Another major advantage of AR is that it enables interaction between real and virtual objects by combining two real-real and virtual realities [10] [11]. Augmented Reality can combine both real and Virtual objects simultaneously, providing an opportunity for real interaction, and providing accurate collaboration of real and virtualized objects [12] [13]. These diverse benefits demonstrate AR's capacity to create engaging learning environments and enhance various student competencies, paving the way for its broader adoption in educational settings.

Recognizing the substantial potential of AR in education, numerous developed countries have begun integrating this technology into their educational systems. In the United States, AR technology in education enhances student engagement and understanding of complex concepts, creating an immersive and interactive learning environment. It also fosters creativity, problem-solving skills, and helps connect theory with practice [14]. Additionally, universities in Turkey have implemented AR technology known as Arloopa, which is an AR visualization tool that merges the physical and digital worlds into one. The application of AR in education has proven useful in making learning enjoyable, providing sustainability in education, and enhancing creativity [15]. Furthermore, Malaysia has adopted Augmented Reality (AR) in its educational system to improve focus, interest, and understanding, demonstrating potential for a more competitive and innovative generation [14]. Japan has implemented AR simulation applications designed for physics, aimed at helping high school students understand concepts such as mass, gravity, and friction. This application integrates real-time object movement on inclines, vector modulation based on forces, and physics calculations using user-defined parameters, which enhances students' problem-solving skills and fosters creativity [16]. This indicates that several developing countries have implemented AR to enhance education. Augmented Reality (AR) continues to evolve in Indonesia across various educational sectors. Research has shown the success of AR in improving physics education by increasing student engagement and motivation. In one Indonesian city, Bengkulu, an AR-assisted physics e-book was developed using flipbook technology. Research indicates that students experienced increased motivation and improved learning outcomes after using the developed physics e-book [17]. Thus, AR significantly contributes to both cognitive and affective aspects of physics learning. The successful implementation of AR in these countries serves as a model and inspiration for developing countries, including Indonesia, to explore and adopt similar technological innovations in their educational frameworks.

While Indonesia has initiated the implementation of AR in education, its widespread adoption faces challenges due to the country's geographical complexity and infrastructural limitations. The implementation of AR in Indonesia has been applied in several regions, but it is not yet widespread due to the country's thousands of islands, which necessitates improvements in technological infrastructure. To address the challenges of implementing Augmented Reality (AR) in Eastern Indonesia, solutions include enhancing technological infrastructure and training human resources. Firstly, technological infrastructure such as adequate internet connectivity, hardware like AR-supporting smartphones or tablets, and relevant software must be available and accessible to the community. The government and private sector can collaborate on investing in improving technological infrastructure in these areas. Additionally, government policy support in the form of regulations and incentives is also needed to accelerate the development of AR technology in this region. Furthermore, training and development of human resources are crucial for maximizing the use of AR technology in Eastern Indonesia. Training programs for teachers and educators to integrate AR into their teaching methods will help expand AR usage in education [18]. Through these concerted efforts, it is anticipated that the implementation of AR in Indonesian education, particularly in the field of physics, will continue to evolve and expand.

In the context of physics education, AR has demonstrated significant potential in enhancing student comprehension and engagement with this complex subject concepts. AR technology offers the ability to provide descriptive resources and visualize physical concepts and phenomena, enabling students to learn more intuitively and improve their understanding through visual and interactive presentations [19] [20] [21] [22]. Research has shown that AR can enhance learning achievement, stimulate critical thinking, and contribute to long-term retention of physics concepts [23] [24] [25]. The increasing prevalence of AR in physics education has led to substantial changes in teaching strategies [26]. AR's unique characteristic of merging real and virtual objects makes it an effective tool in physics education, stimulating students to acquire scientific knowledge, facilitating concept comprehension, and creating an engaging learning environment [27]. Through three-dimensional visualization, AR can assist students in explaining abstract concepts and improve mathematical communication and critical thinking skills [28] [29]. AR has demonstrated positive impacts on various aspects of student learning, including increased engagement and active participation [25] [30] [31], enhanced inquiry-based learning approaches [31], improved learning performance and achievement [25] [32], and higher satisfaction with the learning process [25]. The integration of AR with other pedagogical methods, such as Problem-Based Learning (PBL), has also shown promising results in enhancing learning outcomes and fostering positive attitudes towards physics [23]. Furthermore, AR can be utilized to supplement traditional experiments with virtual content, including videos and simulations, leading to superior learning outcomes compared to conventional laboratory practices [22]. Given the abundance of research related to AR in physics education, conducting a bibliometric analysis is essential to examine the consistency of research findings. Such analysis can provide a comprehensive review of the literature by identifying research trends, countries, authors, and related keywords [33]. Given the proliferation of research on AR in physics education, conducting a bibliometric analysis becomes crucial to examine the consistency of research findings and identify emerging trends, thereby guiding future developments in this rapidly evolving field.

This research is relevant to some research. Research by Dewi et al [34] investigated research trends of the development of research in the field of Augmented Reality in learning Physics over ten years (2012-2021) using VOSviewer on scopus databases. Second, Zhang et al [35] investigated research trends of augmented reality and mixed reality in surgical research uses Web of Science databases with GraphPad Prism 8 and Vos Viewer for visualization. The results of the study showed the highest data in 2019 and the country with the related research contribution is the USA. The trend of the research suggests that the number of global publications on augmented reality will continue to increase in the coming years [36]. Third, Moral-Muñoz et al [37] researched on trend mapping of hotspots and posts using Web of Science databases. The results showed that bibliometric analysis was able to analyze the progress of research every year, countries with high productivity levels, journals with large contributions to related themes, networking of authors and grouping of keywords that could give a clear understanding of the classification [37]. This research differs from previous research in that it will perform bibliometric AR analysis on research in physics education using the RStudio application with biblioshiny package on the Scopus database. This article also presents a stricter filtration and focus on learning physics in educational journals. In-depth content analysis will also be done on some articles that make significant contributions to the development of science in this topic. This research is expected to be able to make important contributions in the interests of the educational stakeholders, and researchers in understanding the development of research related to AR in physics learning such as research developments each year, research trends, the conductivity of authors and countries and related keywords.

