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"OPTIMIZING THE USE OF AUGMENTED REALITY TECHNOLOGY AS AN INTERACTIVE LEARNING MEDIUM": A SYSTEMATIC LITERATURE REVIEW

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Abstract

The rapid advancement of digital technology has encouraged various innovations in education, including the use of Augmented Reality (AR) as an interactive learning medium. This study aims to systematically review the utilization of Augmented Reality in educational contexts and its contribution to improving learning effectiveness and quality in the digital era. This research employs a Systematic Literature Review (SLR) method based on the PRISMA guidelines. Article searches were conducted using the Publish or Perish application with Google Scholar as the database, followed by a screening process using Covidence based on predefined inclusion and exclusion criteria. A total of 29 selected articles were analyzed using qualitative descriptive analysis and bibliometric analysis with the support of VOSviewer. The findings indicate that Augmented Reality has a positive impact on students' conceptual understanding, learning motivation, and engagement, particularly in science, mathematics, and STEM education. However, several challenges remain, including increased cognitive load, limited technological infrastructure, and teachers' readiness to integrate AR into learning activities. Therefore, the optimization of Augmented Reality in education should be implemented holistically by considering pedagogical approaches, instructional design, and the readiness of the educational ecosystem.

Keywords: *augmented reality, learning media, interactive learning, systematic literature review*

Introduction

The rapid advancement of digital technology has brought about significant changes in various aspects of life, including education. The learning process, which was previously dominated by conventional methods, is now shifting toward the use of technology as a tool to support more interactive and meaningful learning. One technology currently receiving significant attention in the education world is Augmented Reality (AR). This technology enables the real-time integration of virtual objects into the real world, thereby providing a more visual, contextual, and engaging learning experience for students.

Various research findings and literature reviews indicate that the use of Augmented Reality in learning has a positive impact on improving conceptual understanding, learning motivation, and student engagement. Meta-analyses and systematic reviews conducted by Howard & Davis (2023), Mystakidis et al. (2022), and Jiang et al. (2025) reveal that AR is effective across various educational levels and subject areas, particularly in STEM education, mathematics, science, and vocational education. Through three-dimensional object visualization and interactive simulations, students can more easily understand abstract material compared to text-based or two-dimensional image-based learning.

Nevertheless, evidence from the field indicates that the use of Augmented Reality technology in education has not yet been fully optimized. Many educators still face limitations in systematically designing and integrating AR into the learning process. Previous studies have tended to focus solely on the effectiveness of AR on student learning outcomes or motivation, without further examining how this technology is utilized as an interactive learning medium that truly supports the quality of the teaching and learning process (Ali et al., 2022).

A research gap is also evident in the dominance of studies focused on the development of AR media products or limited trials within experimental contexts. These studies have not extensively addressed aspects of optimizing AR utilization, particularly in relation to instructional planning, pedagogical strategies, and media alignment with student characteristics and learning objectives. In fact, the success of technology implementation in learning is determined not only by the sophistication of the media but also by how the media is designed, used, and evaluated on an ongoing basis (Pathania et al., 2023)

The previous studies in Indonesia have examined the application of Augmented Reality in education subjects such as mathematics, science, human anatomy, and the introduction to regional scripts (Al-Ansi et al., 2023). The results of these studies generally indicate that AR can enhance students' interest and understanding. However, most of these studies remain limited in scope and focus on final learning outcomes, thus failing to provide a comprehensive picture of how AR can be optimized as an interactive learning medium to improve the overall effectiveness and quality of education.

The urgency of this research is further heightened when considered in light of educational demands in the digital age. Students today face a learning environment that requires critical thinking, creativity, collaboration, and strong digital literacy. In this context, educators are required not only to deliver content but also to create active and meaningful learning experiences. Augmented Reality technology holds great potential to address these challenges; however, without optimal planning and utilization, this technology risks becoming merely a visual innovation without significantly impacting the quality of learning (Wang & Li, 2024).

In addition, several recent studies have also highlighted that the effectiveness of technology-based learning is greatly influenced by the instructional design employed. Effective media must be integrated with appropriate instructional approaches and models to enhance the quality of interaction among teachers, students, and instructional content. Therefore, research on optimizing the use of Augmented Reality as an interactive learning medium is crucial to ensure that this technology is utilized effectively and has a tangible impact on the educational process.

