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A Bibliometric Study on E-books in Physics Education to Support 21st-Century Learning: Trends and Directions (2015–2025)

Muhammad Ghiyats Naufal[1*], Abd Kholiq[1], Tantri Ilvia Suci[1], Cahyo Febri Wijaksono[2]

[1]State University of Surabaya, Surabaya, Indonesia
[2]Deutsche Zentrum für Hochschul- und Wissenschaftsforschung (DZHW), Hannover, Germany

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ABSTRACT

Objective: *Advances in digital technology have accelerated the adoption of e-books as learning media in physics education. However, comprehensive studies that map research development and identify future research directions remain limited. This study aims to analyze publication trends on the use of e-books in physics education during the 2015–2025 period and to identify research gaps that can guide future investigations.* ***Method:*** *employing a bibliometric approach using 612 Scopus-indexed publications on e-books in physics education published between 2015 and 2025, selected through a systematic screening process. The analysis examined publication productivity, and thematic development using annual scientific production, keyword co-occurrence, thematic evolution, thematic maps, and trend topics.* ***Results:*** *The findings reveal a continuous increase in publications, indicating growing scholarly interest in e-books within physics education. The research landscape has shifted toward more interactive digital learning technologies; however, it remains dominated by general themes related to e-books, education, and learning. In contrast, physics-specific topics, such as scientific literacy, conceptual understanding, STEM education, and problem-solving skills, have yet to emerge as major research focuses, highlighting significant opportunities for future research.* ***Novelty:*** *provides a comprehensive bibliometric mapping of e-book research in physics education by integrating publication trends, thematic evolution, and an analysis of research gaps. The findings highlight a lack of focus on scientific literacy, thereby providing a clear direction for the development of interactive e-books in physics education and offering a strategic reference for researchers and learning media developers in designing interactive e-books that support scientific literacy and 21st-century competencies.*

INTRODUCTION

In the 21st century, the demands that must be met in the world of education and the skills that need to be mastered include thinking skills (Arti & Ikhsan, 2020). Thinking activities in the learning process shape a mindset that is the primary goal of learning and is beneficial for future learning. The thinking skills that students must develop to meet 21st-century demands include critical thinking, creativity, communication, and collaboration (Schiefer et al., 2020). One manifestation of 21st-century competencies in science education is science literacy the ability to understand scientific concepts, apply knowledge to solve problems, and make evidence-based decisions (Capone, 2022). An education that prioritizes 21st-century thinking skills requires students to hone skills that are not solely based on academic knowledge (Abustang et al., 2023). The thinking skills possessed in the 21st century can have very important positive effects, such as the creation of new ideas that can be used to solve problems in the school environment (Khaerunisa et al., 2023).

To support the development of these competencies, various digital learning media have been introduced in science education, including learning management systems, educational videos, virtual laboratories, mobile applications, and interactive e-books (Darmaji et al., 2023). Among these alternatives, interactive e-books offer several practical advantages because they integrate text, images, animations, videos, hyperlinks, and interactive assessments into a single, portable, and easily accessible learning resource. Unlike many digital media that often require multiple platforms or continuous internet access, interactive e-books can provide a more structured learning experience while enabling both online and offline use, making them suitable for diverse educational contexts. In physics education, this capability is particularly important because many concepts are abstract, dynamic, and require multiple representations for effective conceptual understanding (Septikasari et al., 2021). Previous studies have demonstrated that interactive e-books can reduce misconceptions, improve conceptual understanding, and enhance students' learning outcomes in physics (Yani et al., 2024). Furthermore, the integration of emerging technologies, such as Augmented Reality (AR), has expanded the functionality of e-books by increasing students' motivation, engagement, and visualization of complex physics phenomena (Bölek et al., 2021; Radu et al., 2023).

In addition, e-books support self-paced learning and asynchronous/synchronous activities, which are essential in both blended and distance learning models; this was clearly evident during the pandemic when educational institutions shifted to online learning and e-books became an easily accessible alternative medium (Adedoyin & Soykan, 2020). Experimental studies also show that interactive features in e-books can enhance cognitive engagement and foster higher-order thinking skills aligned with 21st-century competencies (Gumilar et al., 2021; Tullah et al., 2025). However, the current literature is dominated by development studies and local/classroom-based experiments (small-scale). Bibliometric analyses and systematic reviews focusing exclusively on e-books in physics education remain limited; therefore, a comprehensive analysis is needed to systematically map empirical evidence, patterns of collaboration, and research gaps (Fajri et al., 2024).