Bibliometrics is one approach that can be employed to map research related to AR in physics education. The results of bibliometric methodology are particularly valuable for decision-making regarding research priorities and for observing trends in science and technology [38]. Bibliometric methodology, utilizing a bibliometric analysis approach, yields various scientific outputs that have been published in specific fields through the application of numerical and statistical analyses on several indicators [39]. Bibliometric analysis itself is not a replacement for other review methods but rather a complementary approach that addresses the shortcomings of these methods and is closely

associated with the term informetrics [39] [40]. The bibliometric method differs significantly from experimental methods; in bibliometrics, the data used originates from publications in the relevant field, whereas in experimental methods, the data is obtained from conducted trials. Furthermore, bibliometric analysis excels in identifying macro patterns and trends related to publication data, providing a holistic overview of the development of a discipline, while experimental research emphasizes a micro approach by offering in-depth, controlled, and often causal insights into specific phenomena.

METHOD

This research was a quantitative study employing bibliometric analysis to explore the application of Augmented Reality in physics education. Through meticulous bibliometric analysis and stringent inclusion criteria, it offers valuable insights and trends in the use of Augmented Reality for physics education, highlighting its relevance and potential to guide future research and educational practices. Studies utilizing bibliometric methods can aid researchers in identifying significant research trends and topics [41], and these methods offer a comprehensive view of scientific advancements across different regions and disciplines globally [42].

In this research, the first step is to determine the database of the research carried out. We chose the Scopus database. After that, the researchers applied some inclusion criteria to ensure that the article to be analyzed could represent the purpose of the research. We applied the inclusion criterios to filter articles, as shown in Table 1. The third step was to filter the subject area by choosing social sciences because the research focused on the subject areas of education. As a result of these measures, 55 publications were published between 2010 and 2023. All analyzed publications are publicly accessible, and permissions for bibliometric analysis are inherently granted as part of academic publishing norms.

The analysis has been used to extract information from the corresponding publication set from the Scopus database. The general information of the publication collection has been summarized, and the number of publications each year is analyzed to identify trends in this field of research. The contributions of each country based on the number of articles and quotations published are analyzed to determine which countries are the most successful in this field. Besides, it's also seen AR topics that are most related to physics. The author uses the available Scopus database as well as the Rstudio application with biblioshiny package to perform data analysis.

Table 1. Criteria of article inclusion

Search within	Search documents
Article title	"Augmented Reality"
Source title	education OR educational OR teaching OR teacher OR teach OR pedagogy OR pedagogies
Article title, abstract, keywords	Physics

RESULTS AND DISCUSSIONS

General Results

In this section, we review the annual research results of the publication on Augmented Reality in Physics Education. By scanning Scopus indexed documents from 2010 to 2023, we found relevant publications. Of those, the majority (72%) were articles, 19% conference papers, 6% book chapters, and 4% reviews. The low annual growth rate of publication, which is only 22.51%, indicates that the topic of Augmented Reality in physics learning is not much of a concern for researchers in the field of physics education. Despite the publication of 55 research papers related to Augmented Reality in

physics education from 2010 to 2023, this number remains relatively low. According to Kamaruzaman et al [43], the limited research on Augmented Reality (AR) can be attributed to its perception as a novel concept in the field of education. Particularly in physics education, this concept requires meticulous development of AR media. Consequently, although publications in Scopus-indexed journals remain sparse up to 2023, there has been an increasing number of AR-related articles in physics education published in Sinta-indexed journals. The application of AR in education has made significant progress in urban areas; however, rural regions still face challenges, primarily due to incomplete infrastructure necessary for AR implementation. Furthermore, the limited availability of AR-based learning media poses obstacles for both urban and rural education. Therefore, there is a pressing need for the development of valid and reliable media related to learning materials enhanced by AR, which can be widely utilized and support educational advancement in both urban and rural areas. Figure 1 presented shows a pattern of annual publications and total citations per year, which depicts the trend of publication growth and citation related to this topic.

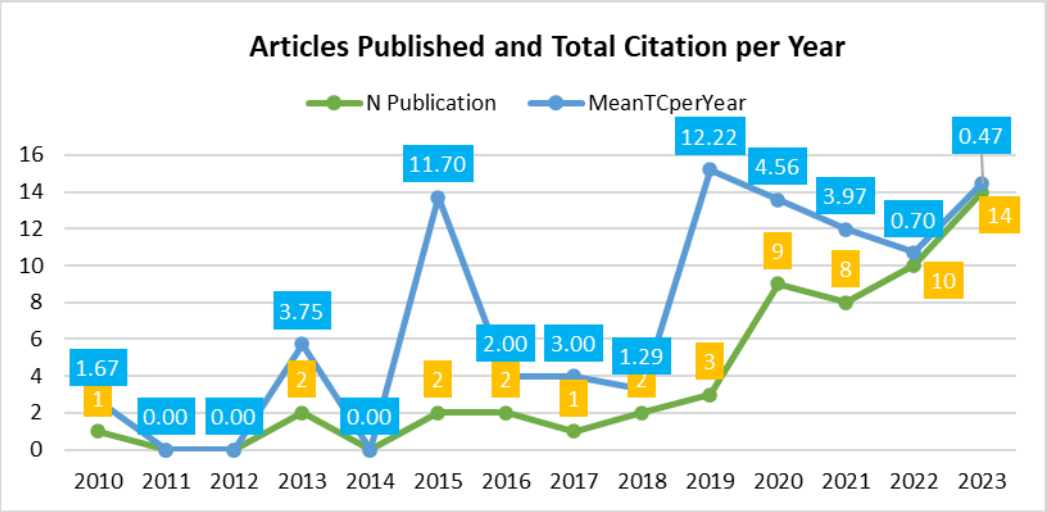

Fig 1. *Articles published by years, 2010-2023 (n=54) and total citation per year*

