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Research Trends of Augmented Reality E-Modules in Improving Students' Science Literacy: A Systematic Review

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Abstract: The rapid development of digital technology has driven transformations in educational practices, including in the presentation of science materials. This article presents a systematic review of research trends on augmented reality (AR)-based e-modules in the context of improving students' science literacy. This study aims to identify the direction of development, publication frequency, and thematic focus of research from 2016 to 2025. Data were collected through document searches on Google Scholar using relevant keywords, which were then analyzed to reveal the contribution of AR e-modules to science learning. The results of the analysis show a significant growth in interest in this topic, especially after 2020, along with the increasing need for interactive and contextual learning media. This study also maps the types of publications, years of publication, and the most widely used journals or proceedings. These findings reinforce the importance of developing AR-based e-modules as a potential learning strategy in improving conceptual understanding, scientific reasoning, and active involvement of students in the science learning process.

Keywords: Augmented Reality; E-Module; Science Literacy

Introduction

Science literacy has become a crucial competency in 21st-century education, where students are required not only to understand scientific concepts but also to be able to apply them in real-life contexts (González Pérez & Cerezo Cortijo, 2020). However, efforts to achieve this goal face increasingly complex challenges, along with the dynamics of the modern curriculum and the characteristics of the digital native generation that require more innovative learning approaches (Rosmayuni, Suma, & Suja, 2024).

In the last decade, the integration of technologies such as augmented reality (AR) into electronic modules (e-modules) has emerged as a potential solution to create immersive, contextual, and inquiry-based learning experiences (Rizqillah & Kholiq, 2023). In line with this, this study aims to conduct a systematic review of the development trends of AR-based e-modules in the context of improving students' scientific literacy, focusing on the period 2016–2025 to understand the evolution of methodologies, pedagogical effectiveness, and implementation challenges.

It should be understood that scientific literacy today is no longer limited to mastering scientific content alone, but also includes epistemological, socio-cultural, and applicative dimensions (Herlina & Abidin, 2024). González and Cerezo (2020) identified that around 67% of elementary school students have difficulty linking scientific concepts to everyday phenomena, which is largely due to an overly textual learning approach. This is exacerbated by the dominance of conventional methods that do not actively involve students in exploration.

In fact, *the Programme for International Student Assessment* (PISA) framework emphasizes the importance of the ability to explain scientific phenomena, evaluate investigative designs, and interpret data as the main indicators of scientific literacy (Herlina & Abidin, 2024). In this context, curriculum

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transformation such as the implementation of the Independent Curriculum in Indonesia requires the development of learning resources that support the principles of differentiation and independent learning (Rosmayuni et al., 2024). Interactive e-modules are one response to this need, because they are able to integrate multimedia, simulations, and adaptive feedback in the learning process.

However, conventional e-modules still have limitations, especially because they only focus on basic cognitive aspects. Therefore, innovation in the form of AR integration is needed to enrich learning in the affective and psychomotor dimensions (Sholikhah & Puspitawati Pratiwi, 2025). AR technology itself offers a new paradigm in science education, by combining virtual objects into the real environment, allowing interactive visualization of abstract concepts such as molecular structure or processes in ecosystems (Adapa et al., 2020).

Rizqillah and Kholiq's (2023) research strengthens these findings by showing that AR-based e-modules (ARLISA) can improve students' understanding of renewable energy concepts by 32% compared to conventional modules, thanks to 3D simulation features and interactive hotspots that encourage independent exploration. This is in line with Sweller's *cognitive load theory,* which states that AR helps reduce cognitive load through the presentation of information in a multimodal manner (González Pérez & Cerezo Cortijo, 2020). In the context of scientific literacy, AR functions not only as a visualization tool, but also as a medium for training critical thinking skills.

A systematic study by Herlina and Abidin (2024) also revealed that AR e-modules that adopt the *inquiry-based learning* (IBL) learning model can improve students' abilities in designing experiments and analyzing data by up to 40%. Features such as *drag-and-drop* on virtual components in chemical reaction simulations—as developed by Suryati, Surningsih, & Mashami (2022)—significantly facilitate procedural understanding which is important in mastering scientific literacy.

Overall, AR modules have shown great potential in improving scientific literacy at various levels of education. A systematic review of AR integration in science education revealed positive impacts on improving students' academic performance, learning motivation, and conceptual understanding. These findings confirm that AR is an effective tool to address challenges in traditional science education while building a deeper understanding of scientific concepts.

