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# Research Trends and Opportunities in Integrating Augmented Reality and Deep Learning into Science Education: A Bibliometric Analysis

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**Abstract:** The integration of technology and innovative learning approaches is essential to promote students' 21st-century skills. Augmented reality and deep learning approaches offer significant potential to support contextual, immersive, and meaningful science education. However, systematic reviews mapping the integration of both within science learning remain limited. This study aims to identify trends, directions, and research opportunities related to the integration of augmented reality and deep learning in science education from 2015 to 2025. A bibliometric analysis was conducted using data retrieved from the Scopus database and analyzed with VOSviewer through visualizations of publication growth, keyword co-occurrence, trend overlays, density maps, and subject area distributions. The results reveal a notable increase in publications in 2024, the emergence of thematic clusters linking technology, pedagogy, and transformational values, as well as a recent shift of augmented reality toward experience-based media. The findings also highlight the opportunities for classroom implementation and the need to strengthen pedagogical designs rooted in deep learning. The multidisciplinary nature of this research opens collaboration across education, technology, environmental science, educational psychology, and media design. These results emphasize the importance of integrating augmented reality and deep learning in designing innovative, globally responsive, and 21st-century skill-oriented science education.

**Keywords:** Augmented reality; Bibliometric analysis; Deep learning; Natural science learning

## Introduction

Education in the 21st century requires essential skills to solve global challenges. These skills emphasize critical thinking, creativity, collaboration, and communication collectively known as the 4C skills rather than focusing solely on subject matter knowledge (Asrizal et al., 2018; Mutohhari, 2020; Trilling & Fadel, 2009). These competencies enable students to solve problems reflectively, collaborate across diverse contexts, and generate innovative solutions that are applicable in real-life situations. Systematic integration of 21st-century skills into the learning process can enhance both the quality of instruction and learning outcomes at various educational levels (Asrizal et al., 2024; Hidayatullah et al., 2021; Ramdani et al., 2019; Selasmawati & Lidyasari, 2023). Therefore, the mastery of these skills contributes not only to academic achievement but also to the development of students' character, enabling them to become adaptive, resilient, and well-prepared to face the challenges of the digital era actively and productively.

Information and communication technology (ICT) plays a crucial role in supporting 21st-century learning.

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It enables the creation of active, interactive, and meaningful learning experiences. The use of technology in science education allows students to access information, process data, conduct simulations and experiments, and effectively communicate their learning outcomes. Technology integration has become a core component in the development of 21st-century skills required to face the challenges of the digital era (Asrizal et al., 2022; Mansyur et al., 2024). In addition, Chen et al. (2019) emphasize that technology integration will only have a positive impact if it is developed and implemented by considering students' psychological needs and learning contexts. Appropriate use of technology in the learning process also encourages students to become independent learners who are capable of exploring knowledge in a broad and in-depth manner.

Integration of technology and innovative learning is essential to promote 21'st skills in the digital era. Augmented reality techbology and deep learning represents a strategic effort to achieve this goal. Augmented reality enables the visualization of abstract objects in a tangible and interactive manner, thereby helping students to comprehend complex scientific concepts more concretely and meaningfully (Lestari & Setyasto, 2025; Nazifah & Asrizal, 2022; Sapira & Ansori, 2024; Virijai & Asrizal, 2023). Deep learning emphasizes the process of critical, creative, reflective, and problem-solving-oriented thinking that is continuous (Fullan et al., 2018; Prawiyogi & Rosalina, 2025). The combination of augmented reality and deep learning allows students to engage not only on a visual and emotional level, but also on a cognitive level, as they construct a deeper understanding of the learning material. This integrated approach has the potential to enhance student engagement, improve information retention, and develop essential competencies that are necessary for real-world applications and to meet the challenges of the 21st century.