Despite the growing body of literature on interactive e-books, most previous studies have primarily focused on evaluating learning effectiveness, students' perceptions, motivation, conceptual understanding, or the development and validation of specific e-book products (Casselden & Pears, 2020; Afriwardani et al., 2023; Amirtharaj et al., 2023). Although these studies provide valuable evidence regarding the educational benefits of e-books, they generally examine individual interventions and are limited to specific learning contexts. Consequently, they offer only a fragmented understanding of how research on e-books in physics education has evolved over time. Furthermore, existing review studies mainly discuss digital learning or educational technology in general rather than specifically examining the intellectual structure, thematic evolution, publication trends, and emerging research opportunities in e-book research within

physics education (Donthu et al., 2021; Nurullina et al., 2024). As a result, researchers still lack a comprehensive overview of dominant themes, research collaborations, and underexplored areas that can inform future investigations. Addressing this gap, the present study employs a bibliometric approach to systematically map the development of e-book research in physics education from 2015 to 2025, identify publication trends, and reveal research gaps that can guide future innovations in interactive e-books for physics learning. This indicates a need for studies capable of providing a comprehensive overview of the direction, developments, and opportunities for research in this field. Given this need, this study aims to answer two main questions, namely, RQ1: What are the trends in research publications on the use of education-based e-books in physics instruction during the 2015–2025 period, based on bibliometric analysis?; and RQ2: What research gaps can serve as a basis for future research on the development of e-books in physics instruction?.

The novelty of this study lies in its specific focus on mapping the development of research on the use of e-books in physics education through a state-of-the-art bibliometric approach covering the period 2015–2025. To date, most bibliometric studies have focused only on e-learning or digital learning in general (Djeki, 2022), while research mapping specifically targeting physics e-books remains very limited (Firdausy & Prasetyo, 2020). In fact, the use of e-books has been proven to increase interest in learning, reduce misconceptions, and strengthen student engagement in learning (Kurniawan et al., 2023).

Furthermore, this study links the role of e-books to 21st-century competencies, particularly science literacy and scientific process skills, which are now the cornerstones of modern science education (Alhusni, 2024). Previous studies have generally focused only on the effectiveness of e-books in improving learning outcomes, without examining how the global literature relates them to science literacy, creativity, collaboration, and the critical thinking skills required in the 21st century (Guo et al., 2020; Haleem et al., 2022). Thus, this study not only provides an overview of publication trends, dominant topics, and research collaboration networks but also generates a future research agenda that can serve as a foundation for the development of physics curriculum and educational policy. This novelty fills a gap in previous research by presenting a comprehensive yet practical bibliometric analysis to support the transformation of science education in the digital age (Boateng, 2024).

RESEARCH METHOD

This study was conducted using the bibliometric method. The use of these two literature review methods aims to summarize clearer conclusions for the upcoming research; a literature review is crucial for research development prior to conducting fieldwork, ensuring a broader scope of the study (Linnenluecke et al., 2020). A systematic literature review (SLR) has the advantage of low bias, making the research more relevant in terms of methodology (Van Dinter et al., 2021). The combination of

this method with bibliometrics is emphasized to obtain analytical references that can reduce bias and improve the adaptation of research trends discussed in the study (Page et al., 2021). The PRISMA flow used in the study is shown in Figure 1 below.