A conference paper written by Jerry and Aaron of Woodgrove Secondary School, Singapore, was first published in 2010 and presented at the 2nd International Conference on Education Technology and Computer in 2010. The paper discusses the use of Augmented Reality technology in learning physics on the subject of Kinetic Graphics. Their study shows that integrating Augmented Reality technology with inquiry-based learning can improve students' understanding of topics considered difficult. This paper also discusses the challenges and limitations in the use of information and communication technology in the learning process [44]. The next publication appeared in 2013 by Buesing and Cook who discussed the implementation of Augmented Reality technology in high school physics learning to help students understand the concepts of magnetic fields that are difficult to visualize. Their research divided the students into three groups: groups that studied with textbooks, magnetic and iron powder demonstration groups, and groups that used the AR Magnet application. The results of the study indicated that the most significant improvement in understanding of the magnetic field concept was obtained in the group that learned with the Magnet AR application, in particular in sketching magnetical fields around magnetic bars [45]. Both early articles on this topic both explore the benefits of Augmented Reality technology in learning physics to help students understand physical concepts on concepts that are difficult to visualize.

Before 2017, research related to the application of AR in physics learning had not been much done. The publication of available research results ranges from one to two papers per year. A significant increase in publications on the subject has only occurred since 2017, despite a decrease in 2021 allegedly due to the Covid-19 pandemic. The highest number of publications was reached in 2023 with 14 articles. This indicates that more and more researchers in the field of physical education are

realizing the potential of AR to improve the effectiveness of learning physics and help students understand the concepts of physics. The findings are in line with the meta-analysis of several previous studies on the impact of AR on education. The various studies reveal that AR has a positive influence on the learning process [46] [47] [48] [49] [50] [51] [52].

Source of Impact

Table 2 presents the ten most cited papers based on Scopus citation data related to the topic of Augmented Reality in physics learning. The analysis of the citation aims to identify influential and important articles that are often referred to by other researchers on this topic. With this, an overview of major literature and research developments in the application of Augmented Reality in physical education can be obtained.

Table 2. Ten most cited articles in AR physic education

Reference	DOI	Source	TC	TCY
Fidan & Tuncel [23]	10.1016/j.compedu.2019.103635	Computers & Education	200	33,33
Saidin et al [53]	10.5539/ies.v8n13p1	International Education Studies	177	17,70
Cai et al [54]	-	International Journal of Engineering Education	81	6,75
Jesionkowska et al [55]	10.3390/educsci10080198	Education Sciences	75	15,00
Altmeyer et al [56]	10.1111/bjet.12900	British Journal of Educational Technology	74	14,80
Cai et al [57]	10.1111/bjet.13020	British Journal of Educational Technology	60	15,00
Ibanez et al [58]	10.1109/TE.2014.2379712	IEEE Transactions on Education	57	5,70
Faridi et al [59]	10.1002/cae.22342	Computer Applications in Engineering Education	41	10,25
Martin-Gonzalez et al [29]	10.1080/14703297.2015.1108856	Innovations in Education and Teaching International	34	3,78
Jerry & Aaron [44]	10.1109/ICETC.2010.5529447	2nd International Conference on Education Technology and Computer	25	1,67

Article from Fidan and Tucel in 2019 is the most cited article. This research integrates AR into PBL activities for learning physical concepts such as style, energy, stress, and physical work. AR is used to support several stages in the PBL process such as problem presentation, data collection, and evaluation. PBL and AR are closely interconnected. AR, with its basis in virtual realism, and PBL, grounded in real-life contexts, form a highly compatible combination. The AR method is particularly well-suited for integration with PBL, as noted by Fidan & Tuncel [23] and Novita [60]. The results showed that the integration of AR into PBL significantly improved student learning performance and positive attitude towards physics compared to just PBL and traditional learning. AR also contributes to the long-term retention of physical concepts. The study concludes that AR is potentially an effective pedagogical tool to stimulate positive emotions in students in PBL [23]. AR can be a powerful tool for learning physics. Implications are the need for good AR design for PBL in physics learning, considering the cognitive and emotional aspects of students. This integration could be a future trend for science education.

The second most cited article was by Saidin et al [53]. This article is a literature review that discusses the potential of AR in education based on a review of previous research in various fields of science, as well as its advantages and challenges to be implemented in learning. The advantages of AR over traditional technology and conventional teaching methods in the learning process, such as visualizing abstract, interactive concepts, increasing student understanding and interest. Meanwhile, current AR constraints such as internet access, technical issues, and time-consuming usage procedures [53].

The third most cited article was by Cai et al [54]. This article discusses the use of AR technology for simulating physics experiments in the classroom and its potential to enhance student learning experience in physics learning. The use of augmented reality (AR) technology to simulate experimental shadow formation on the lens in physics learning. Quasi-experimental research was carried out on 2nd grade 8th grade high school students in China. One class used AR and one control class without AR. The results showed higher increases in post-test values in the AR class, although statistically no significant differences with the control class. The questionnaires showed students responded positively to the use of AR, helping them to focus, motivate learning, and understand the concepts of physics. AR is able to simulate complex and costly physics experiments in an interactive and realistic way [54]. AR has the potential to boost students' interest and motivation in learning physics, although it does not necessarily improve their understanding of concepts significantly.

Overall, the three most cited articles on this topic discuss the huge potential of AR technology to be applied in physics learning to enhance student interest, motivation, and learning experiences by visualizing physical concepts and experiments interactively and realistically.

The Most Relevant Sources

Most of the literature relevant to this topic is journal articles. Based on the data we have obtained since 2010, the Physics Education and Physics Teacher journals appear to be researchers' top choice to publish articles on the application of Augmented Reality in physics learning. This pattern of publication indicates that the topic of Augmented Reality on physics learning is appropriate and aligned with the field coverage and focus of the two journals. Other researchers interested in conducting similar research may consider both journals as target journal for submitting manuscripts of their research.

