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Trends of Augmented Reality in Science Education Studies in Elementary Schools: A Bibliometric Analysis from 2013 – 2023

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Abstract: In the digital era, education has undergone a significant transformation thanks to advancements in information and communication technology. Augmented Reality is an educational medium that utilizes the development of digital technology in its progress. This study aims to analyse research trends regarding the use of Augmented Reality in science education at the elementary school level. The method used is bibliometric analysis with documents sourced from the Scopus database within the last 10 years of publication (2013-2023). This analysis includes emerging themes related to Augmented Reality in science education at the elementary school level, as well as publication trends based on keywords. The results show that (a) there are four themes, namely the development of Augmented Reality media, the effectiveness of Augmented Reality in science education at the elementary school level, the implementation of Augmented Reality media in teaching, and the enhancement of critical and creative thinking skills; (b) one meta-theme, which is the use of Augmented Reality media to improve the quality of science education at the elementary school level; and (c) the keyword Augmented Reality is not yet connected to the keywords cooperative and collaborative learning, which represents a research gap that can be further explored in future studies.

Keywords: augmented reality, science, elementary school, bibliometric analysis.

▪ INTRODUCTION

In today's digital era, education is undergoing a significant transformation with the advancement of information and communication technology. Digital technology offers many advantages, including wider access to information and new methods of delivering educational materials that are more in-depth and effective (Muratbek et al., 2023). The presence of technology in the world of education provides many benefits, one of which is helping educators develop ideas and creativity to support teaching and learning activities through the development of learning media (Puhka et al., 2023). Digital-based learning media allows educators to deliver learning materials that are not only more interesting but also more suited to students' needs and learning styles (Bilynska et al., 2024). One of the latest developments in learning media is the use of Augmented Reality (AR), which offers a new approach to enriching the learning experience (Rajiv, 2024).

Augmented Reality (AR) is a technology that combines virtual elements with the real environment in real-time (Agape et al., 2024; Begum et al., 2023; Shonima et al., 2024; Sudeen Ajit Dalal, 2024). With AR, digital objects can be added to a real-world view through devices such as tablets or AR headsets (Akzhan & Nurlan, 2024). Augmented Reality allows students to view and interact with three-dimensional models of various concepts, making the subject matter more understandable and engaging (Sathyapriya et al., 2024). In the context of education, Augmented Reality has the potential to increase student engagement and motivation in ways that traditional learning media have never done before. Augmented Reality also supports an active, experiential learning

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approach, where students learn not only in theory but also through direct interaction with learning materials (Dhaas, 2024; James et al., 2023).

Natural Sciences is a subject that includes an in-depth understanding of various basic concepts related to nature and the surrounding environment (Kalelova & Abdimanapov., 2022). Science materials not only teach scientific facts, but also develop critical thinking skills and the application of scientific methods, such as observation, experiments, and data analysis (Benny & Ulil, 2024). With the right approach, science can facilitate deeper knowledge about how interactions between the various elements in our environment affect everyday life and the ecosystem as a whole (Munawar & Hartig, 2020). In addition, mastery of science concepts encourages students' ability to solve problems systematically and solve scientific challenges, thus preparing them to think critically and be skilled in dealing with environmental issues in the future (Virtič, 2022).

Science learning in elementary schools often faces a number of problems. One of them is the lack of student understanding of science concepts that are often considered abstract and complex (Liu, 2024). The implementation of learning that tends to be theory-based and less involved in practical experience often makes it difficult for students to relate scientific concepts to real-world situations (Mondal, 2024). In addition, the limitations of media and teaching aids used in teaching can also hinder the learning process (Tayirova, 2023). To overcome this challenge, a more innovative and interactive approach is needed, such as the use of digital technology that can offer more realistic visualizations and simulations. With learning media such as Augmented Reality (AR), it is hoped that students can more easily understand science concepts and be more actively involved in the learning process, so that learning becomes more effective and enjoyable.