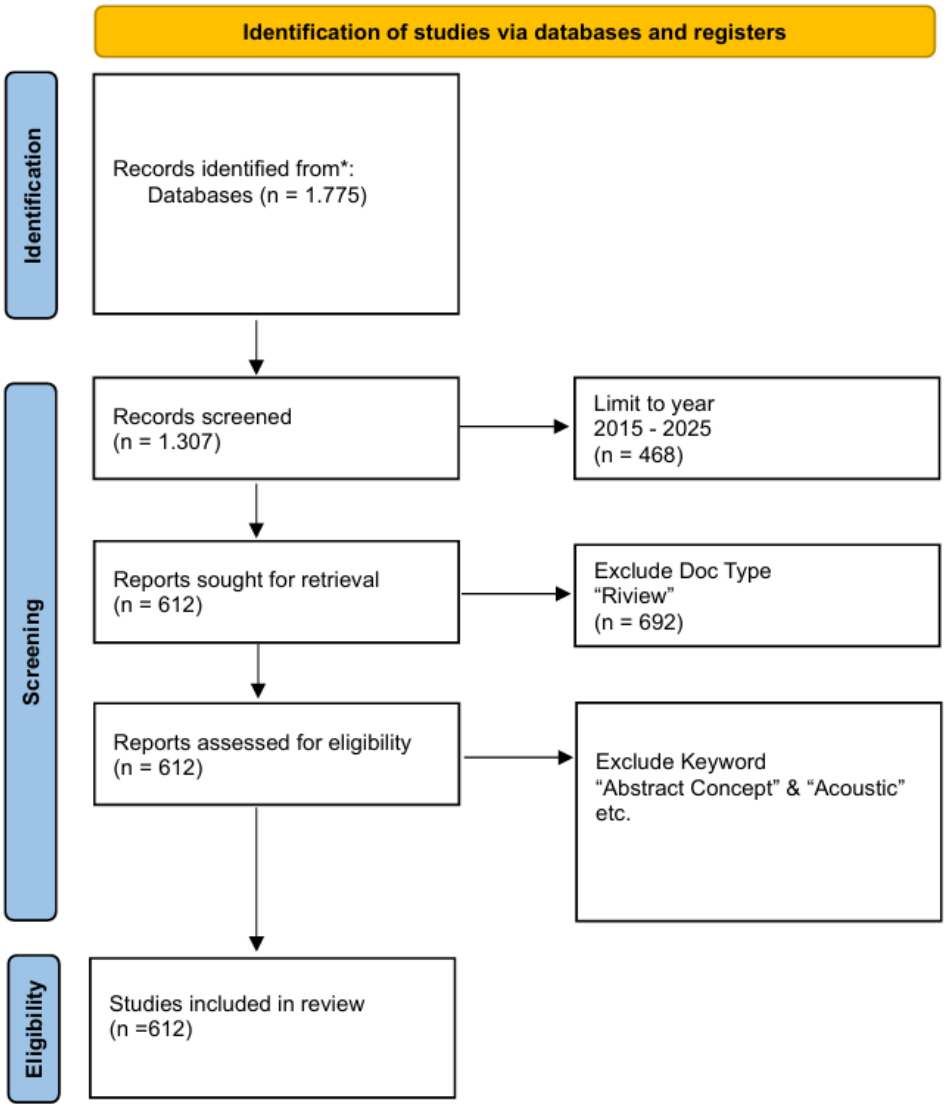

Figure 1. Diagram method

Data collection was conducted by accessing the SCOPUS database of international journals covering the period from 2015 to 2025. The retrieved documents were identified using two main keywords on the search page: E-Book AND Education OR Physics OR Learning. The search results were then compiled in Excel (.csv) format. The next step was to filter the results based on additional keywords from the references, resulting in a three-stage process: identification, filtering, and selection of relevant documents. Afterward, data analysis was performed using RStudio and thematic literature (SCR). In figure 1 illustrates the data retrieval and screening process used in this study. Initially, 1,775 records were identified from the Scopus database using predefined search terms. After limiting the publication period to 2015–2025, 1,307 records remained. Subsequently, publications with the document type "Review" were excluded, resulting in 612 records for further assessment. Additional screening was

conducted by removing publications containing irrelevant keywords (e.g., *Abstract Concept* and *Acoustic*), and the final dataset consisted of 612 publications that met the inclusion criteria and were included in the bibliometric analysis.

RESULTS AND DISCUSSION

Results

To provide an overview of the dataset and publication characteristics analyzed in this study, the main bibliometric information is presented in Figure 2. These indicators summarize the overall profile of the retrieved publications, including the publication timespan, number of documents and sources, authorship characteristics, collaboration patterns, and citation performance. This information serves as the foundation for the subsequent analyses of publication trends and thematic development as seen in figure 2 above.