Merdeka curriculum promotes a transformation in learning to meet current educational needs. It emphasizes a student-centered and contextual approach that encourages active engagement in constructing knowledge. It emphasizes a student-centered and contextual approach that encourages active engagement in constructing knowledge. The merdeka curriculum provides students with the opportunity to explore, reflect on, and connect learning materials with real-life situations relevant to their own experiences. Through differentiated and flexible learning, students are given the chance to study in ways that suit their individual needs, interests, and developmental stages (Marlina et al., 2022). The use of technology such as augmented reality and the implementation of deep learning strategies further strengthen the learning outcomes targeted by the Merdeka Curriculum, as they provide interactive, reflective, and meaningful learning experiences (Choudhary et al., 2022). Teachers who are actively involved in planning and adapting learning materials based on the principles of the Merdeka Curriculum tend to create learning environments that are more relevant to students' needs (Hasibuan et al., 2023; Masbukhin & Sausan, 2023). Therefore, learning within the context of the Merdeka Curriculum focuses not only on academic achievement but also on fostering learner autonomy and preparing students to face the challenges of the 21st century.

21st-century skills are essential competencies for addressing global challenges. Previous studies have shown that Indonesian students' 21st-century skills remain at a relatively low level. Critical thinking, creativity, communication, and collaboration core components of 21st-century skills have not yet been optimally developed among students (Hidayatullah et al., 2021; Nurdian et al., 2023; Virijai & Asrizal, 2023). This deficiency is attributed to teacher-centered learning practices and the lack of innovative instructional approaches that support the achievement of 21st-century education goals (Nazifah & Asrizal, 2022; Ramdani et al., 2019). This condition highlights the urgent need for transformation in the learning process that emphasizes active student participation, the use of technology-based learning media, and the reinforcement of authentic assessment to promote comprehensive mastery of 21st-century skills.

The use of digital technology presents a strategic opportunity to support science learning. One of solution approach involves the integration of deep learning and augmented reality. The collaboration between these technologies enables the creation of adaptive and personalized learning systems that can respond to students' learning needs in real time and in authentic contexts (Happy et al., 2025; Nazifah & Asrizal, 2022; Soraya, 2022). The implementation of deep learning and augmented reality can enhance the understanding of scientific concepts and create a more active, enjoyable, and meaningful learning experience (Lee et al., 2022). This technology can be used to visualize science concepts such as magnetic fields, electricity, and water filtration experiments to address water pollution topics that were previously difficult for students to understand through conventional approaches (Haryanto et al., 2024; Hidayani et al., 2025). Through this learning, students can conduct experiments, explore scientific processes, and analyze data in real time.

The application of augmented reality in education can enhance students' learning interest, engagement, and conceptual understanding. Augmented reality can be used to present abstract topics such as energy transformation or the water cycle through interactive visuals that students can touch, manipulate, or modify directly (Lestari & Setyasto, 2025; Sapira & Ansori, 2024).

The deep learning approach emphasizes the creation of a mindful, meaningful, and joyful learning environment and process, aiming to shape students into agents of change (Hattie & Donoghue, 2016; Kemendikdasmen, 2025). The deep learning approach emphasizes three core principles that is mindful learning, meaningful learning, and joyful learning (Kemendikdasmen, 2025; Nugroho et al., 2025; Salirawati, 2018; Zulyadaini & Kasiono, 2025). Therefore, students can actively construct meaning by reflecting on prior experiences when processing new information, thereby supporting the development of meaningful and long-term understanding.

Research that explicitly explores the integration of augmented reality and deep learning in the context of science education remains limited. Most studies focus on a single aspect, such as the general implementation of either deep learning or augmented reality (Marques & Pombo, 2019; Sarker, 2021). Studies that genuinely combine both approaches in science education are still rare, and no systematic mapping has been conducted to identify trends, directions, and gaps in this field. This indicates an urgent need for in-depth investigations to understand how the two can be developed synergistically.

Bibliometric analysis is used to map the development of research within a particular field of study. It can be applied to scientific literature to analyze publication patterns, research trends, and their impact on the advancement of specific areas of knowledge (Passas, 2024). This analysis also enables the identification of scientific contributions, research directions and scope, as well as institutions involved in its development. Thus, the results of bibliometric analysis can serve as a foundation for designing future research agendas in a more systematic manner and in alignment with current scientific needs.