The novelty of this study lies in its focus on optimizing the use of Augmented Reality technology, rather than merely on its application or development. This study views AR as an integral part of learning strategies in the digital age that must be systematically designed and utilized to enhance the effectiveness of learning as well as the quality of the teaching-learning process. Thus, this study differs from previous research, which tended to separate technological and pedagogical aspects.

Based on this description, this study aims to analyze the importance of optimizing the use of Augmented Reality technology as an interactive learning medium in improving the effectiveness and quality of education in the digital age. The results of this study are expected to provide theoretical contributions to the development of research on Augmented Reality-based learning technology, as well as practical contributions for educators, learning media developers, and education policymakers in designing and implementing AR-based learning that is more effective, relevant, and aligned with current learning needs (Gurevych et al., 2021).

The primary scientific contribution of this study lies in reinforcing the proposition that the optimization of Augmented Reality (AR) is not merely a technical issue but must be rooted in sound instructional design theories and pedagogical approaches. This research successfully aligns the utilization of AR technology with the principles of active and meaningful learning, where AR serves as a cognitive bridge to visualize abstract material without excessively increasing the

students' cognitive load. Consequently, this article provides a new theoretical foundation that holistically integrates technological and pedagogical aspects to create a more effective and sustainable digital education ecosystem

Research Methodology

A concise synopsis of the materials and methods employed in the study is imperative. This synopsis should encompass the subjects or materials studied, the instruments utilized, the experimental or study design, sampling techniques, the variables to be measured, data collection techniques, and the statistical analyses and models employed.

It is important to exercise caution and avoid overuse of statistical formulas. In the event of the utilisation of a well-known method, it is sufficient to state the name of the method. In the event of reference to sources, these should be cited as appropriate. In the context of qualitative research, the methods employed may be adapted to suit the specific requirements of the study.

This study employs a descriptive qualitative approach using the Systematic Literature Review (SLR) method, which adheres to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The utilization of the PRISMA method in this study is intended to ensure that the entire process of literature search, selection, and analysis is conducted systematically, structurally, and transparently, so that the results of the study are scientifically accountable and easily traceable. The present study employs an investigative approach to comprehensively examine the utilization of augmented reality (AR) technology as an interactive learning medium in the context of education in the digital era.

The data sources in this study consist of scientific articles obtained through a literature search using the Publish or Perish application with the Google Scholar database. Google Scholar was selected based on its extensive publication coverage, including both national and international journals, thereby enabling the researcher to obtain relevant and diverse articles. The reviewed articles include publications that discuss the application, utilization, and development of augmented reality (AR) technology in learning across various levels and fields of education.

The process of literature searching commenced with the identification of keywords pertinent to the research focus. The keywords employed in the search engine included augmented reality, educational media, interactive learning, and education. The search was constrained to a specific time frame to ensure that the retrieved literature was contemporary and reflected the latest research developments. Subsequently, the search results were exported as metadata, which included fundamental article information such as title, author, year of publication, journal source, and keywords. This metadata was then utilized in the subsequent selection process.

The selection of articles was conducted in stages in accordance with the PRISMA flowchart. In the initial stage, all search results from Publish or Perish were imported into the Covidence application to facilitate data management and filtering. The filtering process was conducted using convenience sampling, which involves selecting articles based on ease of access, topic alignment with the research focus, and relevance to the established study objectives. The keywords employed in the article search were: augmented reality, learning media, interactive learning, and education.

The screening process involved several steps, including the identification and removal of duplicate articles, an initial selection based on titles and abstracts, and a thorough review of the articles through full-text review. In the interest of maintaining the integrity of the research, articles that were deemed irrelevant to the research topic, did not discuss augmented reality in an educational context, or did not meet the established inclusion criteria were excluded from the analysis. The culmination of this selection process is a curated collection of articles that serve as the foundational material in the subsequent literature review.