The journal Physics Education has been actively published since 1966, published by the UK-based IOP Publishing Ltd. This journal focuses on supporting a community of physics teachers with primary scope of physical learning for students aged 11 to students. Its scope includes advancement of physical knowledge, educational research, up-to-date curriculum development, as well as teaching and classroom management strategies that motivate and engage students. Although it has published the most articles on Augmented Reality in physics learning, it is not in the top 10 of the most cited journals. This indicates that articles related to the subject in this journal have not had much significant impact compared to articles from other journals. Teichrew and Erb tahun 2020 was the most cited in the journal, ranked 15th in the top quotations. The article discusses the use of AR in physics learning with GeoGebra, enriching the physical structure of experiments with virtual objects [61].

The Physics Teacher journal has been actively published since 1996, published by the American Institute of Physics in the United States. The journal's scope covers basic physics teaching and topics of contemporary physics, applied physics as well as history of physics at all levels, from high school to college. Topics discussed include innovative physics demonstrations, new methods of laboratory experiments, a clearer presentation of difficult concepts, the integration of cutting-edge technology in teaching, historical insights to enrich physical courses, and the application of research ideas in physical education in the classroom. Although it has published several articles on Augmented Reality in physics learning, the journal is not in the top 10 in terms of the number of quotations. The article with the highest quotation is ranked at 18, written by Buesing and Cook in 2013 on the use of AR for the concept of magnetic fields [45]. However, the journal is the publisher of the first journal article in the history of publication of this topic in the scopus database. Thus, the journal's contribution to the development of Augmented Reality research in physics learning is considerable.

The Influential Authors and Countries

Table 3 shows the five most productive authors in research education physics topics AR.

Table 3. Top 5 most productive authors in AR physics learning

Author	Affiliation	Country	Number of articles	Most Cited Article (DOI)	Most article citations	Order of authors on most cited articles
Vidak A.	Sveučilište u Zagreb	Croatia	4	10.1088/1361-6552/ac21a3	4	First Author
Cai S.	Beijing Normal University	China	3	-	81	First Author
Altmeyer K.	Universität des Saarlandes	Germany	3	10.1111/bjet.12900	74	First Author
Brünken R.	Universität des Saarlandes	Germany	3	10.1111/bjet.12900	74	Sixth Author
Kuswanto H.	Universitas Negeri Yogyakarta	Indonesia	3	10.3926/jotse.1714	2	Second Author

Based on analysis, it was found that the author of the largest number of journal articles on Augmented Reality (AR) in physics learning was dominated by researchers from the European continent. This active involvement of European researchers indicates a considerable interest in the region in AR research in physics learning. Vidak A. is the most productive writer with four published articles. His most cited article deals with AR simulations on Android mobile devices to investigate the gravitational styles of round objects depending on mass and distance, to the determination of the gravity constant (G) values [62]. The second-largest author is Cai S. with three articles. His most widely cited article deals with the use of AR to simulate shadow formation experiments on the lens in physics learning. Her research findings showed positive student responses to AR, helped focus, motivated learning, and understood the concepts of physics [54]. Meanwhile, Altmeyer K. and Brünken R. each wrote three articles, with the most cited joint articles. The article discusses the implementation of AR in physics practices by showing real-time measurement data on student-built circuits. Compared to learning without AR, the use of AR has been shown to improve student conceptual understanding even though the cognitive load is fixed [56]. The fifth most productive author is Kuswanto with three articles. His most cited article studies the effectiveness of AR-based physics modules with local intelligence in improving students' ability to communicate mathematically and critically [63].

Table 4 shows Countries' Scientific Production and Affiliation active, mapping done based on Author data.

Table 4. Countries' Scientific Production and affiliation

Category	Top 10 Rankings
Countries' Scientific Production	Germany (46); Indonesia (33); USA (26); China (17); Turkey (15); Croatia (9); Italy (9); India (8); Malaysia (6); Australia (5)
Affiliation	Chitkara University Institute of engineering and technology, India, Asia (8); Goethe University, Germany, Europe (7); Saarland University, Germany, Europe (7); Universitas Negeri Padang, Indonesia, Asia (7); Physics Education Research Group, Colorado, US (6); University of Zagreb, Croatia, Europe (6); University of Miami, Florida, US (5); Central China Normal University, China, Asia (4); German Research Center for Artificial Intelligence (DFKI), Germany, Europe (4); Gunma University, Japan, Asia (4)

The study suggests that Augmented Reality research in physics learning has attracted attention from four continents, namely Europe, Asia, America, and Australia. However, it appears that this topic has not received much attention from researchers in physics education from the African continent. Therefore, researchers from the four continent that have previously been active in this topic can consider collaborating with researchers of physics education in Africa. Based on the active affiliation

of institutions, Asia and Europe dominate. This indicates that institutions on both continents have directed their research focus on the application of Augmented Reality in physics learning. It is suggested that these institutions can engage in research collaborations with institutions on other continents such as Africa and Australia, so that the impact of research can be felt even more widely on a global scale.

Keyword Analysis, Themes, and Research Trends
In this section, we conduct a keyword analysis of 54 papers found from the Scopus database. This analysis includes the most pop-up terms, word clouds, and topic trends.

In this study, we identified the most frequently appearing terms in the topic of Augmented Reality in physics learning through the analysis of keyword plus. 10 keywords plus based on frequency of occurrence, augmented reality is the most often appearing word with a total of 15 occurrences, it is logical because the topic being analyzed is really focused on the application of augmented reality technology so that the term becomes the main key word frequently used by researchers in published articles. The second most frequently appearing keyword based on our analysis is students with an 8-fold appearance, this finding indicates that the target or subject of the Augmented Reality research carried out is mostly focused on students or students to help their learning process. AR has the potential to enhance students' understanding of abstract and difficult to visualize physical concepts. The third most frequently appearing keyword is computer aided instruction, which appears five times, indicating that the application of Augmented Reality technology in learning physics is often implemented with the help of a computer. Other keywords that appear in succession include e-learning, laboratories, learning environments, teaching, engineering education, virtual reality, and augmented reality technology. Virtual reality shows the correlations and differences between AR and VR in the context of learning. Overall, AR research in physical education is more focused on implementation and its impact in physics learning, in particular to help students understand physical concepts.