This study maps the integration of augmented reality and deep learning in science education through bibliometric analysis, which is used to identify current trends, research directions, and emerging opportunities in the field. The research aims to examine the development of studies over the past ten years related to augmented reality and deep learning in science education, analyze network visualizations to reveal keyword relationships, use overlay visualizations to identify recent research directions, analyze density visualizations to uncover research opportunities, and examine subject classifications to determine the disciplinary scope. The findings of this study may serve as a reference for educators, policymakers, and researchers in designing science learning that is more contextual, personalized, and meaningful, so that science education can respond more adaptively and sustainably to global challenges. In conclusion, this study is expected to provide both theoretical and practical contributions to the field of education, particularly in promoting innovative and sustainability-oriented science learning.

## Method

This study employs a bibliometric analysis approach. This method is used to systematically map the development of research on the integration of deep learning and augmented reality in science education. It was selected because it enables researchers to trace the influence of specific publications, identify research directions, and determine the key contributors and institutions involved in the field. The mapping procedure follows several steps: research design, bibliometric data collection, analysis, visualization, and interpretation (Zupic & Čater, 2015).

The data were obtained from the Scopus database, which was chosen as it is a leading scientific indexing platform that provides access to internationally reputable journals. The articles collected were published between 2015 and 2025, considering this period as a crucial decade for the advancement of learning technologies and education for sustainable development. The inclusion criteria for the data sources were scientific articles indexed in Scopus that focus on topics relevant to sustainable education and the application of deep learning in science education.

Keywords were carefully selected to obtain relevant literature. The keywords used to search for publications in the Scopus database included "augmented reality" and "natural science." The search was conducted based on specific keywords appearing in the titles and abstracts to ensure that the retrieved articles were truly relevant and focused on the topic under investigation.

The software used for data analysis was VOSviewer. VOSviewer is a bibliometric visualization tool that can display relationships between documents, keywords, and authors based on link strength. It was chosen for its ability to present bibliometric data through complementary visual formats that are easy to interpret and analyze.

This study was conducted through systematic stages to ensure the clarity of the analysis process. The research procedure refers to the five step model described by Irawan et al. (2024). The stages included data collection from the Scopus database, article selection based on inclusion criteria, data processing, bibliometric analysis, visualization of findings, and interpretation of the extracted information. Each step was designed to generate valid data aligned with the research objectives. This process also ensured that the analyzed articles were relevant and met scientific standards. To clarify the workflow, the entire procedure is illustrated in a visual diagram.

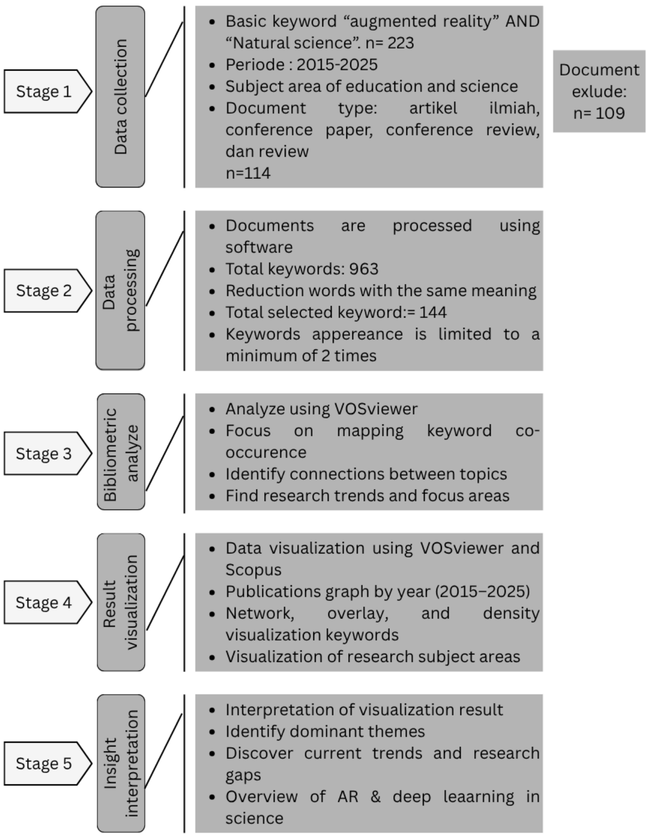


**Figure 1**.Stages of the Bibliometric Research Activities

Based on the figure 1, the first step is the formulation of the research design. This includes defining the main research questions to be answered and selecting the most appropriate bibliometric technique. Various methods exist in bibliometric analysis, such as co-citation, bibliographic coupling, co-word, co-author, direct citation, or a combination of these techniques. In this study, the co-occurrence method was used, which involves mapping keywords that frequently appear together in documents. This technique was chosen because it is considered the most suitable for the focus of the study.