Specifically, AR has been shown to improve students' motivation and academic achievement, especially in biology and life sciences, by providing an engaging and interactive learning experience (Subran & Mahmud, 2024). The use of AR in K–16 education has been systematically reviewed and demonstrated its effectiveness in supporting instructional design and technological features that can drive better learning outcomes (Yin et al., 2022).

In the health sciences, AR is also effective in improving students' practical skills—such as in local anesthesia procedures and dental care—as well as enriching knowledge in anatomy and community nursing (Susilawati et al., 2022). In addition, AR modules have been developed to improve early childhood science literacy, as a solution to the limitations of effective media in traditional learning methods, by providing diverse and challenging learning activities (Eliza, 2023).

AR has been shown to improve cognitive skills such as critical thinking, conceptual understanding, and scientific literacy. It enhances students' ability to visualize and understand abstract concepts in subjects such as physics (Sebastian & Kuswanto, 2024). In special education, AR has positively impacted students with educational needs by providing tailored learning experiences that cater to individual learning styles (Batanero et al., 2022).

The use of AR in education has enabled the creation of detailed anatomical models, facilitating a deeper understanding of complex medical concepts (Xu et al., 2021). The integration of AR in science learning often involves mobile applications and AR picture books, which are favored for their ease of use and rapid development capabilities (Rahmat et al., 2023)]. Quantitative research designs and cognitive tests are commonly used to assess the impact of AR on learning outcomes (Rahmat et al., 2023). The focus on 21st-century skills, such as critical thinking and creativity, aligns with the goals of digital-age education, making AR a valuable tool in modern science education (Prananta et al., 2024)

The benefits of AR in biology education not only include increasing knowledge retention and understanding, but also forming a positive attitude towards learning, especially in the affective aspect (Subran & Mahmud, 2024). However, the widespread adoption of AR still faces various challenges, such as technical constraints, lack of relevant content, and limited internet connectivity (Subran & Mahmud, 2024).

This article aims to conduct a systematic review of studies that focus on the development of augmented reality (AR)-based e-modules in the context of improving students' scientific literacy, published between 2016 and 2025. Through this review, it is expected to gain an in-depth understanding of the developing research trends, challenges faced in integrating AR into e-modules, and the potential contribution of this technology to improving students'

scientific literacy skills. In addition, the results of this study are expected to be an initial reference and foundation for the development of similar research in the future.

Method

This study uses a descriptive-analytical approach that aims to systematically explore and map research trends related to the development of augmented reality (AR)-based e-modules in improving students' scientific literacy. This study is designed within the framework of *a Systematic Literature Review (SRB). Review/SLR)* to compile a comprehensive, transparent and replicable mapping of relevant publications.

Primary data were collected from the Google Scholar database, which was selected for its wide reach, open access, and consistency in indexing scientific papers in the field of education and learning technology. A total of 1,000 publications published between 2016 and 2025 were downloaded using the *Publish or Perish (PoP) application* , which supports the extraction of metadata such as title, abstract, author names, and number of citations. To improve the accuracy of relevance and citation validation, the *Dimensions.ai database* was also used as a complement.

The literature search process was carried out by compiling and combining several main keywords such as: "*augmented reality,*" "*e-module,*" "*science literacy,*" "*science learning,*" and "*development of AR-based learning media*" . Keywords were entered gradually, either singly or in combination, in order to obtain maximum study coverage according to the focus of the study.

In ensuring the accuracy and integrity of the selection process, this study refers to *the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol* . The PRISMA stages followed include: identification, screening, eligibility evaluation, and inclusion of documents. Duplicate or irrelevant studies were eliminated based on the results of an initial review of the title and abstract, followed by a complete content analysis of the remaining articles.

Documents that passed the final selection were analyzed descriptively to identify key trends-themes, dominant focuses in the development of AR e-modules, publication dynamics from year to year, and research gaps that are still open. This approach provides a comprehensive understanding of how AR integration in e-modules contributes to improving students' scientific literacy in contemporary science learning.