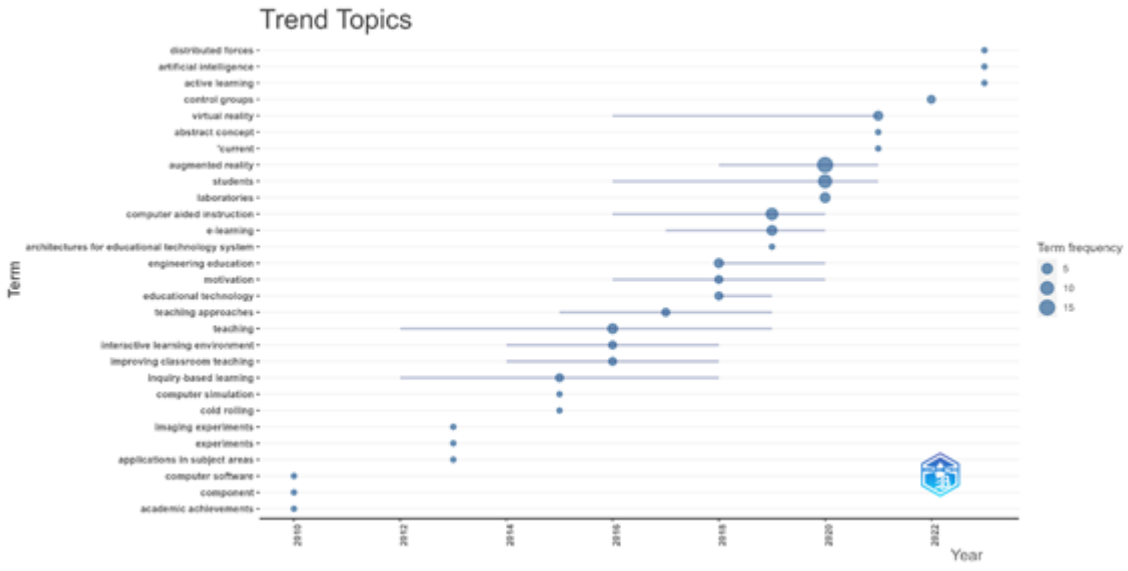

Fig 2. *Trend Topics*

Figure 2 shows the trend of discussion topics on research surrounding AR in physics education. In 2010, when AR research began to emerge in physics education, the dominant keywords were computer software, component, and academic achievements, indicating that in this early era, the trend of AR research in physical education was more focused on the development of software and the AR technology component itself as well as its application to improve student academic performance. Then in 2013, imaging experiments, experiments and applications in subject areas emerged as the trending

keyword, which meant that the direction of AR study in physicist education in that period shifted to its application in experimental modeling and simulation based and trial implementation for a variety of physical subjects. Furthermore, in 2015, inquiry-based learning, computer simulation, and cold rolling became popular keywords, indicating that the focus of AR research in physics education at the moment is aimed at its use to support inquisition-based physics learning, computational simulations, and cool rolling materials. Later in 2016, teaching, interactive learning environment, improving classroom teaching emerged as a trending keyword, which showed more research direction towards improving the quality of teaching and interactive teaching environments in the classroom through AR technology. In 2017, teaching approaches stood out as keywords, which meant more research interest in innovative approaches to teaching with AR. Further, in 2018, engiineering education, motivation, and educational technology became popular keywards, which indicated the research focus shifted to the application of AR in engineering education that can motivate students as well as its relationship with educational technologies. In 2019, computer aided instruction, e-learning, and architectures for educational technology systems dominated, indicating the research trend towards AR through computer aid and online learning as well as architecture of AR-based education technology systems. Keyword trend patterns for 2020 to 2023 also describe the development of research focus from the technology, methods, and teaching materials of physics using AR technology. Overall, the focus and direction of AR research in physics education continues to evolve following the progress of AR technology and physical learning needs.

Fig 3. *Word-cloud related to the research of AR in physic education (Generated using R)*

Figure 3 was generated using the R programming language to visualize the word-cloud. It presents wordcloud of the entire array of keywords of research topics AR in physics education that are interlinked to be identified. The closer to the center and the larger the size of the writing, suggests that the keyword is increasingly being discussed on AR research in physics education. It seems that Augmented Reality is closely related to students and computer aided instruction. Other keywords that also dominate are learning environments, e-learning, virtual reality, teaching, and laboratories. This indicates that in general, AR research in physical education is much focused on the use of AR technology as a computer aid to enhance student learning, both in real and virtual learning environments, as well as applied in online learning, laboratory activities, and teaching processes.

To complement this study mapping, we used thematic maps to analyze emerging topic trends. The thematic map divides the identified themes into strategic diagrams by axes X and Y. The axis X shows the centrality of a theme that defines its importance, while the axis Y shows the density which defines a theme's development.

