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Exploring the potential of technology in physics education: current research and innovation trends to support 21st century skills

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ABSTRACT

Introduction. Education today is required to prepare students with 21st century skills, which are essential to thrive in a rapidly changing world. Technological innovation is becoming increasingly important in enhancing students' learning experience and motivation, particularly in physics education. Traditional learning methods, such as lectures and simple laboratory activities, often fail to capture students' interest or convey real-world applications of physics concepts. *This research aims* to explore the potential of technology, in physics learning to enhance 21st century skills.

Methods. This research utilizes bibliometric method and literature review with the aim to answer several main questions: 1) emerging trends in the use of technology in physics learning between 2019 and 2023 based on literature collected from Scopus, 2) author contributions and international collaborations on the topic, 3) technological innovations applied in physics learning and their impact on learning quality, and 4) research gaps that still exist in the application of technology for physics education. The research method combines bibliometric analysis to obtain quantitative and systematic results using tools such as VOSviewer, as well as an in-depth literature review with the PRISMA approach. Data were collected online in March 2024 from the Scopus database, which filters out internationally reputable articles relevant to the topic under study.

Results. Bibliometric analysis reveals that AR and VR technologies show significant potential in physics education, although their adoption has fluctuated over the past few years. AR and VR provide immersive learning experiences that can improve students' understanding of abstract concepts and increase engagement. Indonesia was found to be the most active country in contributing to the research and application of these technologies in physics learning, demonstrating a strong commitment to integrating technological innovation in education. The findings underscore the importance of these technologies in enhancing 21st century skills and suggest areas for further research, especially in optimizing the use of AR and VR in STEM education.

Practical significance. The implications of this study are significant for educators and policy makers. The findings provide insight into current trends and innovations in physics education and highlight the importance of integrating technology to foster 21st century skills. This research serves as a valuable reference for future research and development in physics education, especially in the use of AR, VR, and other digital tools to create more engaging and effective learning environments.

KEYWORDS

21st century skills, physics education, bibliometric, technological innovation, PRISMA

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INTRODUCTION

Education has long been a priority in various international initiatives, with the United Nations Educational, Scientific and Cultural Organization (UNESCO) leading efforts to improve access and quality of education worldwide [1]. UNESCO, through programs such as Education for Sustainable Development (ESD) has emphasized the importance of education that is sustainable, and relevant to future needs [2]. This reflects the global need to ensure that education not only serves academic purposes, but also prepares learners to face the challenges of a rapidly changing world [3]. In today's education, there is a demand to prepare learners with skills that are relevant and appropriate to the 21st century, such as critical thinking, collaboration, problem solving, and technological literacy [4].

Education today is faced with the demand to prepare learners with relevant skills appropriate for the 21st century [5; 6]. The transformation of education in facing the demands of the 21st century is strongly influenced by rapid technological advances [7; 8]. In the era of Industrial Revolution 4.0, the need for adaptive and innovative skills is becoming increasingly important, especially in physics education [9,10]. However, conventional learning methods that are often limited in providing interesting and relevant learning experiences can cause a lack of motivation and interest in learning in students [11]. Learning models centered on lectures, whiteboards, and simple labs may no longer be sufficient to capture the attention of a generation of learners who are accustomed to technology [12]. In some cases, students can feel a lack of understanding from physics learning materials due to the lack of real-world applications of the concepts taught, or the lack of opportunities to explore and interact deeply with the material. In this case, the challenge faced in physics education is how to create a motivating and relevant learning environment for students in this digital era [13].

Technological advances such as artificial intelligence, virtual reality, augmented reality, game-based learning, website, open new opportunities to improve physics learning [14; 15]. Such technologies can be used to create realistic simulations, provide engaging visualizations, and facilitate virtual experiments that are not possible in a traditional classroom environment [16; 17]. With an interactive and technology-based learning approach, students have the opportunity to be more actively involved in the learning process [18], explore physics concepts in greater depth, and develop a better understanding of the practical applications of the material learnt [19]. In addition, the integration of technology in physics learning can also open the door to the development of important 21st century skills, such as problem solving, collaboration, communication, and digital literacy [20; 21]. In an increasingly connected and rapidly changing world, students need to have these skills to succeed in the future. Therefore, research on how technology can be used effectively in supporting the development of these skills is becoming increasingly important.

Therefore, research on how technology can be optimally integrated in physics learning is crucial to support the development of 21st century skills needed by students in the future. Thus, this study aims to describe the latest trends in the use of technology in physics education, highlight recent innovations, and evaluate their impact on the development of future-relevant skills for students. By understanding the challenges and potentials of technology in physics education, research and innovation are ongoing to identify the best approaches in utilizing technology to enhance the physics learning experience and prepare students with relevant skills for the future.