Result and Discussion

The purpose of this study is to describe research trends on the development of augmented reality (AR)-based e-modules aimed at improving students' scientific literacy in the period 2016 to 2025. The documents analyzed in this review are focused on studies that integrate AR technology into interactive learning media in the form of e-modules, especially in the context of science learning at elementary to secondary education levels. The literature collected comes from various relevant scientific publications and is systematically selected based on certain inclusion criteria. Figure 1 below presents a visualization of research trends on the topic over the past decade.

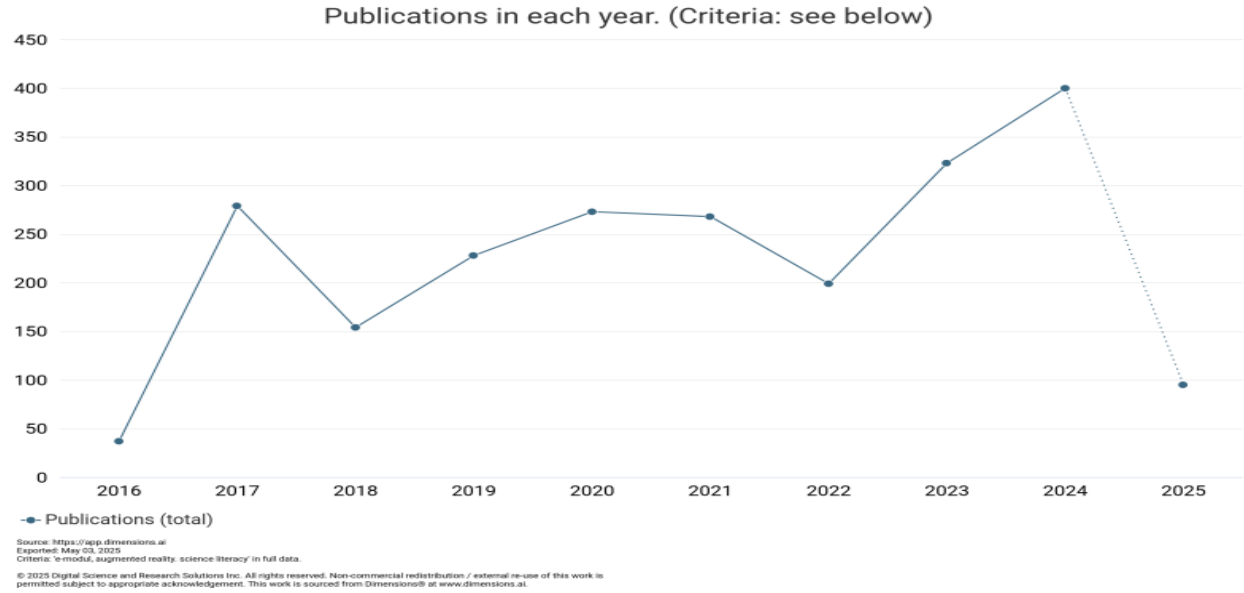

Figure 1. shows research trends related to issues in science education, especially in the development of augmented reality-based e-modules to improve science literacy

Figure 1 illustrates the trend of research publications on the development of augmented reality (AR)-based e-modules to improve students' science literacy from 2016 to 2025. It can be seen that the number of publications increased significantly in 2017 and again showed a spike in 2020 and 2024. This increase indicates a growing interest in the integration of innovative technologies such as AR in science learning. The highest peak occurred in 2024 with the number of publications reaching more than 400 documents.

However, the graph shows a drastic decline in 2025. This is likely because the data for 2025 has not been fully accumulated until now, considering that the year is still ongoing. The spike in interest in 2020 and 2024 can be attributed to the need for digital-based learning post-pandemic and the increasing push to develop 21st-century skills through technology-based science literacy approaches.

Table 1. Research Trends on Augmented Reality E-Modules to Improve Students' Science Literacy Based on Publication Type

Publication Type	Amount
Edited Book	813
Proceeding	740
Article	739
Chapter	162
Monograph	104
Preprint	5

Based on Table 1, it can be seen that the results of research on learning models (in general) have been published in various types of scientific documents over a certain period of time.

It is recorded that there are five types of publications containing the results of the research, namely in the form of edited books , proceedings , articles , chapters , monographs , and preprints . The type of publication with the largest number is edited books with a total of 813 documents. Next, proceedings and articles follow with almost equal numbers, 740 and 739 documents respectively.

Other types of publications such as chapters were recorded as many as 162 documents, monographs as many as 104 documents, and preprints were the least type of publication found, only as many as 5 documents. This shows that the results of research related to learning models are more often compiled in the form of edited books and journal articles than in the form of preprints or monographs.