In accordance with the established criteria, articles that were deemed irrelevant to the research topic, did not discuss augmented reality in an educational context, or failed to meet the

inclusion criteria were excluded from the analysis. The specific inclusion and exclusion criteria applied in this study are detailed in Table 1.

Table 1. Articles' inclusion and exclusion process

Inclusion Criteria	Exclusion Criteria
Discussing the application, utilization, and development of Augmented Reality technology.	Irrelevant to the research topic or objectives.
Focusing on learning contexts across various educational levels and fields.	Do not focus on educational contexts or Augmented Reality in learning
Specifically concentrating on learning media	Do not concentrating a topic about learning media.
Articles containing adequate data or sufficient information for analysis.	Articles lacking sufficient information for further analysis.
Published within a specific timeframe (e.g., 2020-2025) to ensure the literature is up-to-date.	Duplicate articles.

The data collected from the selected articles included metadata and article content, such as article titles, author names, publication years, journal sources, citation counts, and keywords used. The data selected from Covidence were subsequently exported and prepared for further analysis, specifically bibliometric analysis.

The present study employed two primary analytical approaches: bibliometric analysis and qualitative descriptive analysis. The selected article data was then entered into the VOSviewer software to map the relationships between keywords, form research topic clusters, and identify dominant trends and research focuses in studies related to augmented reality as an interactive learning medium. The visualizations generated by VOSviewer were then analyzed descriptively to explain patterns of relationships between topics, the direction of research development, and research gaps that still hold potential for further investigation.

The present study does not emphasize the use of complex statistical formulas or models; rather, it employs a systematic interpretation of literature findings based on bibliometric mapping results and article content analysis. Consequently, the research findings are expected to provide a comprehensive understanding of research trends in augmented reality for learning and its contribution to enhancing the effectiveness and quality of education in the digital age.

Result and Discussion

The present study was initiated with a comprehensive literature search and selection process, adhering to the PRISMA guidelines. This process yielded a total of 500 scientific articles, obtained from a search utilizing the Publish or Perish application within the Google Scholar database. Subsequently, all of these articles were imported into the Covidence application for systematic screening.

During the preliminary identification phase, no duplicate articles were identified, either through manual identification or through the automatic detection process implemented by the Covidence system. Consequently, all 500 articles advanced to the screening phase, which was based on titles and abstracts. At this stage, an initial assessment was conducted to evaluate the alignment of the articles' topics with the study's focus, which is the utilization of augmented reality technology as an interactive learning medium in an educational context.

The results of the title and abstract screening showed that 230 articles were deemed irrelevant because they did not directly address augmented reality in the context of learning or did not align with the research objectives. Consequently, 270 articles were advanced to the eligibility assessment stage through a full-text review.

During the assessment phase, a more in-depth evaluation was conducted to assess the alignment of the articles' content with the established inclusion criteria. Consequently, 241 articles were excluded based on various criteria, including a failure to prioritize the educational context, an absence of consideration for learning media, or an inadequate supply of pertinent information for analysis. Furthermore, there were no articles classified as "ongoing" or "awaiting classification."

Following a thorough examination of the relevant literature, 29 scientific articles were identified as meeting the established criteria and were selected for analysis in this study. The detailed article selection flow is presented in a PRISMA diagram, which systematically illustrates the stages of identification, screening, eligibility, and inclusion of articles.

The 29 articles that were analyzed encompass various types of research, such as systematic literature reviews, meta-analyses, bibliometric studies, and research on the development and implementation of augmented reality in learning. These articles encompass a wide spectrum of educational levels, ranging from elementary to higher education, and diverse academic domains including STEM, science, mathematics, and teacher education (Garzón, 2021; Theodoropoulos & Lepouras, 2021; Pahmi et al., 2023).