The next step is data collection. This process was carried out by searching the Scopus database and filtering articles based on specific keywords found in the titles and abstracts. This stage also involved narrowing the scope to ensure that the collected data remained relevant to the research objectives. Once the data were collected, the third step was analysis. The researchers used VOSviewer software as a tool to process and analyze the bibliometric data.

The fourth step is visualization. The researchers created three types of visual maps: network visualization to examine the relationships between keywords, overlay visualization to map keywords based on their time of appearance, and density visualization to show the frequency of keyword occurrences across the dataset. The final step is interpretation. The visualized results were not only described descriptively but were also supported by a review of the most frequently cited articles and the most recent publications. This approach ensures that the conclusions drawn are well-founded and remain aligned with the initial research questions.

## Result and Discussion

The data used in this study were obtained from the Scopus database. The researchers set the time span from 2015 to 2025 as the analysis period to capture developments over the past decade and ongoing research trends. This time range was strategically selected to understand current dynamics and anticipate future trends in the integration of deep learning and augmented reality in science education. The keywords used in this study were "augmented reality" and "natural science."

The search process was carried out to obtain relevant publications related to the integration of deep learning and augmented reality in science education. To improve the accuracy and relevance of the data, restrictions were applied not only to the publication year but also to document types, including articles, conference papers, conference reviews, book chapters, and reviews. After a multi-layered filtering process based on keywords, document types, and time span, the researchers obtained 114 articles, which were then exported in CSV and RIS formats.

After the data were collected, the next stage was data analysis. The researchers used VOSviewer software as the primary tool to process and analyze the bibliometric data. In addition, data cleaning and refinement were performed using Microsoft Excel and Notepad by merging keywords with similar meanings.

In the keyword mapping process, the researchers set a minimum occurrence threshold of two to filter terms that have a significant influence within the research network. Out of a total of 963 keywords across 114 documents, only 144 keywords met this threshold. These steps enabled the identification of trends in scientific publications. Additionally, an evaluation was conducted on the thematic contexts of existing studies. The results of this evaluation allowed the researchers to propose more strategic and innovative directions for future developments in technology integrated and sustainability oriented science education.

*Trends in Research Over the Past Decade*

The initial findings of this study involve an analysis of publication trends over the past ten years. The data were visualized based on search results from the Scopus database using the keywords "augmented reality" and "natural science." The generated graph provides a comprehensive overview of the dynamics in annual publication growth. This pattern reflects the influence of technological advancements, global educational policy directions, and sustainability issues that have become major focuses over the past decade, as illustrated in Figure 2.

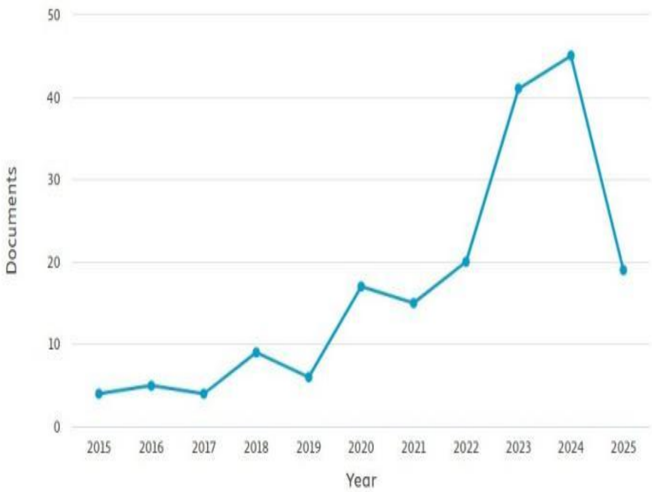


**Figure 2.** Distribution of Publications per Year (2015–2025)

Figure 2 shows that research on science education using deep learning and augmented reality has generally exhibited an upward trend. However, some fluctuations are observed in certain years. A significant increase occurred in 2024, with 47 articles published in a single year. This surge reflects a growing interest in the topic, aligned with rapid advancements in educational technology and increasing awareness of the importance of sustainable education.