RESEARCH METHODS

1. Methods of Analysis

This research uses bibliometric method and literature study with literature review which involves a series of activities related to data collection from literature sources, such as Scopus [22]. The data obtained included internationally reputable articles relevant to the topic of technology utilizations in physics learning. This combined method provides quantitative results through bibliometric analysis, while at the same time providing qualitative insight results with a systematic review related to the topic to be studied [23; 24]. Bibliometric analysis is used to present visualizations of publication trends, evaluate the contribution of articles to knowledge development, and assess literature sources from various perspectives [7; 25].

2. Data collecting

This research was conducted online in March 2024, using the Scopus database to obtain extensive and complex data, which was then stored in .CSV and .ris formats. The data obtained was then processed and visualized using the VOSviewer application. The research time span covers articles published between 2019 and 2023. The keyword search stages were carried out using the PRISMA method in Figure 1.

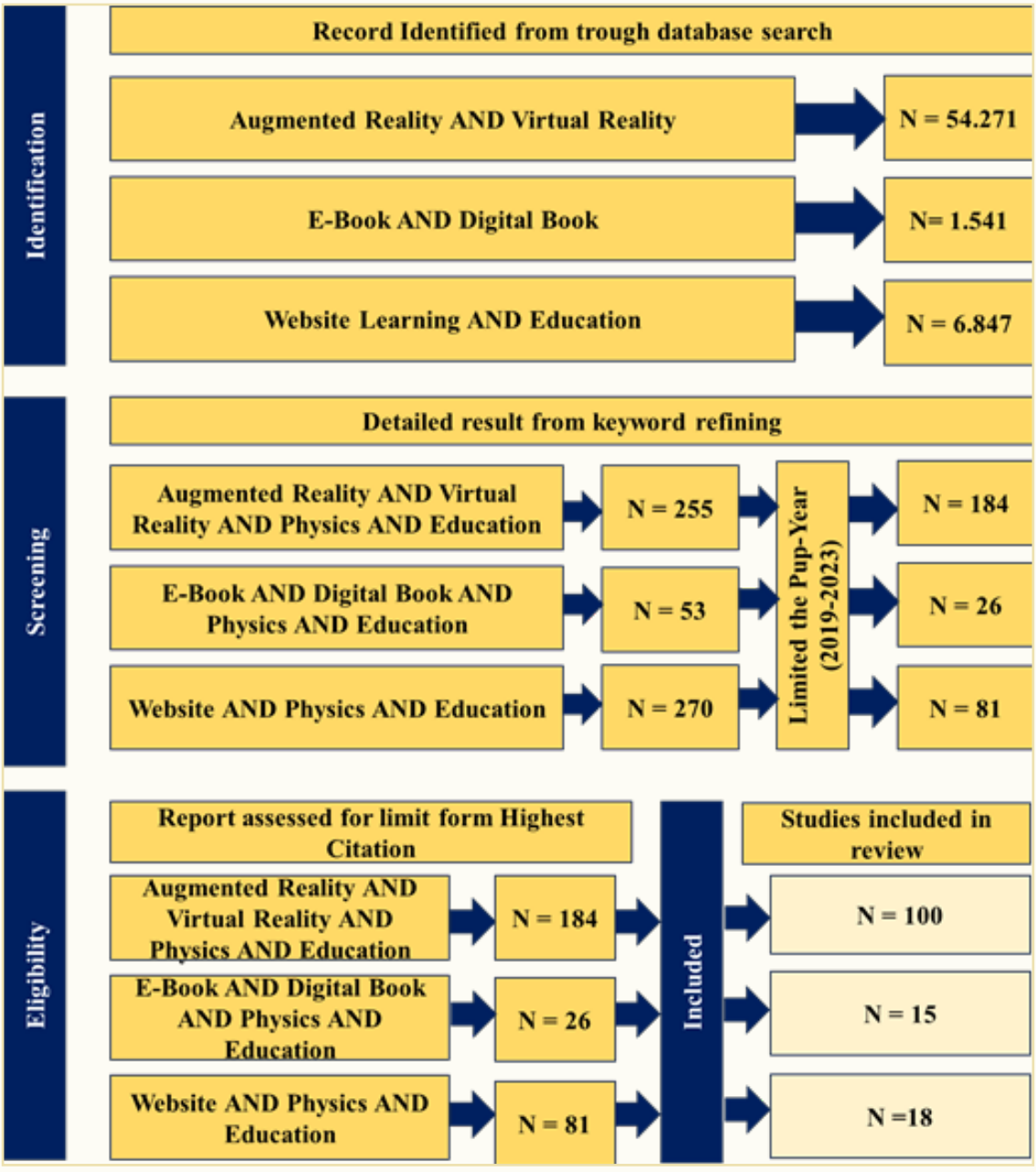


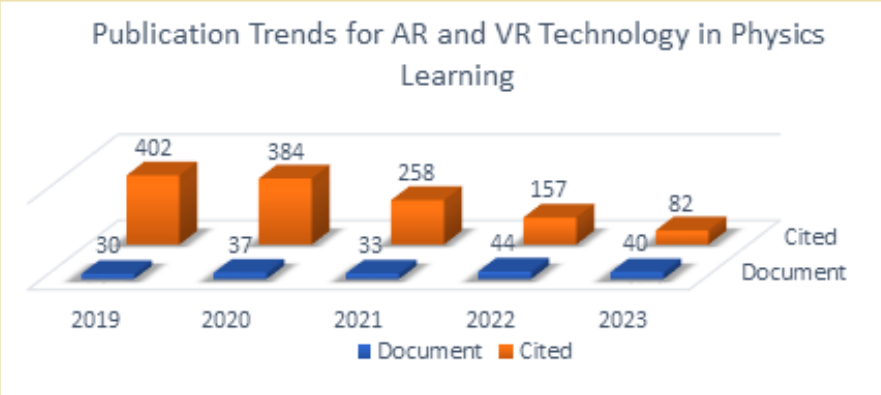
Figure 1 PRISMA Method Research Flow Chart