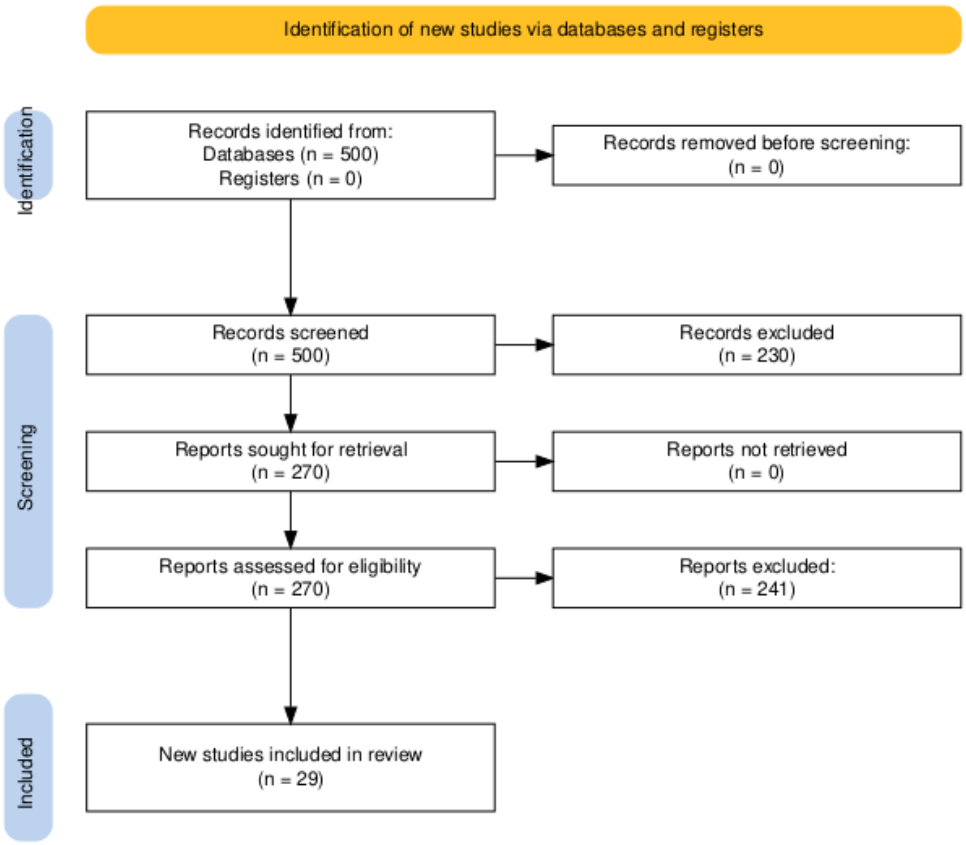

Figure 1. PRISMA flow diagram of the study selection process.

The results of the analysis also indicate that the majority of studies report positive effects of using augmented reality on improving conceptual understanding, learning motivation, and student engagement. These findings are consistent with those of previous meta-analyses and systematic reviews, which have also confirmed the potential of AR as an effective interactive learning medium when designed and integrated with appropriate pedagogical approaches (Chang et al., 2022; Buchner et al., 2022; Ali et al., 2022).

Distribution of Articles by Publication Year

The results of the analysis indicate that research on augmented reality in education has seen a significant increase over the past five years. This phenomenon is indicative of an expanding interest among researchers in leveraging augmented reality (AR) as an interactive learning medium in the digital age (see Avila-Garzon et al., 2021; López-Belmonte et al., 2023).

Table 2. Distribution of articles by year of publication

Publication year	Article count	Percentage (%)
2020	6	20,7
2021	5	17,2
2022	8	27,6
2023	5	17,2
2024	3	10,4
2025	2	6,9
Total	29	100

As indicated by the data presented in Table 1, the highest number of publications was recorded in 2022. This finding is consistent with the mounting imperative for digital technology-based learning innovations, particularly in light of the rapid transition towards online and hybrid learning models (Iqbal et al., 2022; Koumpouros, 2024).

The Concentration Area of Augmented Reality Research in Education

A review of the extant literature reveals a preponderance of focus on the application of augmented reality in the disciplines of science, technology, engineering, and mathematics (STEM). This is because augmented reality (AR) is regarded as an effective medium for visualizing abstract and complex concepts that are challenging to comprehend through conventional learning methods (Abad-Segura et al., 2020; Hidayat & Wardat, 2024).