In this study, the mapping of article metadata was carried out using VOSviewer. This application enables the systematic and informative visualization of thematic relationships between keywords. The purpose of this mapping is to explore the trends and research directions related to science education through the integration of deep learning and augmented reality over the past ten years. The results of this analysis are presented through visualizations based on the keywords found in the article database. These visualizations are displayed in three models: network visualization, which illustrates the connections between keywords; density visualization, which shows the frequency of keyword occurrences; and overlay visualization, which depicts the development of keywords over time.

*Network Visualization Analysis Results*

The results of the network visualization analysis illustrate the interconnections between items. The analyzed items may belong to the same cluster or span across different clusters. These connections are visualized through a complex yet informative network structure, using colored circles and connecting lines. Each colored circle represents a keyword, while the lines indicate the strength of the relationship between keywords within a single document. Items with similar colors suggest that they belong to closely related thematic groups.

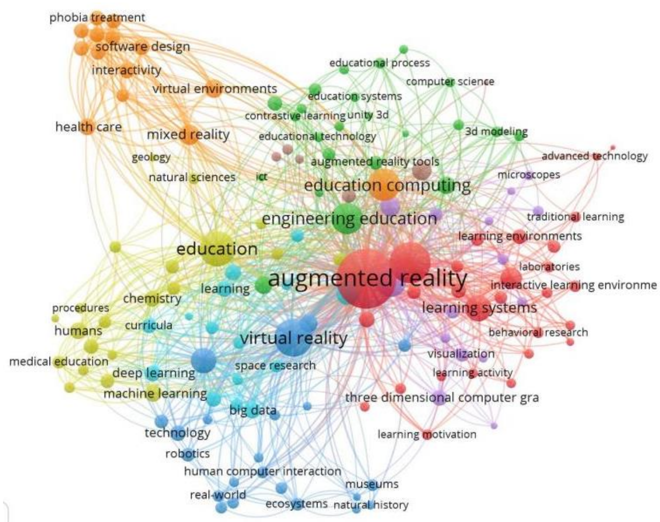


**Figure 3**. Nework visualization dalam pembelajaran IPA dengan pendekatan deep learning dan augmented reality

Based on the bibliometric visualization analysis shown in the figure above, the term augmented reality occupies a central position within the co-occurrence keyword network. This term serves as the largest and most widely connected node, linking to various other keywords across the analyzed literature. Its strategic position indicates that augmented reality is a primary focus in research integrating technology and education. This strong association suggests that the use of immersive technology is increasingly seen as relevant for enhancing the quality of learning, particularly in the context of 21st-century education. Research involving *augmented reality* has not only grown within the field of information technology but has also expanded into other disciplines such as engineering education, science, and health. Therefore, it can be concluded that augmented reality plays a key role in the scientific discourse on educational innovation.

The visualization results reveal the presence of several interconnected thematic clusters within the network. The blue cluster, which includes terms such as virtual reality, deep learning, and machine learning, highlights a concentration of research on simulation technologies and artificial intelligence in education. Meanwhile, the green cluster featuring terms like education computing and engineering education reflects a focus on technology-based instructional design within the field of educational engineering. The red cluster is dominated by keywords such as learning systems, curricula, and instructional design, emphasizing the importance of systematic and adaptive pedagogical approaches. Equally important, the yellow/orange cluster includes terms like medical education and phobia treatment, indicating the application of immersive technologies such as augmented reality in health education and therapy. The connections between these clusters illustrate a multidisciplinary integration of augmented reality to support more contextual and meaningful learning experiences.

These findings offer significant implications for the future development of technology-based education. The integration of augmented reality in learning not only brings visual and interactive innovations but also fosters deeper understanding of complex concepts through simulation-based approaches. In the context of sustainable education, augmented reality holds great potential as a strategic medium to instill sustainability values and cultivate students' critical awareness. Therefore, the integration of immersive technologies like augmented reality in education systems should continue to be developed not merely as learning tools, but as a foundation for building a future-oriented education that is responsive to global challenges.