From the data, it can be seen that the publication trend is more inclined towards types that have wide distribution and are easily accessible to academics, such as articles and edited books. This tendency can be caused by the nature of journal articles which are more concise, focus on research results, and can be accessed online through open journals, thus facilitating distribution and citation. Conversely, the low number of preprints and monographs indicates that researchers tend to choose media that have gone through a formal review process rather than the form of an initial manuscript or a single-theme publication.

In the context of scientific publication, articles are seen as the most relevant form of publication for disseminating ideas and findings systematically and can be tested through citation and peer-review.

Table 2. 10 Sources Title Research Trends Augmented Reality E-Modules in Improving Students' Science Literacy (2016–2025)

Journal Name	Number of Publications	Number of Citations	Average Citation
Journal of Science Education Research	79	154	1.95
Advances in Social Science, Education and Humanities Research	78	85	1.09
Epidemiology	50	39	0.78
Lecture Notes in Networks and Systems	35	305	8.71
Lecture Notes in Computer Science	34	372	10.94
Journal of Educational Technology	16	133	8.31
Elementary School Scientific Journal	15	54	3.60
JPI (Journal of Indonesian Education)	13	45	3.46
Indonesian Journal of Science Education	13	58	4.46
International Journal of Elementary Education	12	14	1.17

Table 2 shows the main publication sources in the research trend of augmented reality-based e-modules to improve students' science literacy. The journal with the largest number of publications is Jurnal Penelitian Pendidikan IPA, with a total of 79 publications and 154 citations, resulting in an average of 1.95 citations per article. This journal consistently publishes articles that focus on innovations in science learning, including the use of technology such as augmented reality in education.

In addition, Advances in Social Science, Education and Humanities Research also showed significant contributions with 78 publications, although with a lower citation average of 1.09. Meanwhile, although the number of publications of Lecture Notes in Computer Science and Lecture Notes in Networks and Systems were fewer (34 and 35 publications respectively), both journals had very high citation averages, indicating a strong impact on the academic community.

In general, these data indicate that studies of AR e-modules in the context of scientific literacy have been spread across various journals, both those focused on science education, educational technology, and interdisciplinary, and show increasing attention from researchers across fields.

Figure 2 displays the results of visual mapping of keywords using VOSviewer that represent research trends in the development of augmented reality-based e-modules to improve students' science literacy during the period 2016 to 2025. This visualization groups keywords into six interconnected thematic clusters, marked with different colors. The blue cluster is the center of the network with main keywords such as augmented reality, e-module, teaching material, and flipbook, reflecting the research focus on the development of technology-based digital teaching tools. The red cluster includes keywords such as science learning, conceptual understanding, and augmented reality enhances sci, indicating that most studies examine the effect of augmented reality in deepening the understanding of science concepts.

Meanwhile, the yellow cluster highlights the importance of strengthening 21st-century skills, with keywords such as scientific literacy, critical thinking, and e-module learning media. The green cluster shows the integration of technology in learning through terms such as project, technology, learning activity, and smartphone, which describe the practice of using digital media in learning activities.

The purple cluster focuses on the development of visual representations and simulations through keywords such as augmented reality technology, virtual reality, and multiple representation. The light blue cluster contains words such as literacy skills and science literacy skills, which strengthen the relationship between the use of technology and improving students' science literacy. Overall, this mapping shows that research in the last decade has increasingly led to the development of innovative interactive media to support the achievement of scientific literacy skills in science learning.