The stages of the PRISMA method begin with the identification of keywords in the Scopus database. Then, the data is filtered by adding additional keywords that match the scope of the research, namely "Physics Education". Furthermore, the data is filtered with a year limit for the last five years (2019-2023). After the filtering process, the next step was to assess the eligibility of the documents based on the highest number of citations. Finally, documents were selected based on relevance to the research topic. Through the bibliometric analysis process, it is expected to provide insights into innovations and trends in research, as well as highlight the impact and contribution of scientific works to the development of science [26].

RESULTS

1. Publication Trends Innovation and technology in physics education in the last five years

This research explores various innovative technologies applied in physics learning to strengthen skills relevant to the 21st century. A literature search was conducted using the Scopus database with keywords corresponding to those shown in Figure 1. The results of the search for trends in the use of innovative technologies in the last five years are presented in Figure 2.



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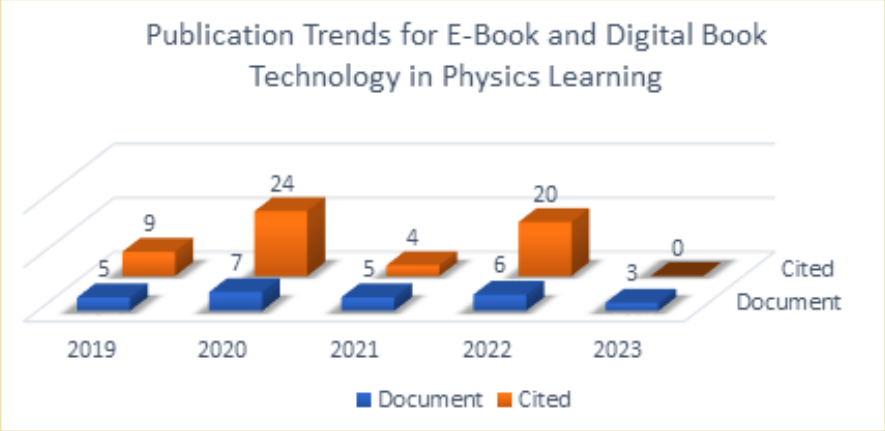

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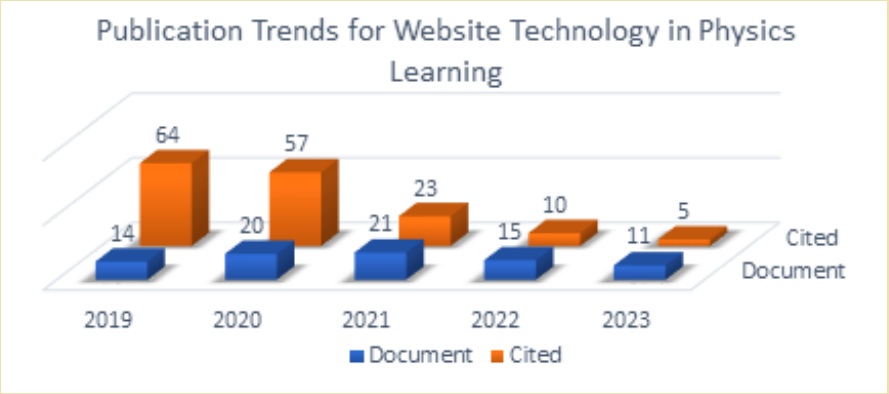

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Figure 2 Research Trends Publications in the Last Five Years Related to a) AR and VR, b) E-Book and Digital Book, and c) Website