*Overlay visualization analysis results*

The third result of this study is an overlay visualization that illustrates the temporal distribution of keywords. Each node in the visualization is color-coded to represent the average publication year in which the keyword most frequently appeared. This representation provides insights into the direction of research development and highlights shifts in scientific focus over time.

The overlay visualization presented in Figure 4 provides important insights related to science learning, deep learning, and augmented reality. This visualization uses a color spectrum as a temporal indicator. The spectrum serves as an effective visual tool to identify emerging research focuses while also highlighting underexplored research gaps. The data show that since 2022, augmented reality has gained increased attention, with the topic receiving notable focus from 2019 to 2023. This dominance suggests that research on augmented reality in the context of education has developed earlier and is relatively more mature compared to deep learning.

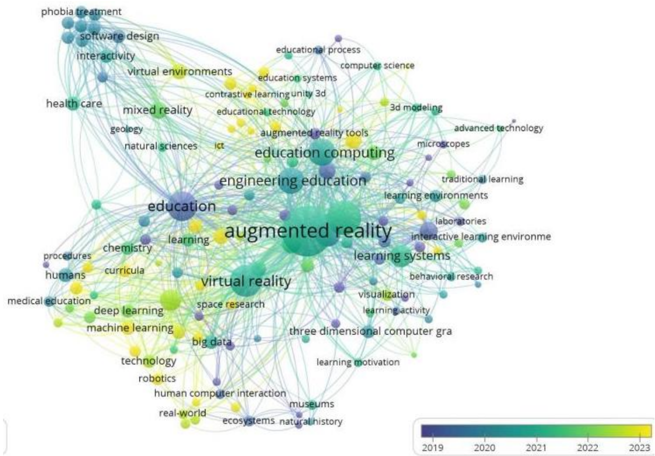

Figure 4. Overlay visualization in science learning using deep learning and augmented reality approaches

The topic of deep learning in education began to show an increase in publications between 2022 and 2024. The appearance of yellow in the overlay visualization indicates that this is a relatively new and still emerging field. Interestingly, most occurrences of the term deep learning are found in broader contexts, such as artificial intelligence, rather than being specifically applied to science education design. This is a noteworthy finding, as it suggests that the implementation of deep learning has not yet been fully directed toward in-depth applications within science education.

The overlay visualization indicates that the integration of deep learning and science education remains a highly open area for further research. The relatively low but gradually increasing frequency of related keywords suggests that this topic has not yet reached academic saturation, making it a promising focus for future studies.

In practice, these findings can encourage researchers and curriculum developers to focus more on designing science learning grounded in deep learning one that is not only adaptive to students' needs but also contextualized with global issues. This aligns with the direction of 21st-century education, which emphasizes the development of critical thinking, scientific literacy, and eco-social awareness. Therefore, the results of the overlay visualization do not merely represent the temporal emergence of keywords, but also offer strategic guidance on underexplored areas of research. By identifying this gap, researchers can develop a more targeted and impactful research roadmap to advance innovative and sustainable science education.

*Density visualization analysis results*

The fourth result of this study is the analysis of the density visualization. The density visualization displays a color gradient, in which bright yellow indicates topics with high frequency and central relevance in discussions, while darker shades suggest that the corresponding terms have received limited attention. This map is presented in Figure 5.