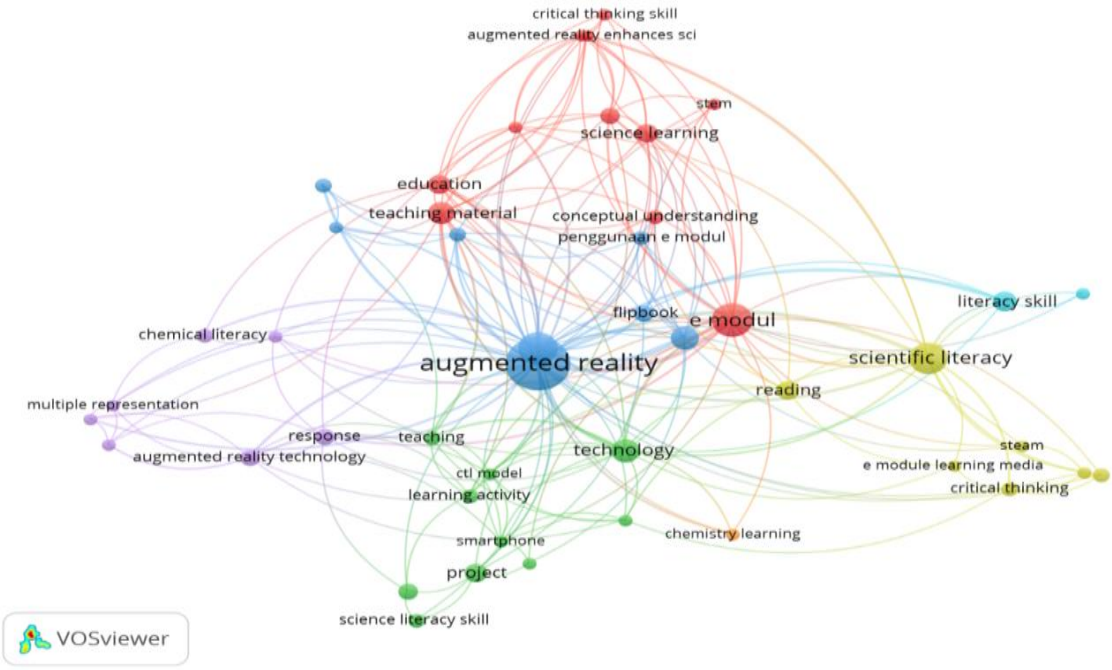

Figure 2. Network visualization of the research trend of augmented reality e-modules in improving students' scientific literacy

Figure 2 also presents a network-shaped visual mapping, illustrating the relationship between keywords in research on augmented reality-based e-modules to improve students' scientific literacy. Each group of terms is visualized with a different color, reflecting thematic grouping and structural relationships between topics. Keywords such as augmented reality , scientific literacy , e-modules , and

science learning stand out, indicating the main focus in scientific publications in this field. Larger circles represent high frequency of keyword occurrence, indicating their central role in the development of related literature. The overlay display in this visualization also emphasizes emerging trends, showing new directions and continued potential in research on the development of interactive technology-based learning media that support deeper understanding of scientific concepts.

Figure 3 displays a visualization of keyword trends related to research on the development of augmented reality-based e-modules in the context of improving students' scientific literacy, as indexed in Google Scholar during the period 2015 to 2024. In this representation, the shift in research focus is visualized through a color gradient, from blue for the early years to yellow for the most recent years. Keywords such as augmented reality, e-modules, and science learning began to be widely used in the period 2020–2021, indicating increasing attention to the use of interactive technology in science education. Meanwhile, terms such as scientific literacy and digital media began to dominate in more recent years, reflecting the direction of research developments that increasingly emphasize 21st-century competencies and the integration of technology in the teaching and learning process.

AR-based e-modules provide a three-dimensional interactive learning environment that enhances student engagement and understanding. For example, an e-module developed to teach the solar system to sixth graders showed high validity and feasibility, as evaluated by experts and users (Sa'diah et al., 2022).

Another study focused on integrating AR with thematic learning modules that incorporate Pancasila student profiles, which aims to strengthen character education in elementary schools. This module was validated as highly effective by media and content experts (Mahmud, 2022).

E-AR modules have also been developed using a guided discovery learning model, which significantly improves students' problem-solving skills and learning outcomes in vector mathematics (Saumi et al., 2022). E-modules have been highly rated by students and educators for their practicality and effectiveness in the classroom (Saputra & Octavia, 2024) (Rahmadani & Sunarmi, 2023). Future research should explore the long-term impact of AR on various educational needs and its potential to further enhance science literacy across diverse student populations (Batanero et al., 2022). The use of AR in education is increasing, with significant contributions from countries such as India, the United States, and China. This trend is part of a broader movement towards digitalization and modernization in education, in line with the requirements of Industry 4.0 (RHENA et al., 2025).

Improving Science Literacy: AR applications, such as Assemblr Edu, have been shown to effectively improve science literacy among students by providing interactive and scientifically engaging content (Kelas et al., 2024).