Based on the data presented, it can be seen that the use of AR and VR technology in physics learning experienced significant fluctuations from 2019 to 2023. Although there was an increase in 2020 and 2022, there was a decrease in 2021 and 2023. This indicates a fluctuation in research trends related to the use of AR and VR in the context of physics learning. Nonetheless, these fluctuations indicate the potential for further research to understand the factors that influence the interest and application of these technologies in physics learning. The increase in the number of publications on the use of AR and VR in physics learning indicates a growing interest and demand for further understanding of the application of AR in physics learning [27; 28]. The publication trend related to E-Book technology shows a more volatile variation from 2019 to 2023. Although stable from 2019 to 2022, there was a significant decline in 2023. This indicates a decrease in interest in the use of E-Book technology in physics learning. A possible contributing factor is the emergence of alternative technologies that are more innovative and attractive to educators and students, such as interactive learning applications or game-based platforms. Meanwhile, interest in the use of website technology is higher than E-Books but still less than AR and VR in physics learning. This could be because websites can be accessed from various devices and provide greater flexibility [29], while AR and VR offer more innovative and interactive learning experiences [30]. Therefore, the use of AR and VR tends to be more desirable as an interesting and effective learning tool in physics learning.

In terms of future research potential, AR and VR technologies may still be interesting to be researched further, although the trend shows a decline. This is due to the potential of these technologies in providing immersive and interactive learning experiences, which can increase student engagement and understanding in physics E-Book technology, despite the declining trend, still has potential for further research especially in the context of digital curriculum adaptation and flexibility of access to learning materials. Website technology, although not showing a significant growth trend, remains important to consider in research due to its flexible and accessible nature [31], as well as its potential to provide rich and diverse learning resources [32]. In terms of enhancing 21st century skills, all of these technologies have potential. AR and VR can improve engagement and thinking skills, E-Books can improve digital literacy skills and online collaboration, while websites can improve information and critical skills through access to diverse and valid resources.

2. Top 3 authors, affiliates, and language with high productivity in each category of research topics

Table 1

Top 3 Authorship, Affiliates, and Language in Each Research

Top Authorship		Top Affiliation		Top Language	
Author	Total	Affiliation	Total	Language	Total
Fidan, M.	15	Universitas Negeri Jakarta	17	English	180
Jesionkowska, J.	3	International Information Technology University	7	Spanish	2
Altmeyer, K.	13	Universität des Saarlandes	6	Chinese	1
Unsworth, L.	68	Universitas Negeri Padang	7	English	26
Kuromiya, H.	16	Universitas Negeri Jakarta	3		
Rahim, F.R.	8	University of Sout Australia	2		
Darmaji	23	Universitas Negeri Jakarta	8	English	78
Covington, E.L.	29	Organisation Européenne pour la Recherche Nucléaire	3	Spanish	2
Yeter, I.H.	41	University of Bern	3	Korean	1

Table 1 presents information on the three most prolific authors, leading affiliations, and main language distribution in several topics of technological innovation in physics learning. Studies on AR and VR in physics learning show that the most prolific author is Fidan, M., with a total of 15 documents related to Augmented Reality, Education, and online learning. The leading affiliate that publishes the most AR and VR research is Universitas Negeri Jakarta, with a total of 17 documents. On the topic of E-Books and Digital Books, the most prolific author was Unsworth,

L., with a total of 68 documents focusing mostly on Multimedia learning, Literacy Practices, and education. Universitas Negeri Padang is the leading affiliate that publishes the most research on E-Books and Digital Books, with a total of 7 documents. Furthermore, in the topic of Website technology innovation, the most productive author is Darmaji, with a total of 23 documents that mostly research related to Physics Education, inquiry, and Student Attitudes. Universitas Negeri Jakarta is also the leading affiliate that publishes the most research on Website utilisation, with a total of 8 documents. Overall, English is the most widely used language in these publications. From this information, a deeper understanding of research trends, the contribution of articles to the development of science, and also the identification of researchers and institutions that are dominant in the field is obtained. In addition, bibliometric mapping can also help identify knowledge gaps and potential future research directions [33].