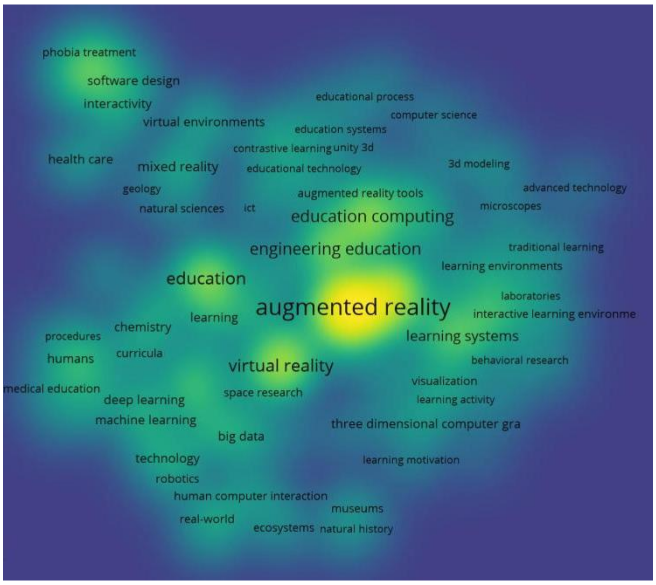


**Figure 5.** Density visualization of science learning with deep learning and augmented reality

Based on the density visualization presented in Figure 5, topics such as augmented reality, education, and learning systems dominate the current body of research. This trend confirms that the use of AR in education has become a relatively mature and widely explored area, as highlighted in studies by (Virijai & Asrizal, 2023) and (Purwanti et al., 2024). Many studies in this area have explored the potential of AR to enhance environmental literacy, improve scientific concept comprehension, and foster reality-based learning experiences.

In contrast, terms such as deep learning approach and science learning appear in areas with lower color intensity. This suggests that the connection between deep learning and science education remains relatively limited. The visualization serves as an important indicator that the integration of deep learning within the context of science education has not yet been extensively explored. Therefore, there is still significant room for researchers to further develop studies on this topic.

This finding also reinforces the results of the overlay visualization, which previously indicated that the topic of deep learning in education has only started to develop in recent years. The low density of this keyword in the density visualization further supports the argument that the scientific novelty of this topic remains high and is therefore worthy of further exploration.

Overall, the density visualization not only highlights popular topics but also helps identify research gaps that can be leveraged to design innovative and relevant studies. With the right approach, researchers can utilize these low density areas as opportunities to produce high-impact scientific work.

*Results of subject area distribution analysis*

The fifth result of this study is a subject area visualization that illustrates the distribution of academic disciplines across the analyzed documents. Each color or category in the visualization represents the scientific fields that have most significantly contributed to relevant publications. This information provides an overview of the dominant disciplines involved in studying the topics of augmented reality and sustainable education, thus helping to identify the direction of multidisciplinary contributions in the development of this research area.

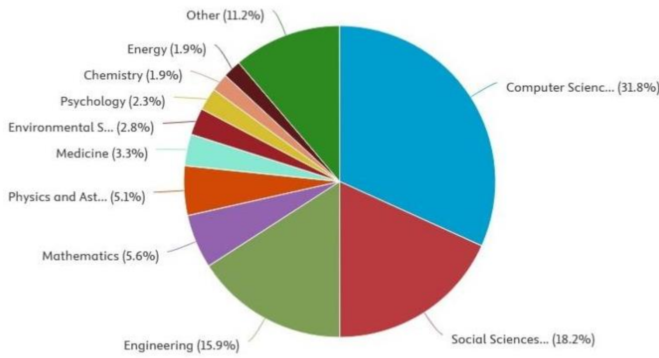


**Figure 6.** Distribution of science learning using deep learning and augmented reality approaches

Figure 6 shows that the distribution of publications related to science learning using deep learning and augmented reality spans across various academic disciplines. The majority of studies fall under the field of computer science (31.8%), followed by social sciences (18.2%) and engineering (15.9%). This distribution clearly reflects the interdisciplinary nature of science education research involving deep learning and augmented reality. In other words, these studies integrate approaches, theories, and methods from multiple fields to address complex educational challenges. This indicates that there is still a wide-open opportunity for further research in this area. Rather than being confined solely to the natural sciences, future research can be enriched through interdisciplinary collaboration. Such collaborations will help move science education beyond traditional boundaries, promoting more integrative and globally responsive learning models.

Based on the bibliometric analysis of scientific publications over the past decade, the integration of deep learning and augmented reality in science education has shown a notable upward trend. The density and overlay visualizations indicate that research on deep learning within the context of science learning began to emerge around 2022; however, studies that explicitly combine both approaches remain limited (Happy et al., 2025; Virijai & Asrizal, 2023). This indicates that the field still offers ample opportunities for future research, particularly in designing science learning models that are adaptive, contextual, and sustainable.