Figure 2. Main information

In Figure 2, *Main Information*, A total of 612 documents published between 2015 and 2025 and drawn from 367 publication sources were identified, indicating that research on the use of educational e-books in physics instruction has expanded significantly and attracted the attention of various academic communities. Figures 2 through 9 present key bibliometric information automatically generated using the Bibliometrix package via the Biblioshiny web interface in RStudio. These visualizations are based on the final dataset comprising 612 publications retrieved from the Scopus database and summarize the main characteristics of the analyzed literature as seen in figure 3.

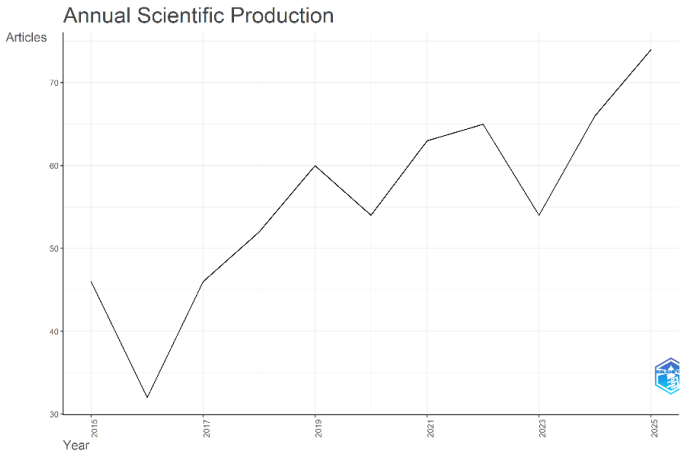

Figure 3. Annual scientific production

Figure 3, Annual scientific production, shows that research on the use of e-books in physics education has followed a positive growth trend during the 2015–2025 period. The number of publications increased from 46 articles in 2015 to 74 articles in 2025, although there were some fluctuations in 2016, 2020, and 2023. After a decline in 2016, research productivity showed a relatively consistent increase, reaching 60 publications in 2019. Although it declined briefly in 2020, the number of publications rose again during the 2021–2022 period and peaked in 2025. The most relevant sources can be seen in Figure 4.

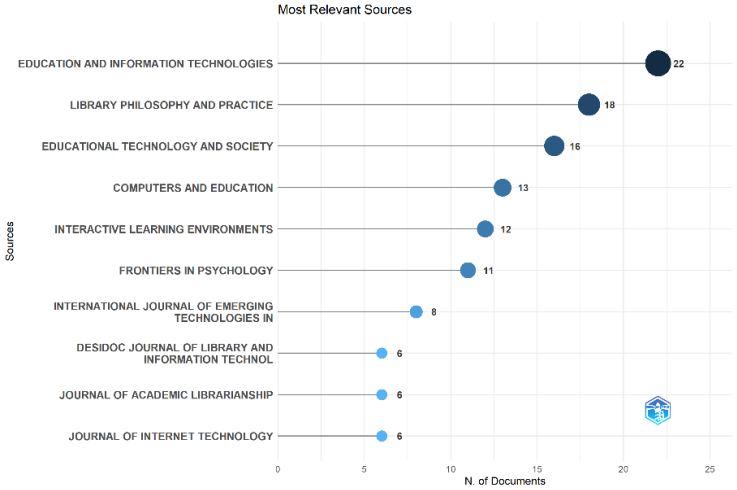

Figure 4. The most relevant sources can be seen in Figure 4.

Figure 4, Most relevant sources shows that publications on the use of e-books in physics education are spread across various journals focusing on educational technology, digital learning, and information science. The most productive journal is Education and Information Technologies with 22 documents, followed by Library Philosophy and Practice (18 documents) and Educational Technology and Society (16 documents). Furthermore, Computers and Education and Interactive Learning Environments contributed 13 and 12 documents, respectively, indicating that research on e-books is frequently examined in the context of integrating digital technology to improve the quality of learning. The scientific output by country can be seen in Figure 5.