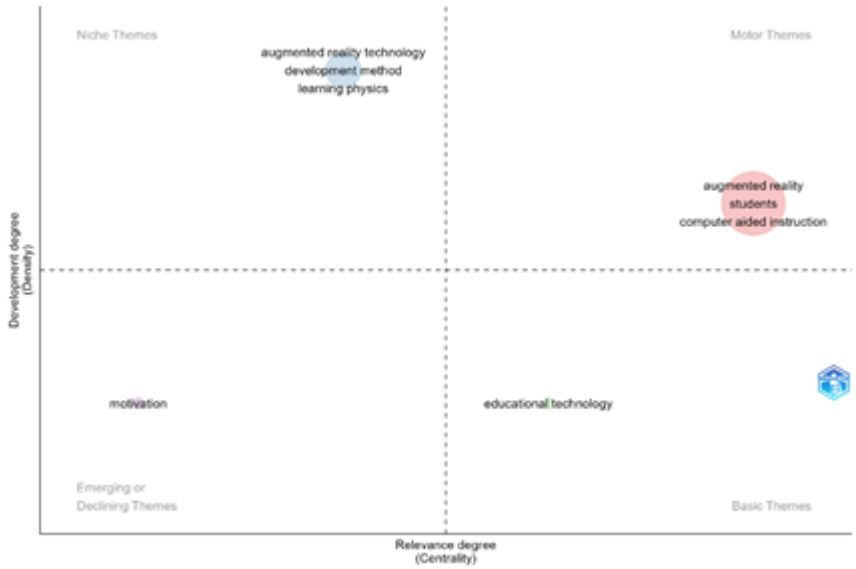

Fig 4. *Thematic map in AR physic education research*

The results of the thematic map analysis in Figure 4 show that educational technology belongs to the basic themes, which means that education technology is an important fundamental foundation in augmented reality research for improved physics learning. The integration of augmented reality into physical learning must take into account the principles of educational technology design in order to produce effective and beneficial physics learning solutions for students. Motivation belongs to the emerging or declining themes, which means that motivation is a topic that emerges or decreases in augmented reality research for learning physics. This indicates that student motivation has not been a major focus and needs to be further investigated the effectiveness of augmented reality in increasing student physics learning motivation. Augmented reality technology, development method, and learning physics belong to the niche themes, which means these three topics are specific themes that are rarely studied in relation to augmented reality for physics learning. However, the development of technology and augmented reality methods suitable for physics learning as well as its application to enhance students' physical learning is essential for further research so that augmented realities can provide optimal benefits for physics learning.

Augmented reality, students, and computer aided instruction belong to the motor themes, which suggests these three topics are major themes that are extensively researched in the use of augmented reality for learning physics. This is reasonable because the use of augmented reality technology must be tailored to students' characteristics and learning processes so that it can benefit students' improved physical learning. Based on this, researchers are further advised to focus on integrating augmented reality with a special emphasis on student motivation. Furthermore, the development of technology and methods of increased reality for physics learning should be a priority, while continuing to deepen their understanding of the role of Augmented Reality in relation to the student's characteristics, and the learning process. Thus, significant innovations can be produced to enhance physical learning through the use of augmented reality.

There are several previous studies that are relevant to this study including the study carried out by Talan in 2021 which explains the relationship of Augmented reality in STEM on the respondent by performing bibliometric analysis and obtained as many as 741 relevant studies from the database of WOS and got the state and spread of research related to Augmented Reality on STEM [64]. Furthermore, the research conducted by Masalimova et al [65] where the results of the research show that Augemeted reality has many advantages such as being able to motivate students and improve learning outcomes and judged that AR pain research is very important in education especially

bibliometrical research so that the trend of research relating to AR in the world of education is known [65].

So the updating of this investigation is to do bibliometric analysis on the augmented reality hat on the physics education is still undertaken. Hopefully from this research will be known the trends and topics that are very much needed to apply AR in the subject of its study.

CONCLUSION AND SUGGESTION

Research on augmented reality in physics education shows an increasing trend in publication in recent years. Nevertheless, this topic is still not getting much attention from researchers in the field of physics education compared to other topics. Inter-country and inter-affiliate research collaboration on this topic still needs to be enhanced. Current research is largely focused on the potential of augmented reality to enhance students' interest, motivation, and understanding of physical concepts through interactive and realistic visualization. Future research is expected to focus more on student motivation aspects, developments in technology and augmented reality methods, as well as their implementation specifically to improve learning of specific physical materials. Thus, the benefits of augmented reality in improving the quality of physical learning can be maximized through comprehensive and in-depth research. A limitation of this research is its reliance solely on data from the Scopus database, which may exclude relevant studies indexed in other databases. This research provides valuable insights into trends and developments in augmented reality research that can enhance physics education. It identifies key areas for future investigation and serves as a reference for researchers in physics education, highlighting potential research areas in augmented reality. Future studies should consider utilizing additional databases, such as Web of Science, to encompass a broader spectrum of relevant research.

REFERENCES

[1] Marín, V., Sampedro, B. E., Muñoz González, J. M., & Vega, E. M. (2022). Primary education and augmented reality. Other form to learn. *Cogent Education*, *9*(1), 2082082.
[2] Thees, M., Kapp, S., Strzys, M. P., Beil, F., Lukowicz, P., & Kuhn, J. (2020). Effects of augmented reality on learning and cognitive load in university physics laboratory courses. *Computers in Human Behavior*, *108*, 106316.
[3] Salmi, H., Thuneberg, H., & Vainikainen, M. P. (2017). Making the invisible observable by Augmented Reality in informal science education context. *International Journal of Science Education, Part B*, *7*(3), 253-268.
[4] Chen, C. H., Chou, Y. Y., & Huang, C. Y. (2016). An augmented-reality-based concept map to support mobile learning for science. *The Asia-Pacific Education Researcher*, *25*, 567-578.
[5] Sırakaya, M., & Alsancak Sırakaya, D. (2022). Augmented reality in STEM education: A systematic review. *Interactive Learning Environments*, *30*(8), 1556-1569.
[6] Elfeky, A. I. M., & Elbyaly, M. Y. H. (2021). Developing skills of fashion design by augmented reality technology in higher education. *Interactive Learning Environments*, *29*(1), 17-32.
[7] Chang, S. C., & Hwang, G. J. (2018). Impacts of an augmented reality-based flipped learning guiding approach on students' scientific project performance and perceptions. *Computers & Education*, *125*, 226-239.
[8] Makhataeva, Z., & Varol, H. A. (2020). Augmented reality for robotics: A review. *Robotics*, *9*(2), 21.
[9] Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational research review*, *20*, 1-11.
[10] Alkhabra, Y. A., Ibrahem, U. M., & Alkhabra, S. A. (2023). Augmented reality technology in enhancing learning retention and critical thinking according to STEAM program. *Humanities and Social Sciences Communications*, *10*(1), 1-10.