3. Research Trends in the Use of Technology in Physics Education Worldwide

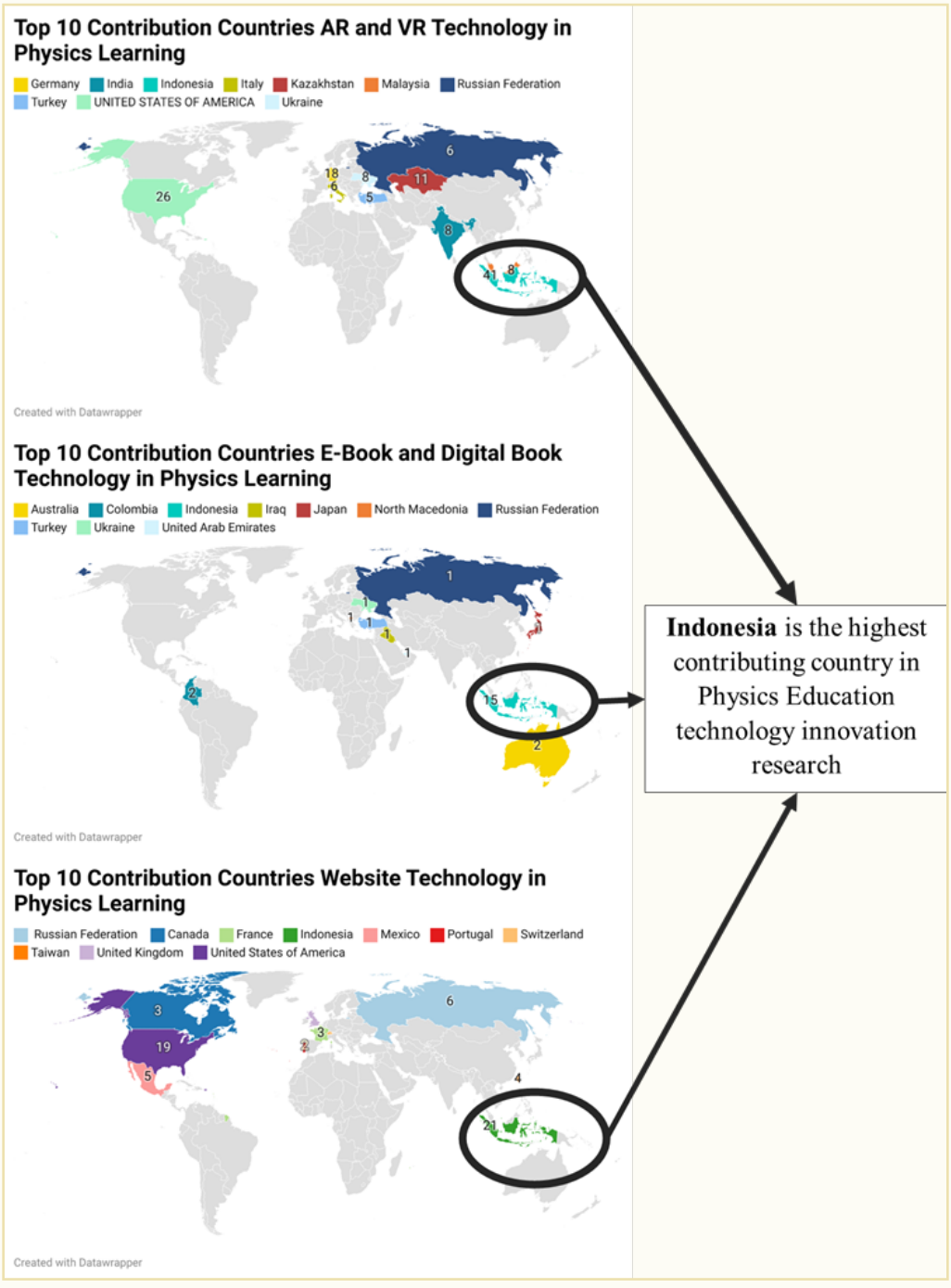
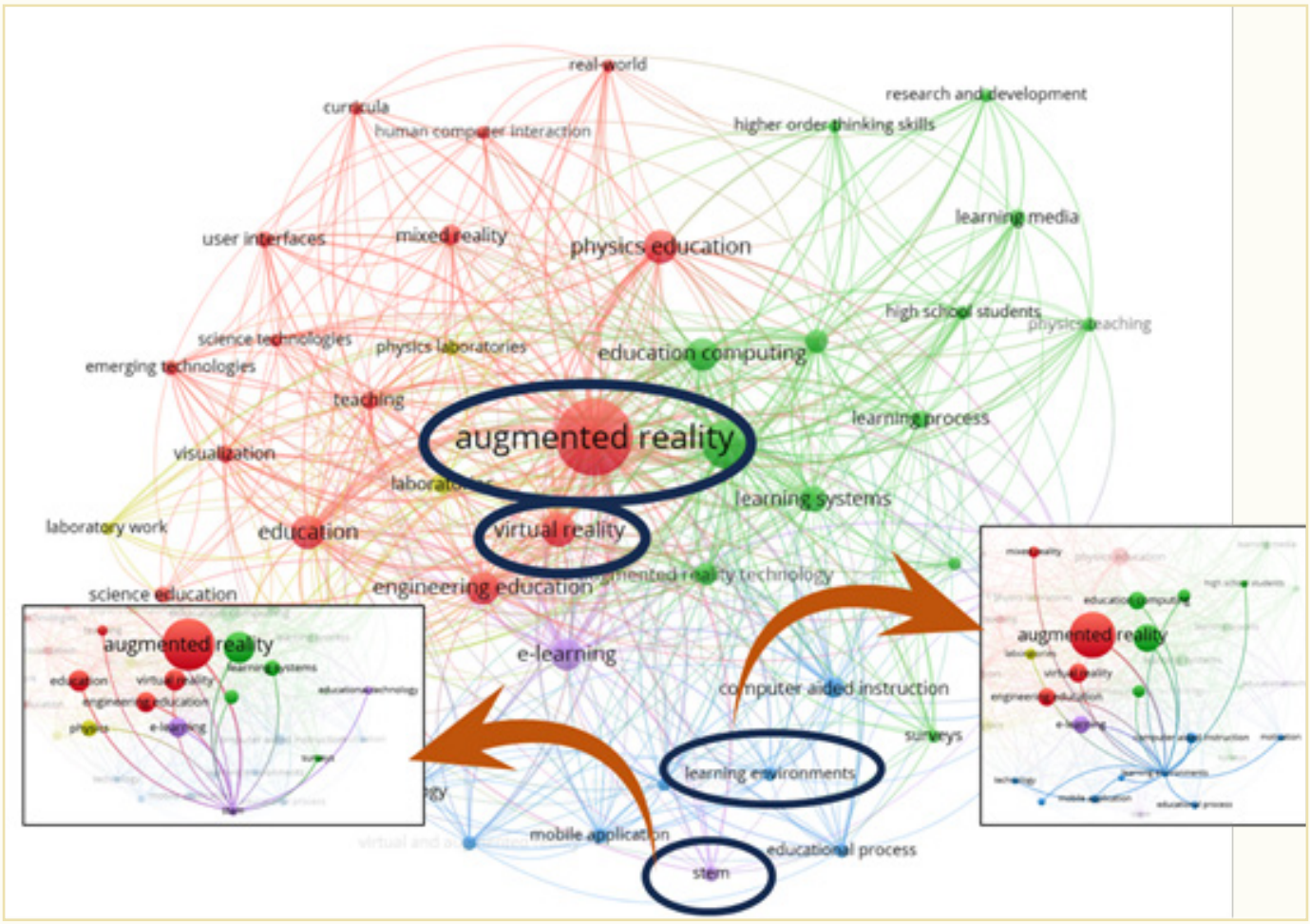