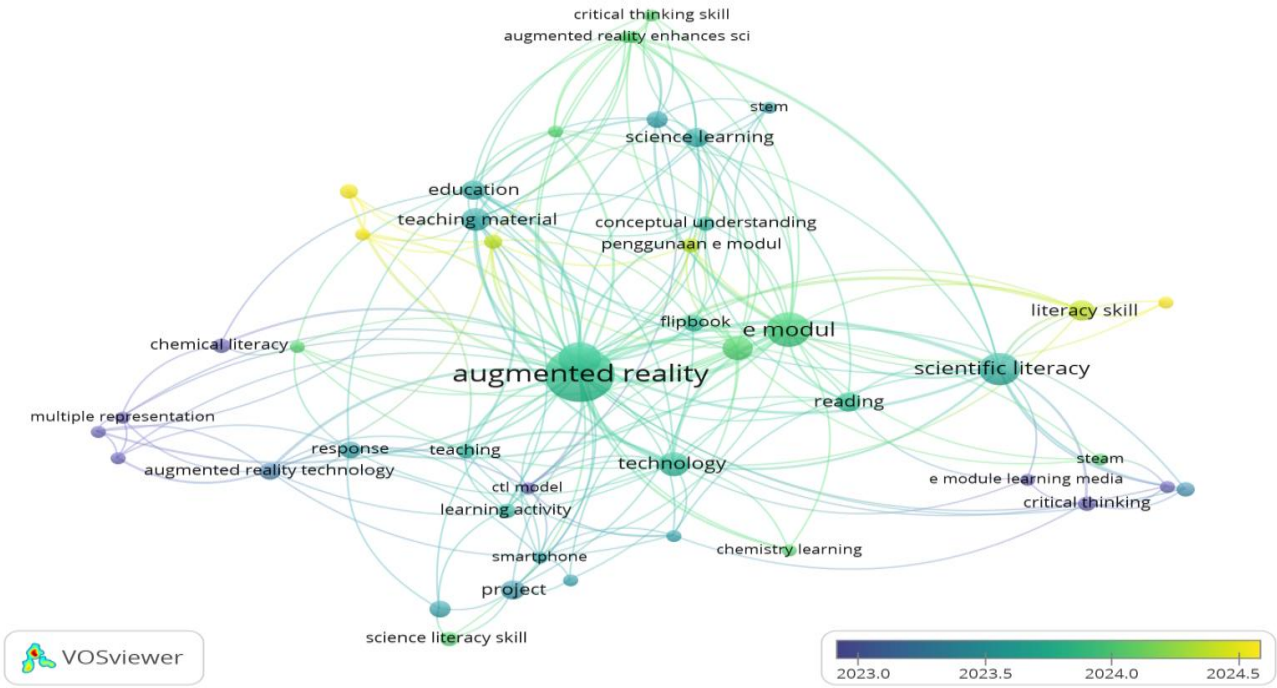

Figure 3. Overlay visualization of research trends on augmented reality-based e-modules to improve students' scientific literacy.

This visualization shows the development of keywords over the time span of 2016 to 2025, with a color gradient from blue (early years) to yellow (latest years), illustrating the shift in research focus from developing learning technologies to utilizing augmented reality in improving science understanding. Keywords such as e-modules, augmented reality, and science literacy dominate recent publications, indicating the increasing attention to the integration of immersive technologies in science education in the digital era.