[11] Cevahir, H., Özdemir, M., & Baturay, M. H. (2022). The effect of animation-based worked examples supported with augmented reality on the academic achievement, attitude and motivation of students towards learning programming. *Participatory Educational Research*, *9*(3), 226-247.
[12] Koutromanos, G., Sofos, A., & Avraamidou, L. (2015). The use of augmented reality games in education: a review of the literature. *Educational Media International*, *52*(4), 253-271.
[13] Yenioglu, B. Y., Ergulec, F., & Yenioglu, S. (2023). Augmented reality for learning in special education: a systematic literature review. *Interactive Learning Environments*, *31*(7), 4572-4588.
[14] Shaukat, S. M. (2023). Exploring the potential of augmented reality (AR) and virtual reality (VR) in education. *International Journal of Advanced Research in Science, Communication and Technology*, *3*(2), 51-56.
[15] Yildiz, E. P. (2022). Augmented Reality Applications in Education: Arloopa Application Example. *Higher Education Studies*, *12*(2), 47-53.
[16] Shirai, K., & Cohen, M. (2024). Dynamic Physics Educational Application for AR Environment. In *SHS Web of Conferences* (Vol. 194, p. 03002). EDP Sciences.
[17] Kartika, H. A., Purwanto, A., & Risdianto, E. (2024). Development of Physics E-Books Assisted by Flipbook and Augmented Reality (AR) to Increase Learning Motivation of High School Students. *Asian Journal of Science Education*, *6*(1), 70-81.
[18] Yawan, H. (2022). Augmented reality application. *EDUTEC: Journal of Education and Technology*, *5*(3), 652-663.
[19] Yu, S., Liu, Q., Ma, J., Le, H., & Ba, S. (2023). Applying Augmented reality to enhance physics laboratory experience: does learning anxiety matter?. *Interactive Learning Environments*, *31*(10), 6952-6967.
[20] Lyrath, F., Stechert, C., & Ahmed, S. I. U. (2023). Application of Augmented Reality (AR) in the Laboratory for Experimental Physics. *Procedia CIRP*, *119*, 170-175.
[21] Ferdiman, B., Al Akbar, H., Faturrahman, M. R., & Maulana, F. I. (2023). Development of augmented reality application in physics through newton's laws and object interaction. *Procedia Computer Science*, *227*, 699-708.
[22] Sarapak, C., Sukman, S., Kong-In, P., Sonsrin, K., Nakchat, O., Jumpatam, J., & Yoomark, J. (2022). The physics classroom in an online 3D virtual world: A Thai high school teacher needs analysis. *International Journal of Information and Education Technology, Online First*.
[23] Fidan, M., & Tuncel, M. (2019). Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education. *Computers & Education*, *142*, 103635.
[24] Wulandari, S., Wibowo, F. C., & Astra, I. M. (2021, October). A review of research on the use of augmented reality in physics learning. In *Journal of Physics: Conference Series* (Vol. 2019, No. 1, p. 012058). IOP Publishing.
[25] Wang, Y. (2022). Effects of augmented reality game-based learning on students' engagement. *International Journal of Science Education, Part B*, *12*(3), 254-270.
[26] Sánchez, J., & Diaz, M. H. R. (2022). Augmented Reality in Physics Teaching. *European Journal of Physics Education*, *13*(1), 14-27.
[27] Abdusselam, M. S., & Karal, H. (2020). The effect of using augmented reality and sensing technology to teach magnetism in high school physics. *Technology, Pedagogy and Education*, *29*(4), 407-424.
[28] Dewi, S. S., & Kuswanto, H. (2023). The effectiveness of the use of augmented reality-assisted physics e-module based on pedicab to improve mathematical communication and critical thinking abilities. *JOTSE*, *13*(1), 53-64.
[29] Martin-Gonzalez, A., Chi-Poot, A., & Uc-Cetina, V. (2016). Usability evaluation of an augmented reality system for teaching Euclidean vectors. *Innovations in Education and Teaching International*, *53*(6), 627-636.
[30] Wulandari, R., & Hindrayani, A. (2021, March). Measuring Critical Thinking Skills with the RED Model. In *Journal of Physics: Conference Series* (Vol. 1808, No. 1, p. 012030). IOP Publishing.
[31] Radu, I., Huang, X., Kestin, G., & Schneider, B. (2023). How augmented reality influences student learning and inquiry styles: A study of 1-1 physics remote AR tutoring. *Computers &*