Figure 3 Research Top 10 contributions world research trends in top countries

From the number of published documents, Indonesia is the country with the highest contribution in the use of AR and VR technology in physics learning, with a total of 41 documents. This shows that Indonesia has a high interest in using AR and VR technology in the context of physics learning. Most likely, this is due to an increased awareness of the importance of using technology in education to improve student engagement and understanding of physics materials [34]. The use of AR and VR can provide an interactive and immersive learning experience, in accordance with the demands of 21st century skills such as creativity, critical, and collaborative [16].

Indonesia also dominates in publications related to E-Book and Digital Book technology in physics learning, with 15 documents. This shows that Indonesia is also active in adopting digital technology in presenting physics learning materials. The use of E-Book and Digital Book technology allows easy and flexible access to learning materials, which can support independent and innovative learning that suits the needs of 21st century skills [24; 35]. In terms of the use of Website technology in physics learning, Indonesia again dominates with 21 documents. The use of Website technology allows the presentation of physics learning materials interactively and can be accessed online, which can increase accessibility and student engagement [36]. This is in accordance with the needs of 21st century skills in terms of digital literacy and adaptability to technology. Overall, Indonesia's dominance in all three technology categories indicates a strong commitment to adopting technological innovations in physics learning. The use of such technologies is in line with the demands of 21st century skills and can support more effective and engaging physics learning [37].