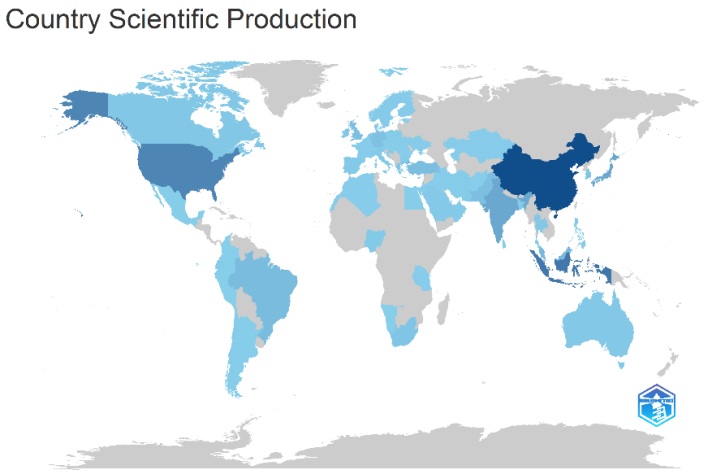

Figure 5. Country scientific production

In Figure 5, *Country Scientific Production*, Research on the use of e-books in physics education has expanded globally, with contributions from various countries in Asia, the Americas, Europe, Africa, and Oceania. Based on the color intensity on the map, China appears to be the country with the highest publication output, followed by several other countries that have also made significant contributions, such as the United States, Indonesia, India, and European nations. The dominance of these countries indicates that the development and utilization of e-books have become a key focus in the transformation of education based on digital technology. Figure 6, Word Cloud, The word cloud shows that the most dominant keywords.

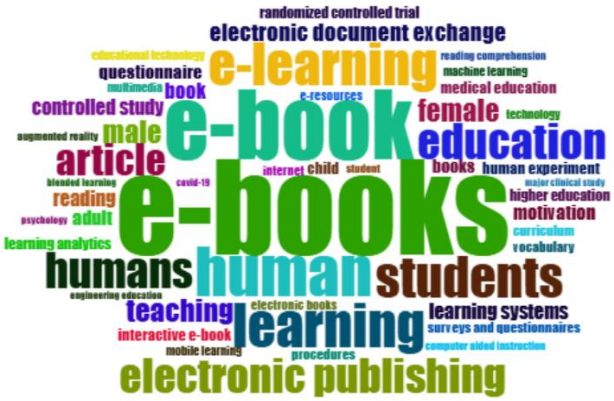

Figure 6. Word cloud

Figure 6, Word Cloud, The word cloud shows that the most dominant keywords in research related to e-books during the 2015–2025 period are “e-books,” “e-book,” “learning,” “education,” “students,” and “electronic publishing.” The dominance of these keywords indicates that the primary focus of research remains on the use of e-books as a digital learning medium to support students’ learning processes in various educational contexts. In addition, the emergence of keywords such as “e-learning,” “teaching,” “learning systems,” “motivation,” and “interactive e-book” suggests that research not only highlights aspects of media development but also the effectiveness of e-books in improving the quality of learning, student engagement, and the digital learning experience. Overall, these findings suggest that e-book research is transitioning toward more interactive and learner centered approaches; however, there remains a critical need to develop e-books that explicitly support the acquisition of subject-specific competencies and 21st-century skills in physics education. Figure 7, Keyword co-occurrence network, shows that research on e-books has developed into two main, interconnected clusters.

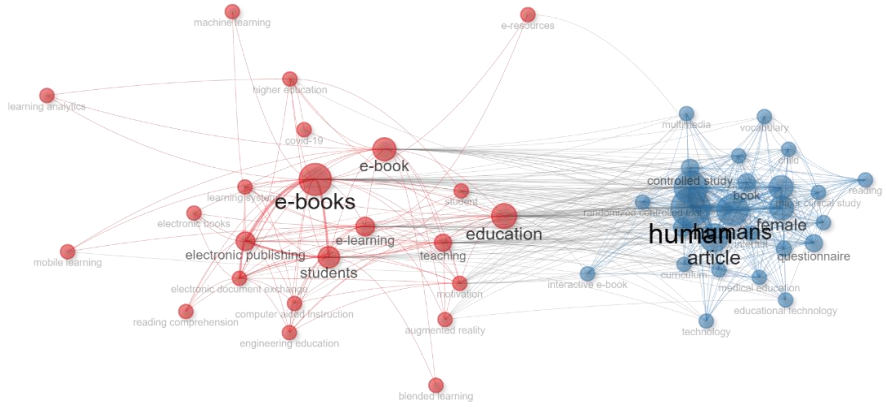

Figure 7. Keyword co-occurrence network

The first cluster (red) is dominated by keywords such as e-book, e-learning, education, and terms related to digital learning, which serve as the conceptual core of the research. This cluster reflects the research focus on the development, implementation, and utilization of e-books as part of a technology-based learning ecosystem. Meanwhile, the second cluster (blue) is dominated by keywords such as human, students, female, male, article, and controlled study, indicating that most research focuses on evaluating the use of e-books among learners through various empirical research designs. These results can be seen in Figure 8.