Several studies have demonstrated the potential of this technology to strengthen students' understanding of scientific concepts. Choudhary et al. (2022) explain that deep learning plays a crucial role in developing adaptive and personalized learning systems. Deep learning, which encompasses understanding and linking conceptual and procedural knowledge, as well as the ability to apply conceptual knowledge to new contexts by relating it to real-world conditions, is expected to create learning experiences that are practical and beneficial in students' lives.

Related to this, Sarker (2021) explain that deep learning can also enhance student engagement by creating interactive, data-driven learning environments, particularly in STEM education. However, emphasizes that the integration of such technology should aim to fulfill more humanistic educational objectives. In other words, the systems developed must take into account multiple intelligences and the holistic character formation of students.

The utilization of augmented reality has begun to show positive effects on student engagement and understanding in science learning. According to Virijai & Asrizal (2023), augmented reality can bridge the gap between the real world and abstract scientific concepts, enhance the visualization of scientific phenomena, and create more authentic learning experiences. This is further supported by studies from (Mei & Yang, 2019; Saidin et al., 2015) which emphasize that augmented reality not only reinforces conceptual understanding but also strengthens students' environmental literacy by enabling interactive exploration of ecological issues. Nevertheless, the simultaneous integration of augmented reality and deep learning in science education remains scarce, signaling a significant opportunity for further development of cross-technology approaches within the context of sustainability.

Analysis of the article by Trott & Weinberg (2020) reveals that science learning integrated with sustainability values is crucial for fostering students' ecological awareness and systemic thinking skills. Unfortunately, most research approaches remain limited to module development. The lack of integration with intelligent technologies indicates that the significant potential of deep learning and augmented reality has yet to be fully optimized to transform sustainability education. This shortcoming highlights the need for integration of deep learning and augmented reality technologies not only within digital learning systems but also through transformative curriculum design.

Although bibliometric studies have provided valuable insights into trends and key terms within this field, several limitations remain regarding the scope of existing research. Most identified studies are still rooted primarily in computer science disciplines and have yet to extensively explore science education from a comprehensive pedagogical perspective (Larson & Chambers, 2020). Therefore, future research directions should promote collaboration among education, technology, and environmental fields to develop deep learning and augmented reality-based science learning models that support sustainability both epistemologically and practically.

## Conclusion

This study concludes that the bibliometric analysis of literature related to the integration of deep learning and augmented reality approaches in science education shows a significant increasing trend over the past decade. First, there is a surge in the number of publications with a sharp increase in 2024, indicating growing attention to the utilization of augmented reality and deep learning in science learning. Second, the bibliometric mapping successfully identifies major thematic clusters that illustrate the synergy between technology, pedagogy, and transformative values in education. The dominance of computer science, engineering, and medical fields reinforces the multidisciplinary nature of this research development. Third, based on overlay visualization, this study contributes importantly to the direction of innovative science learning model development, particularly through the deep learning approach. Current research trends show a shift in the use of augmented reality from merely a visualization tool to an experiential learning medium that fosters awareness and engagement among learners through deep learning approaches. Fourth, these findings open further exploration opportunities regarding the implementation of augmented reality in real classroom contexts, including strengthening pedagogical designs relevant to deep learning approaches. Fifth, based on the analysis of subject areas, research related to augmented reality and deep learning in science education is multidisciplinary in nature, with significant potential for cross-disciplinary collaboration between education and technology. Such collaboration is essential to create more innovative and contextual learning practices. Overall, the findings of this study indicate that the integration of augmented reality and deep learning in science learning is increasingly significant in addressing the challenges of 21st-century skills and can serve as a strategic foundation for researchers, practitioners, and policymakers in designing adaptive learning strategies responsive to technological advances and global issues.

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**Author Contributions**
All authors have contributed with their respective tasks which are equally important for the completion of the writing of this paper. Elvaretta Efendi contributed in collecting data in the field, compiling paper drafts, processing data, and analyzing. Asrizal contributed as a guide for the implementation of research up to the paper's authorship, idea designer, and review of paper drafts.

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**Conflicts of Interest**
In making the paper, the authors found no conflicts. The research implementation ran smoothly according to procedures with legal permits. Research implementation does not interfere with conducive learning in class because the research material is in accordance with the curriculum used in schools.

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