4. Novelties publications on Technological Innovation in Physics Education over the last 5 years



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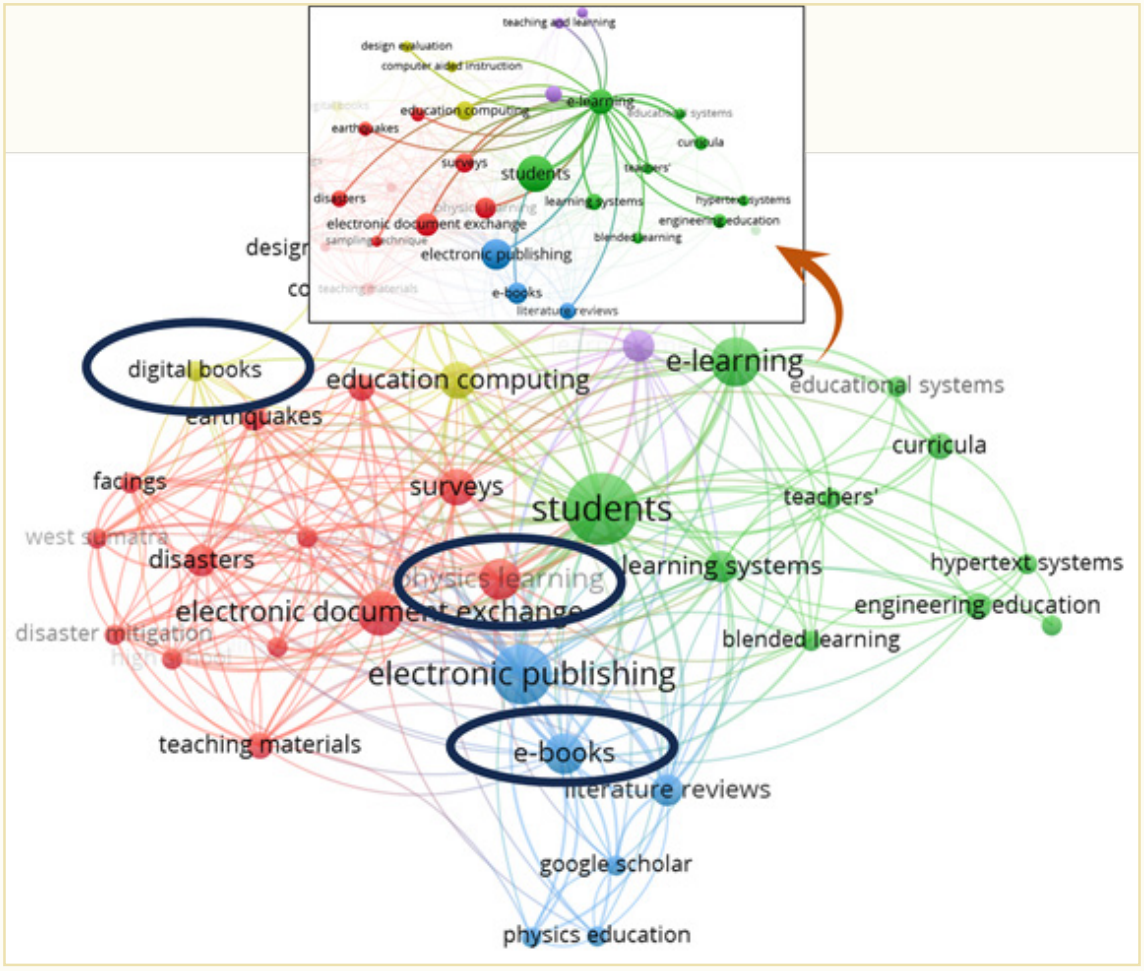

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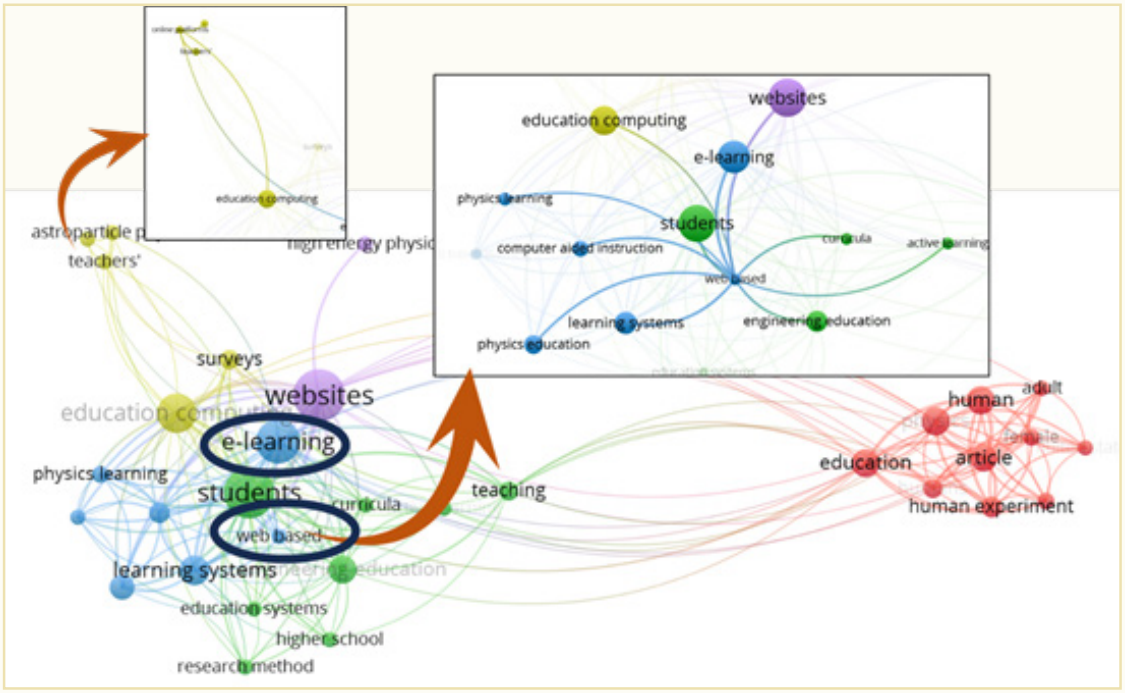

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Figure 4 Keyword visualization mapping of various occurrences of keyword mapping results more specifically on the topics of a) AR and VR, b) E-Book and Digital Book, and c) Website.