Several previous studies have examined the effectiveness of Augmented Reality in science learning in elementary schools. Research by Wen et al (2023) shows that the application of augmented reality media is effective for understanding science concepts in grade V elementary school students. In addition, Augmented Reality media has an effect on improving the science learning outcomes of elementary school students (Ping et al., 2023; Sachin & Sambit, 2022). The application of Augmented Reality media can improve the quality of science learning and increase learning motivation as well as critical thinking skills and scientific literacy (Gülboy & Denizli-Gulboy, 2024; Syskowski et al., 2024). Augmented Reality (AR) technology has a significant ability to increase students' interest in learning, especially in science lessons (Khawaji, 2024). By offering interactive and dynamic three-dimensional visualizations, AR has been shown to effectively assist students in grasping abstract concepts that can be challenging to comprehend using traditional teaching methods (Sathyapriya et al., 2024). This innovative approach not only makes the learning experience more engaging and enjoyable but also motivates students to take a more active role in their educational activities (Kuanbayeva et al, 2023). As a result, integrating AR into the classroom could lead to a more immersive learning environment that fosters deeper understanding and enthusiasm for the subject matter.

Moreover, the integration of Augmented Reality in education opens up new avenues for experiential learning, where students can engage directly with digital content that overlays their real-world environment (Mehta & Singh, 2024). This hands-on interaction encourages curiosity and exploration, enabling learners to experiment with scientific principles in ways that traditional methods cannot replicate. For instance, students can manipulate virtual models of complex systems, conduct virtual experiments,

or visualize phenomena that are otherwise invisible, such as molecular interactions or astronomical events. Additionally, the collaborative aspects of AR can enhance peer-to-peer interaction, as students work together to solve problems or complete tasks in a shared augmented space. Such collaborative learning not only reinforces individual understanding but also cultivates essential skills such as teamwork and communication (Nadzeri et al., 2023). Ultimately, the widespread adoption of AR in science education has the potential to revolutionize how concepts are taught and understood, preparing students for a future where technology plays an integral role in their learning experiences (Peikos & Sofianidis, 2024).

In recent years, various studies have been conducted to evaluate the effectiveness of Augmented Reality media in learning, but there is no systematic study that identifies trends, themes, and collaborations in the research as a whole. This research seeks to fill this gap and offer novelty by conducting a comprehensive bibliometric analysis to evaluate the development trend of Augmented Reality media research in the context of science learning in elementary schools. Bibliometric analysis provides a more comprehensive picture of research developments in this field, including identification of the most researched topics (Paszkowska & Vallejo, 2023).

Through bibliometric analysis, this research will offer a holistic view of progress in this field, allowing the identification of the most researched topics, influential authors, and important publications that have shaped this field. Additionally, this analysis will help reveal patterns of research results over time, illustrating how interest in AR technology has developed and how it is being integrated into learning practices. By synthesizing existing literature, this research will not only highlight the current state of AR in science education, but also reveal emerging themes and potential avenues for future inquiry, ultimately contributing to a deeper understanding of how AR can improving the learning experience in basic education.

The purpose of this study is to present a comprehensive overview of the development trends of Augmented Reality media research in science learning in elementary schools over the past ten years, and to identify the main findings emerging from these studies with a bibliometric approach using VOSViewer software. Thus, this study is expected to provide a deeper understanding of research progress in this field, as well as identify opportunities and challenges for the development of more effective learning models in the future.

▪ METHOD

Research Design

The method in this study is the bibliometric analysis method. Bibliometric analysis is a method that systematically examines and maps scientific studies in a structured manner from article metadata (Evran et al., 2024). According to Donthu et al (2021) the objectives of bibliometric analysis include: (1) Identifying trends in scientific studies, (2) Finding gaps in existing knowledge, (3) Generating new ideas for future research, and (4) Determining the position of scientific contributions in the context of existing research.

Search Strategy

This research utilizes international publication data related to the topic of Augmented Reality media in science education at the elementary school level, obtained

from the Scopus database (www.scopus.com). The literature analyzed consists of publications available on Scopus from 2013 to 2023. The search keywords used are "augmented reality," "science," and "elementary school." These keywords are employed to find relevant literature.

The literature search in the Scopus database went through 4 stages, namely identification, data filtering, determining data eligibility and drawing conclusions. These stages are presented in the following figure:

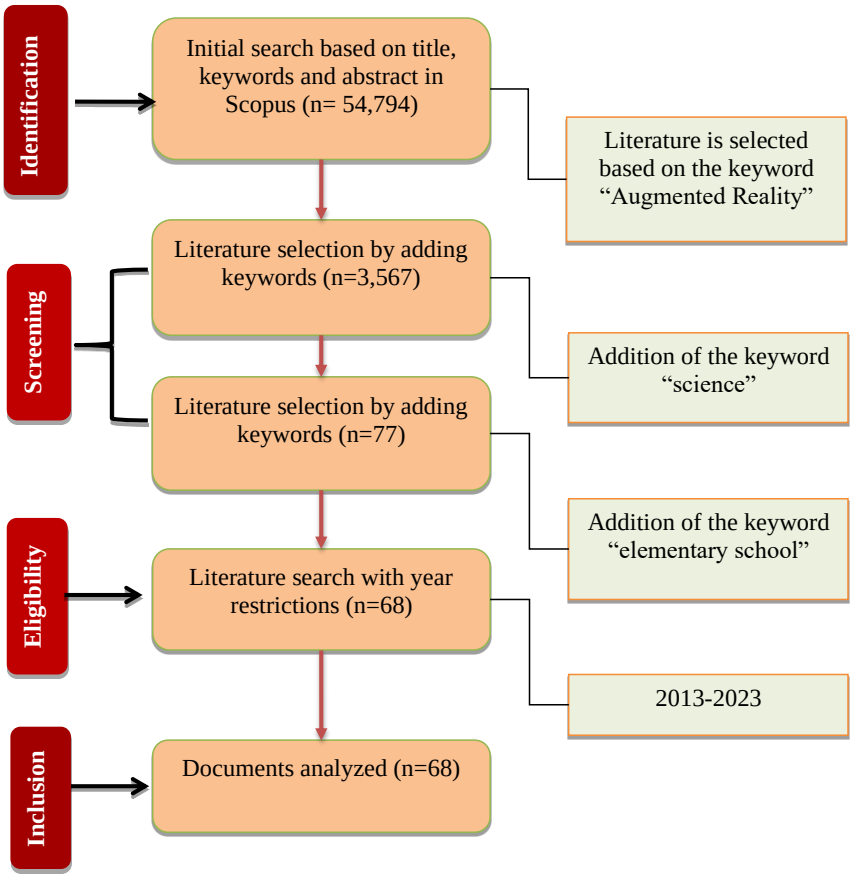

Figure 1. stages of literature search in the scopus database

Inclusion and Exclusion Criteria

The purpose of the inclusion and exclusion criteria is to determine the eligibility of literature for analysis and to identify which studies should be excluded based on specific characteristics or conditions (Felix, 2024). The literature is selected based on the established inclusion criteria, namely: a) publications that match the keywords "augmented reality," "science," and "elementary school," b) scientific literature published within the time frame of 2013-2023, c) literature written in English.

Data Analysis

Content analysis

This method aims to identify themes or topics frequently discussed within a particular research field. Using this technique, researchers can uncover themes that emerge from the analysis of trends in augmente research in elementary science education.

Data Visualization

This data analysis technique utilizes VOSviewer software to present network visualizations and identify patterns of relationships among keywords. This approach allows researchers to better understand the connections between concepts and identify research areas that are emerging or underexplored.

▪ RESULT AND DISSCUSSION

From the search results of articles in the Scopus database, 68 literatures were found that met the established inclusion criteria. Based on the analysis of these 68 literatures, four themes were identified, and grouping these four themes resulted in one meta-theme that emerged related to trends in Augmented Reality research in science education at the elementary school level.

Theme 1: Development of Augmented Reality Media

The development of Augmented Reality technology focuses on integrating virtual elements into the real world through digital devices such as smartphones or Augmented Reality glasses (Azhar et al., 2019). Augmented Reality technology blends digital information or objects into the user's physical environment in real-time, creating a more immersive and interactive experience (Daniela & Lytras, 2019).

An important aspect of developing Augmented Reality media includes advancements in hardware, such as improving cameras, sensors, and processors to enable more accurate recognition of the physical environment (Kersten & Edler, 2020). Additionally, software development focuses on image and space recognition algorithms, visual processing, and data integration (Yue, 2021). A key component of Augmented Reality development is accurate tracking technology, such as GPS, gyroscope sensors, accelerometers, and visual recognition (Dec, 2018). These technologies allow Augmented Reality systems to recognize the user's physical position and track their movements in space, providing an experience that aligns with their real-world environment.

Theme 2: Effectiveness of Augmented Reality in Elementary School Science Education

The effectiveness of using Augmented Reality media in elementary school science education has shown positive impacts on student learning outcomes (Liao et al., 2021; Maijarern et al., 2018). With the interactive visualizations provided by Augmented Reality, students can view and directly interact with virtual objects representing scientific phenomena, making it easier for them to connect theory with real-world experiences (Nincarean et al., 2019). This process helps deepen students' of the material being taught.