Table 2. Focus Areas of Augmented Reality Research in Education:

The field of study	Article count	Percentage (%)
STEM (as general)	10	34,5
Science (Physics, Chemistry, Biology)	7	24,1
Mathematics	5	17,2
Teacher Education & Higher Education	4	13,8
Elementary & General Education	3	10,4
Total	29	100

These results reinforce previous findings that AR is most widely used in learning contexts that require visual representation and high levels of interaction, such as STEM and science (Mystakidis et al., 2022).

Results of the Bibliometric Analysis Using VOSviewer

The bibliometric analysis using VOSviewer yielded a keyword map that formed several major research clusters. These clusters reflect the focus and trends of research topics on augmented reality in education. A summary of the cluster analysis results is presented in Table 3.

Table 3. Research Topic Clusters Based on VOSviewer Analysis

Cluster	Main Focus	Key Words
1	Development of AR-based educational media	augmented reality, learning media, visualization,

2	The Impact of AR on Learning Outcomes	learning outcomes, achievement, performance
3	Engagement and motivation to learn	engagement, motivation, interactive learning
4	Pedagogical approaches and instructional design	pedagogy, instructional design
5	Challenges and Future Research Directions	cognitive loads, challenges, future research

The most prominent cluster pertains to media development and the impact of augmented reality (AR) utilization on learning outcomes. These findings are consistent with the results of previous meta-analyses and systematic reviews, which indicate that AR has the potential to enhance learning effectiveness when designed with an appropriate pedagogical approach (Mazzuco et al., 2022).

A systematic literature review of 29 articles reveals that augmented reality (AR) technology has evolved into one of the most extensively researched and implemented interactive learning media in educational contexts in the digital age. The substantial increase in the number of publications over the past five years indicates that AR is regarded as a promising solution to address contemporary learning challenges, particularly in the creation of more contextual, visual, and meaningful learning experiences.

The majority of the articles that were analyzed indicated that the implementation of augmented reality has a favorable impact on students' conceptual understanding and engagement. This phenomenon is especially pronounced in fields such as science, mathematics, and STEM education, where augmented reality (AR) assists students in visualizing concepts, processes, or phenomena that are abstract and challenging to observe directly (Ahmad & Junaini, 2020; Irwanto et al., 2022). The utilization of augmented reality (AR) in education has been shown to facilitate a shift from a passive to an active and exploratory learning process, characterized by direct interaction with learning materials.

In addition to enhancing the conceptual understanding, the use of AR has also been demonstrated to contribute to increased student motivation and interest in learning. A multitude of studies have indicated that the interactive elements and immersive experiences facilitated by augmented reality (AR) have the potential to engender a more engaging and enjoyable learning environment, which, in turn, can result in enhanced student engagement in the learning process (Sırakaya & Sırakaya, 2022). These findings underscore the notion that the efficacy of AR implementation is not solely determined by cognitive factors but is also influenced by affective aspects and engagement in learning.

The results of a bibliometric analysis using VOSviewer reveal several major clusters in Augmented Reality research in the field of education. The most dominant cluster relates to the development of AR learning media and its impact on learning outcomes. This indicates that research focus to date has remained centered on demonstrating the effectiveness of AR and the development of innovative media (Hincapie et al., 2021; Guntur et al., 2020). Meanwhile, another cluster addressing pedagogical approaches and instructional design suggests that the issue of integrating AR with learning strategies is beginning to gain attention, although the number of studies remains relatively limited.