Figure 4 is an example of keyword mapping results that are more specific to technological innovation in physics learning. Figure 4a shows the relevance and potential for further research related to VR and AR in STEM contexts and learning environments. VR and AR technologies have great potential to enhance STEM learning by providing immersive and interactive learning experiences [38: 39]. Further research could explore the effectiveness of using VR and AR in facilitating the understanding of complex and abstract STEM concepts. VR and AR can change the way students interact with their learning environment [16]. Research can explore how the use of these technologies can affect student motivation, engagement and achievement. In addition, the integration of VR and AR with real-world contexts can enrich students' learning experience by linking STEM concepts with real situations [40]. Further research could investigate the use of these technologies in simulated real environments, such as virtual laboratory explorations or visits to locations outside the classroom. So that the use of VR and AR technology in physics learning can increase student motivation and engagement in the learning process. In the research trend there is also a relationship where the use of AR and VR can be used to develop and support High Order Thinking skills. This is in accordance with research from [16] The use of technology like this can improve problem solving skills and critical thinking.

Then the use of E-Books in physics learning is one of the important elements in e-learning. E-Books provide easy and flexible access to learning materials, which can be accessed by students from various electronic devices such as computers, tablets, or smart phones [41]. By using E-Books or digital books, learning materials can be accessed online from anywhere and anytime [24]. E-Books or digital books often present learning content in an interactive and multimedia way, such as videos, moving images, animations, and external links [42]. In addition, E-Books or digital books can assist in the development of students' science literacy by providing easy access to science information and knowledge [43]. E-Books can also present learning materials in an interesting and easy-to-understand format, thus helping students to develop a better understanding of science concepts.

Then the third technology utilization is Web-based Learning. Online platform utilization provides various features and facilities that support web-based learning, such as access to digital learning materials, use of discussion forums for interaction between students and instructors, online quizzes, and online assignments [44]. This enables interactive and effectively structured learning. Online platforms can often be integrated with various other technologies, such as video conferencing, mobile applications, and customized learning software. This extends the functionality of the platform and enables the provision of a richer and more engaging learning experience for students [45].

Based on the data obtained, this study confirms that technological innovations such as VR, AR, E-Books, and Web-based Learning have great potential in improving physics learning and supporting the development of 21st century skills. This research supports the findings from [46; 47] previous studies which show that VR and AR technologies can enrich the learning experience by providing more immersive and relevant interactions, especially in STEM contexts and learning environments. This study agrees with the opinion of [48] which states that the use of VR and AR in physics learning can increase motivation, student engagement, as well as critical thinking and problem-solving skills.

In addition, this study is also in line with the opinion of [49] that E-Book as an important element in e-learning provides easy access and flexibility in physics learning. The use of interactive and multimedia E-Books can assist students in developing a better understanding of science concepts [50]. In the context of web-based learning, our study supports the findings of [51] that online platforms provide various features that support interactive and structured learning.

The main conclusion of this study is that the utilization of innovative technologies such as VR, AR, E-Books, and web-based learning platforms can improve the quality of physics learning, particularly in the context of STEM and 21st century skills development. However, further research is needed to explore how these technologies can be integrated more effectively in various educational contexts and how potential barriers can be overcome. As such, the findings of this study contribute to a deeper understanding of the role of technology in physics education and provide direction for future research to explore the full potential of these technologies in creating inclusive and student-centered learning.

CONCLUSION

Based on a systematic review with a bibliometric approach, it was found that in physics learning, the use of technology is essential to support the development of 21st century skills. Technologies such as AR and VR, E-Books and Digital Books, as well as Websites, have great potential to enhance the learning experience and present challenges that need to be further explored in future research. Overall, Indonesia is one of the countries that most actively contributes to the utilization of these technologies in physics learning. The findings suggest that the use of technology in physics education can enhance 21st century skills. Future research opportunities highlight further exploration of how technology supported by STEM-based learning environments can enhance higher order thinking skills (HOTS). The implications of these findings are significant, providing new insights into the role of technology in physics education internationally, as well as providing valuable references for future research. For future research, it is recommended to consider using additional database sources other than Scopus. This may help in gaining a more holistic and comprehensive understanding and visualization of future research trends related to the utilization of technology in learning.

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