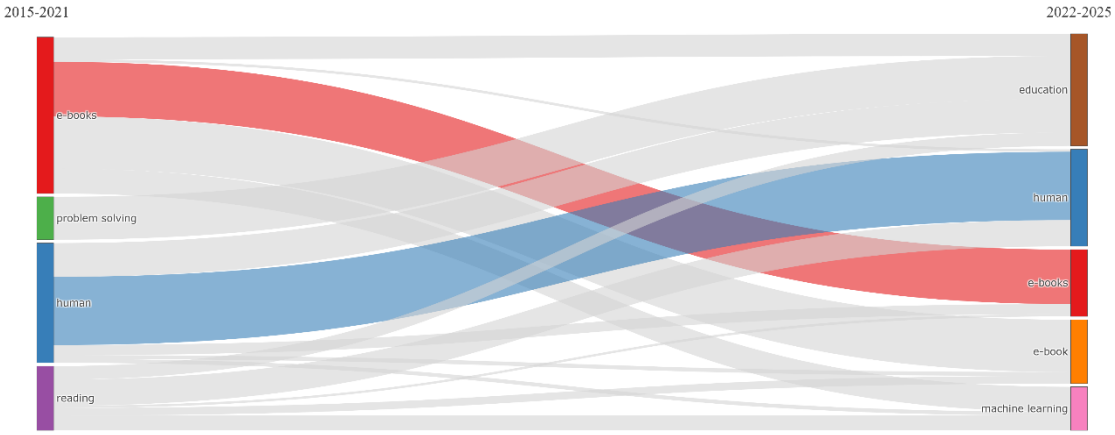

Figure 8. Thematic evolution

In Figure 8, Thematic evolution, analysis reveals a shift in the focus of e-book research from the 2015–2021 period to the 2022–2025 period. In the earlier period, the dominant themes included e-books, human, reading, and problem solving, reflecting a research focus on the use of e-books as a digital reading medium and their impact on students' cognitive abilities. Entering the 2022–2025 period, these themes evolved and transformed into broader clusters namely, education, human, e-books, and e-book indicating a shift in focus from the mere utilization of digital media to its role as an integral part of the educational ecosystem. Furthermore, the emergence of the "machine

learning" theme in the most recent period indicates the beginning of the integration of smart technologies and artificial intelligence-based approaches into e-book research. Nevertheless, the evolution of themes remains dominated by general issues related to education and learning technologies, while more specific themes in physics education such as scientific literacy, physics education, conceptual understanding, STEM education, heat transfer, and inquiry-based learning have not yet emerged as primary lines of development. These results can be seen in Figure 9.