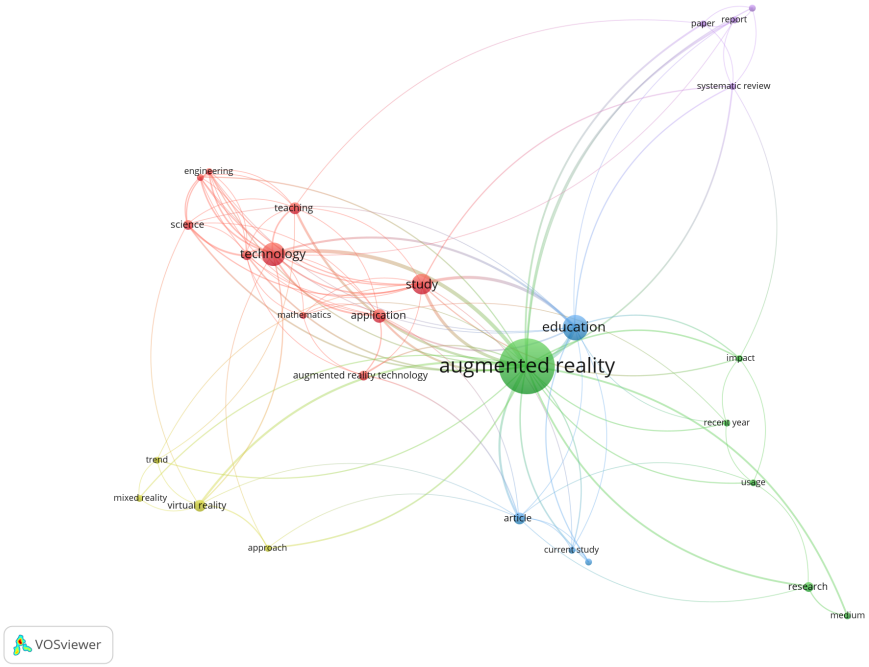

Figure 2. Visualization of Keyword Clusters for Research on Augmented Reality in Education Using VOSviewer

Several studies have also highlighted the challenges and limitations of implementing augmented reality in educational settings. One frequently discussed challenge is the increased cognitive load on students caused by overly complex visual displays and interactions. If AR design does not consider students' characteristics and learning objectives, the technology can disrupt learning focus. Therefore, the design of AR-based learning media must consider principles such as simplicity, clarity of information, and alignment with students' developmental levels.

Beyond design, limitations in technological infrastructure and educators' readiness act as barriers to optimizing AR utilization. Several studies reveal that insufficient supporting devices, limited technology access, and inadequate teacher training are the main obstacles to sustainable AR implementation (Pahmi et al., 2023; Wibowo et al., 2022). These findings suggest that the success of AR in education hinges not only on the technology itself but also on the readiness of the broader educational ecosystem.

Based on the results of this study, it can be concluded that optimising Augmented Reality technology as an interactive learning medium requires a holistic approach. Integrating AR should focus not only on visual and technological aspects, but also on appropriate pedagogical approaches, clear learning objectives, and learner characteristics. Thus, as reported by various previous studies (Geroimenko, 2020; Merino et al., 2020), AR can truly contribute to improving the effectiveness and quality of education in the digital age.

Conclusion

A systematic literature review of selected articles indicates that augmented reality (AR) technology has evolved into an interactive learning medium with great potential to improve the effectiveness and quality of learning in the digital age. Various studies indicate that AR can help students understand abstract concepts by providing contextual, interactive visualizations, especially in science, mathematics, and STEM subjects. In addition to improving conceptual understanding, AR contributes to enhancing students' motivation, interest, and engagement during the learning process. However, the success of AR implementation depends heavily on appropriate

instructional design, educator readiness, and technological infrastructure support. If not carefully designed, AR has the potential to cause excessive cognitive load and reduce learning effectiveness. Therefore, to optimize the use of AR in education, it must be integrated with appropriate pedagogical approaches, clear learning objectives, and consideration of students' characteristics and needs, so that this technology can truly contribute to improving the quality of education.

This study provides a significant contribution by comprehensively analyzing current trends in the use of Augmented Reality (AR) as a learning medium and identifying key challenges in its implementation. These findings offer a practical foundation for educators seeking to integrate interactive technology into the classroom and provide valuable insights for technology developers aiming to create more accessible and effective AR solutions.

Recommendations

Future research is encouraged to place greater emphasis on empirical studies regarding the integration of augmented reality (AR) with various learning models and strategies. This will ensure that research focuses not only on technological aspects but also on pedagogical effectiveness. Additionally, research is needed to examine the readiness of teachers and educational institutions to sustainably implement AR, including training, policy support, and infrastructure availability. When used in education, AR should be tailored to learning objectives and students' developmental levels while adhering to the principles of simplicity and clarity to avoid excessive cognitive load. With the right approach, AR is expected to optimize its use as an interactive learning medium that supports creating a more effective, meaningful, and relevant learning process in line with the demands of the digital age.

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