Education: X Reality, *2*, 100011.
[32] Lin, M. H., Chen, H. C., & Liu, K. S. (2017). A study of the effects of digital learning on learning motivation and learning outcome. *Eurasia Journal of Mathematics, Science and Technology Education*, *13*(7), 3553-3564.
[33] Zupic, I., & Čater, T. (2015). Bibliometric methods in management and organization. *Organizational research methods*, *18*(3), 429-472.
[34] Dewi, I. S., Mashurin, A. H., Anidhea, N. O., Jauhariyah, M. N., Prahani, B. K., Safitri, N. S., & Mubarok, H. (2021, December). Bibliometric Analysis of Research Developments in the Field of Augmented Reality in Physics Education (2012-2021*). In *International Joint Conference on Science and Engineering 2021 (IJCSE 2021)* (pp. 471-478). Atlantis Press.
[35] Zhang, J., Yu, N., Wang, B., & Lv, X. (2022). Trends in the use of augmented reality, virtual reality, and mixed reality in surgical research: a global bibliometric and visualized analysis. *Indian Journal of Surgery*, *84*(Suppl 1), 52-69.
[36] Liu, A., Yuan, C., Xu, L., & Zhao, L. (2024). Scientific mapping of hotspots and trends of post and core research based on the Web of Science: A bibliometric analysis. *Heliyon*, *10*(1).
[37] Moral-Muñoz, J. A., Herrera-Viedma, E., Santisteban-Espejo, A., & Cobo, M. J. (2020). Software tools for conducting bibliometric analysis in science: An up-to-date review. *Profesional de la Información*, *29*(1).
[38] Mejia, C., Wu, M., Zhang, Y., & Kajikawa, Y. (2021). Exploring topics in bibliometric research through citation networks and semantic analysis. *Frontiers in Research Metrics and Analytics*, *6*, 742311.
[39] Öztürk, O., Kocaman, R., & Kanbach, D. K. (2024). How to design bibliometric research: an overview and a framework proposal. *Review of managerial science*, 1-29.
[40] Ellegaard, O., & Wallin, J. A. (2015). The bibliometric analysis of scholarly production: How great is the impact?. *Scientometrics*, *105*, 1809-1831.
[41] Huang, C., Yang, C., Wang, S., Wu, W., Su, J., & Liang, C. (2020). Evolution of topics in education research: A systematic review using bibliometric analysis. *Educational Review*, *72*(3), 281-297.
[42] Gautam, P., Kodama, K., & Enomoto, K. (2014). Joint bibliometric analysis of patents and scholarly publications from cross-disciplinary projects: implications for development of evaluative metrics. *Journal of Contemporary Eastern Asia*, *13*(1), 19-37.
[43] Kamaruzaman, M. F., Ahmad, M., Zambri, A. A., & Mukmin, T. M. (2022). Use of Augmented Reality in the Education Setting. *Asian Journal of Environment-Behaviour Studies*, *7*(23), 43-54.
[44] Jerry, T. F. L., & Aaron, C. C. E. (2010, June). The impact of augmented reality software with inquiry-based learning on students' learning of kinematics graph. In *2010 2nd international conference on education technology and computer* (Vol. 2, pp. V2-1). IEEE.
[45] Buesing, M., & Cook, M. (2013). Augmented reality comes to physics. *The Physics Teacher*, *51*(4), 226-228.
[46] Zhang, J., Li, G., Huang, Q., Feng, Q., & Luo, H. (2022). Augmented reality in K–12 education: A systematic review and meta-analysis of the literature from 2000 to 2020. *Sustainability*, *14*(15), 9725.
[47] Cai, Y., Pan, Z., & Liu, M. (2022). Augmented reality technology in language learning: A meta-analysis. *Journal of Computer Assisted Learning*, *38*(4), 929-945.
[48] Chang, H. Y., Binali, T., Liang, J. C., Chiou, G. L., Cheng, K. H., Lee, S. W. Y., & Tsai, C. C. (2022). Ten years of augmented reality in education: A meta-analysis of (quasi-) experimental studies to investigate the impact. *Computers & Education*, *191*, 104641.
[49] Cao, W., & Yu, Z. (2023). The impact of augmented reality on student attitudes, motivation, and learning achievements—a meta-analysis (2016–2023). *Humanities and Social Sciences Communications*, *10*(1), 1-12.
[50] Li, F., Wang, X., He, X., Cheng, L., & Wang, Y. (2023). How augmented reality affected academic achievement in K-12 education–a meta-analysis and thematic-analysis. *Interactive Learning Environments*, *31*(9), 5582-5600.
[51] Xu, W. W., Su, C. Y., Hu, Y., & Chen, C. H. (2022). Exploring the effectiveness and moderators of augmented reality on science learning: A meta-analysis. *Journal of Science Education and Technology*, *31*(5), 621-637.

[52] Lin, Y., & Yu, Z. (2023). A meta-analysis of the effects of augmented reality technologies in interactive learning environments (2012–2022). *Computer Applications in Engineering Education*, *31*(4), 1111-1131.
[53] Saidin, N. F., Halim, N. D. A., & Yahaya, N. (2015). A review of research on augmented reality in education: Advantages and applications. *International education studies*, *8*(13), 1-8.
[54] Cai, S., Chiang, F. K., & Wang, X. (2013). Using the augmented reality 3D technique for a convex imaging experiment in a physics course. *International Journal of Engineering Education*, *29*(4), 856-865.
[55] Jesionkowska, J., Wild, F., & Deval, Y. (2020). Active learning augmented reality for STEAM education—A case study. *Education Sciences*, *10*(8), 198.
[56] Altmeyer, K., Kapp, S., Thees, M., Malone, S., Kuhn, J., & Brünken, R. (2020). The use of augmented reality to foster conceptual knowledge acquisition in STEM laboratory courses—Theoretical background and empirical results. *British Journal of Educational Technology*, *51*(3), 611-628.
[57] Cai, S., Liu, C., Wang, T., Liu, E., & Liang, J. C. (2021). Effects of learning physics using Augmented Reality on students' self-efficacy and conceptions of learning. *British Journal of Educational Technology*, *52*(1), 235-251.
[58] Ibáñez, M. B., Di-Serio, Á., Villarán-Molina, D., & Delgado-Kloos, C. (2014). Augmented reality-based simulators as discovery learning tools: An empirical study. *IEEE Transactions on Education*, *58*(3), 208-213.
[59] Faridi, H., Tuli, N., Mantri, A., Singh, G., & Gargrish, S. (2021). A framework utilizing augmented reality to improve critical thinking ability and learning gain of the students in Physics. *Computer Applications in Engineering Education*, *29*(1), 258-273.
[60] Novita, R. R. (2023). Physics e-book with augmented reality to improve students' interest in physics. *JPI (Jurnal Pendidikan Indonesia)*, *12*(1), 145-154.
[61] Teichrew, A., & Erb, R. (2020). How augmented reality enhances typical classroom experiments: examples from mechanics, electricity and optics. *Physics Education*, *55*(6), 065029.
[62] Vidak, A., Šapić, I. M., & Mešić, V. (2021). An augmented reality approach to learning about the force of gravity. *Physics education*, *56*(6), 065026.
[63] Dewi, S. S., & Kuswanto, H. (2023). The effectiveness of the use of augmented reality-assisted physics e-module based on pedicab to improve mathematical communication and critical thinking abilities. *JOTSE*, *13*(1), 53-64.
[64] Talan, T. (2021). Augmented Reality in STEM Education: Bibliometric Analysis. *International Journal of Technology in Education*, *4*(4), 605-623.
[65] Masalimova, A. R., Erdyneeva, K. G., Kryukova, N. I., Khlusyanov, O. V., Chudnovskiy, A. D., & Dobrokhotov, D. A. (2023). Bibliometric analysis of augmented reality in education and social science. *Online Journal of Communication and Media Technologies*, *13*(2), e202316.