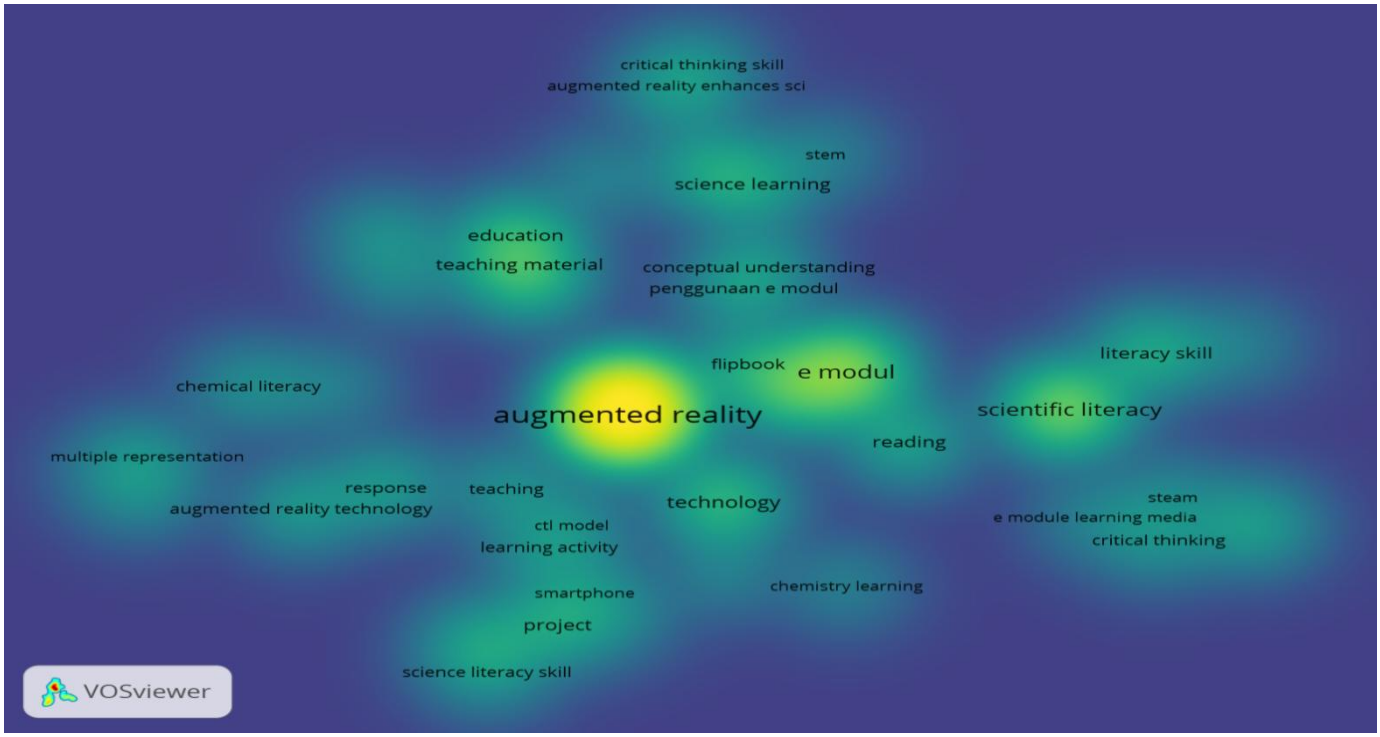

Figure 4. Density visualization of research trends on augmented reality-based e-modules in improving students' scientific literacy

Overall, research on ***augmented reality-based e-modules*** to improve students' scientific literacy shows quite diverse dynamics throughout the period 2016–2025. Based on data indexed by Google Scholar, the number of publications on this topic has increased fluctuatingly, with peak research activity recorded in 2020 and 2023, before declining again in 2024. Various types of documents—ranging from book chapters, edited books, journal articles, monographs, to proceedings—have included the results of this research, reflecting interest across publication formats. In bibliometric studies, terms such as *augmented reality, e-modules*, *scientific literacy*, *interactive*, *concepts*, *sensors*, and *digital media* appear most frequently, indicating the main focus of research on developing immersive and contextual learning content. Despite a slight decrease in the number of studies in 2024, the general trend indicates that AR e-modules remain an important area of study with potential for continued development—especially in the integration of 3D features, interactive hotspots, and adaptive feedback—to strengthen students' scientific literacy in the digital era.

Conclusion

Research on the trend of developing augmented reality (AR)-based e-modules in improving students' scientific literacy shows high urgency, given the great potential of this technology in revolutionizing science learning. From 2016 to 2025, studies recorded in various scientific publications show a dynamic pattern of increasing interest in this topic, although it has begun to show a stable or declining trend in recent years. This indicates the need for a new approach in the development and implementation of AR e-modules to remain relevant and effective in the context of modern education. This study found that the literature discussing this topic is spread across journal articles, proceedings, book chapters, and monographs, with the main focus on keywords such as *augmented reality*, *e-modules*, *scientific literacy*, and *learning interactivity*.

In general, AR integration in e-modules provides a positive contribution to strengthening conceptual aspects, inquiry skills, and students' learning motivation. Therefore, future research directions need to pay attention to more integrated developments with

inquiry-based learning models and differentiation approaches to address the challenges of 21st-century education.

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Conflicts of Interest
The author declares no conflict of interest

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