Moreover, Augmented Reality also plays a role in enhancing students' motivation and engagement in the learning process (Baabdullah et al., 2021). The interactive and appealing nature of Augmented Reality encourages students to be more motivated to learn as they feel more directly involved (Bhagat et al., 2021). AR offers a learning approach that differs from traditional methods, creating a more enjoyable learning atmosphere and promoting active student participation (Oleksiuk & Oleksiuk, 2022). Consequently, Augmented Reality technology not only improves cognitive learning outcomes but also contributes to increased motivation and student engagement during the teaching and learning process (Anuar et al., 2021).

Theme 3: Implementation of Augmented Reality Media in Education

The implementation of Augmented Reality allows for the visualization of complex concepts in learning (Mota et al., 2016). Teachers can utilize Augmented Reality to create more engaging and in-depth learning experiences, such as simulating natural phenomena or conducting virtual scientific experiments (Zhang et al., 2020). Students can directly interact with virtual objects, like 3D models of the solar system or the human body, making learning more engaging and easier to understand (Lee et al., 2021). However, the application of Augmented Reality media requires careful planning, both in terms of developing appropriate teaching materials and aligning with the existing curriculum, to ensure that this technology is effectively implemented in daily learning practices (Kudale & Buktar, 2022).

On the other hand, challenges faced by teachers in adopting Augmented Reality cannot be overlooked, particularly concerning the readiness of technological infrastructure in schools. Many schools may not have adequate access to hardware such as tablets or Augmented Reality glasses, or strong internet networks to support the smooth use of Augmented Reality (Kravtsov & Pulinets, 2020). Additionally, teachers need to develop sufficient technical skills to operate Augmented Reality devices and integrate them into teaching methods (Mystakidis et al., 2021). Training and support for educators are crucial to overcoming these barriers, allowing Augmented Reality to be maximally utilized as a learning support tool in the classroom.

Theme 4: Enhancing Critical and Creative Thinking Skills

This theme focuses on how Augmented Reality can support the development of students' critical and creative thinking skills in elementary school science education. With Augmented Reality, students can directly interact with simulations and visualizations of complex scientific concepts, encouraging them to analyze, interpret, and evaluate information more deeply (Nincarean et al., 2019). This technology allows students to engage in critical thinking processes through virtual observation of phenomena, predicting outcomes, and exploring various possibilities (Kairu, 2021). By presenting both real and abstract contexts simultaneously, Augmented Reality helps students sharpen their thinking skills in solving scientific problems more independently and systematically (Karagozlu, 2017).

Additionally, Augmented Reality plays a role in stimulating students' creativity, particularly in designing innovative solutions to problems posed (Ghernaout, 2018). Through Augmented Reality, they can explore different approaches to understanding a concept or finding answers to questions (Tosto et al., 2022). In the context of elementary school science education, students can experiment virtually with various scenarios that allow them to develop new ideas (Ravichandran & Mohan, 2022). Thus, the integration of Augmented Reality in education not only enhances logical problem-solving skills but also facilitates the creative thinking process, which is highly needed in the digital era (Lin et al., 2021).

Meta-Theme: The Use of Augmented Reality Media to Improve the Quality of Science Education in Elementary Schools

Augmented Reality serves as a tool to modernize existing teaching methods (Tosto et al., 2022). By integrating Augmented Reality into science education, the learning

process becomes more interactive and engaging, which in turn captures students' attention and increases their involvement in learning (Yoon & Kang, 2021). Through the visualization of objects and concepts that were previously difficult to grasp, Augmented Reality helps students better understand the material and connect it with real-world experiences, thus enhancing learning effectiveness (Kan & Özmen, 2021).

The application of Augmented Reality media in education is expected to have a positive impact on student learning outcomes at the elementary level. With a more innovative and enjoyable method, students are not only passively learning but also actively participating in the exploration and discovery of new knowledge (Macauda, 2018). This allows them to develop critical and creative thinking skills, as well as facilitate more efficient problem-solving (Karagozlu, 2017). Therefore, the use of Augmented Reality in elementary school science education not only functions as a learning aid but also as a strategy that can transform how students learn and understand science (Liao et al., 2021).

Publication Mapping by Keywords

After identifying the themes that emerged from the analysis of research trends in Augmented Reality in science education at the elementary school level, a bibliometric analysis of keywords in the scientific literature was then conducted using VOSviewer software. VOSviewer is software for conducting bibliometric analysis and displaying network visualizations (Malea & Costas, 2021). VOSviewer is used to analyze the relationship between topics or concepts in a scientific literature. This software facilitates users in identifying patterns and trends in a particular research field (Eck & Waltman, 2017). In this study, the author determines a minimum of keywords that appear 2 times in the publication or are used 2 times by the author. From the analysis of 68 documents, 144 keywords were found to be used by the author. Among these keywords, there are 24 keywords that are used at least 2 times by the author.

The results of keyword visualization on VOSviewer in Figure 3 show 6 clusters indicated by different colors. Cluster 1 in red consists of 5 items, namely cognitive load, learning, learning media, natural science and steam. Cluster 2 in green consists of 5 items, namely educational games, game-based learning, games, science learning and storytelling. Cluster 3 in blue consists of 4 items, namely cooperative/collaborative learning, elementary education, interactive learning environment and teaching/learning strategy. Cluster 4 in yellow consists of 4 items, namely augmented reality, education, learning effectiveness and science education. Cluster 5 in purple consists of 4 items, namely elementary school, mobile learning, scientific literacy and stem. Cluster 6 in turquoise consists of 2 items, namely computer assisted instruction and k-12 education.

The network visualization in Figure 3 shows the relationships of each topic or term depicted in a network. The size of the circles indicates how often or not the keyword is used (Istiana, 2022). The large circle indicates that the keyword is the most frequently used. Augmented Reality is the most widely discussed keyword in the analyzed literature. The curved line connects the distances between the keyword circles. Interconnected keywords mean that the keywords have appeared together in scientific literature. Conversely, keywords that are not connected mean that the keywords have never appeared together in scientific literature. In the network visualization in Figure 3, it shows that the keyword Augmented Reality has not been connected to the keywords cooperative

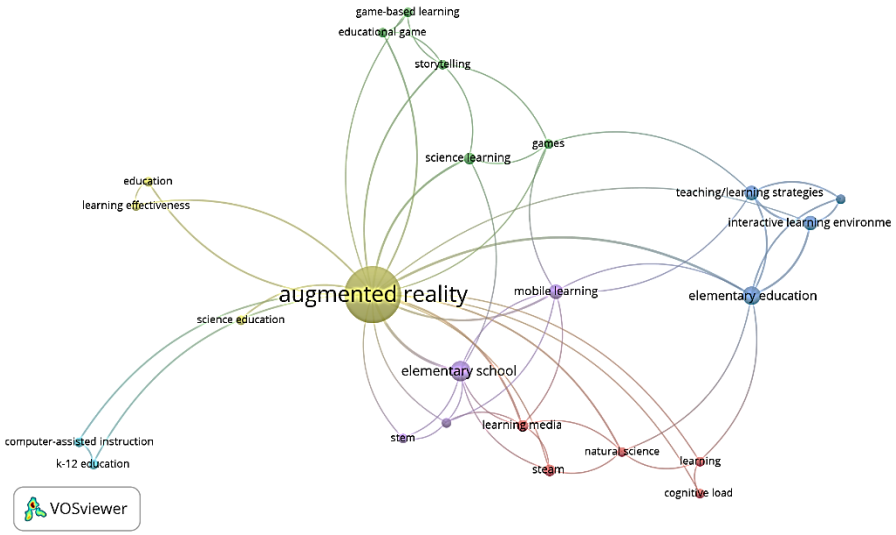

Figure 3. Network visualization based on keywords

and collaborative learning, where this can be a research gap to be discussed further in future research

▪ CONCLUSION

Based on the results of the research and discussion, it can be concluded that that there are four themes related to research trends in augmented reality media in science learning in elementary schools, including: development of augmented reality media, effectiveness of augmented reality in elementary school science education, implementation of augmented reality media in education, and enhancing critical and creative thinking skills. apart from that, one meta theme was obtained, namely the use of augmented reality media to improve the quality of science education in elementary schools.

From the analysis of 68 articles using VOSviewer, 144 keywords were found to be used by the authors. Among these keywords, there are 24 keywords that are used at least 2 times by the author. These keywords are divided into 6 clusters that are distinguished by their colors. Based on the visualization of the relationship between keywords, it is known that the keyword Augmented Reality is not yet connected to the keywords cooperative and collaborative learning. This can be a research gap that can be discussed further in further research.

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