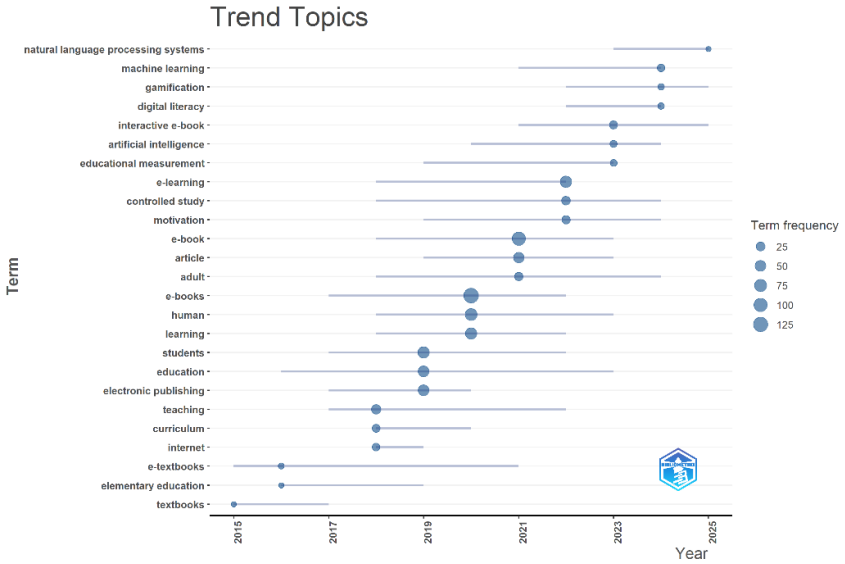

Figure 9. Trend topics

Figure 9, Trend topics An analysis of trending topics shows that research on e-books has undergone a fairly dynamic evolution of themes during the 2015–2025 period. In the early phase (2015–2018), the dominant topics still focused on textbooks, e-textbooks, elementary education, the internet, and curriculum, reflecting the research focus on the transformation of printed books into digital learning resources. Entering the 2019–2022 period, the research focus shifted to broader themes, such as education, students, learning, humans, e-books, and e-learning, indicating the increasing use of e-books as an integral part of the digital learning process. In the most recent period (2022–2025), new themes have emerged, such as interactive e-books, digital literacy, gamification, artificial intelligence, machine learning, and natural language processing systems, signaling that e-book research has evolved toward the integration of smart technologies and more interactive learning.

Discussion

In Figure 2, all publications were authored by 1,761 authors, with an average of 3.25 authors per document, indicating the predominance of collaborative research in this field. Furthermore, the international collaboration rate of 13.24% indicates cross-national cooperation, although it remains relatively limited. The analyzed dataset includes 24,352 references and 1,932 author keywords, reflecting the diversity of research themes and a strong theoretical foundation. In terms of scientific impact, the analyzed documents averaged 16.09 citations per document with an average document

age of 5.46 years, indicating that studies on e-books in physics education have considerable relevance and influence within the educational literature. Furthermore, the annual publication growth rate of 4.87% indicates that research in this field continues to expand and remains a topic of interest in supporting the transformation of physics learning based on digital technology (Donthu et al., 2021). Furthermore, Figure 3 shows a trend indicating growing academic interest in the use of e-books as a medium for physics learning, in line with the development of digital transformation in education and the increasing need for interactive, flexible, and easily accessible learning resources. In addition, the increase in publications during the post-pandemic period indicates that the integration of digital technology into learning has become one of the main focuses of educational research, leading to e-books being viewed as a potential innovation to support more effective physics learning that meets the demands of 21st-century education (Bond et al., 2021)

The prevalence of publications in internationally renowned journals in the field of educational technology such as Computers & Education, Education and Information Technologies, Educational Technology & Society, and Interactive Learning Environments indicates that research on e-books has undergone a paradigm shift from the mere development of digital instructional materials toward the development of technology-based learning ecosystems that emphasize interactivity, personalized learning, student engagement, and more meaningful learning experiences. This shift aligns with the direction of educational technology development, which integrates adaptive digital learning, learning analytics, and the use of artificial intelligence (AI) to support more effective and personalized learning experiences (Crompton & Burke, 2023; UNESCO, 2023). Furthermore, the findings of this study indicate that the development of e-books in physics education is increasingly linked to the global research agenda in the field of educational technology. However, the results of the bibliometric analysis also suggest that the integration of e-books with specific competencies in physics education such as scientific literacy, conceptual understanding of physics, virtual laboratories, adaptive learning, and AI-based learning remains relatively limited. This situation opens up broad research opportunities for developing more innovative, contextual, and adaptive physics e-books to support the mastery of 21st-century competencies while strengthening students' science literacy (OECD, 2023; Hwang & Tu, 2021).

The high level of publication output in the Asian region indicates that countries in the region are increasingly adopting digital technology as part of the transformation of their education systems to improve accessibility, flexibility, and the quality of learning. This trend is driven by the increasingly widespread implementation of digital learning as well as policies supporting the use of electronic learning resources at various levels of education (Bozkurt et al., 2020; Dwivedi et al., 2023). The distribution of publications across various countries also indicates that research on e-books has evolved into a global issue closely linked to the digitization of education, learning innovation, and the development of 21st-century competencies. Nevertheless, the distribution of

publications remains dominated by a few countries with high research capacity, while the contributions of other developing countries remain relatively limited. This situation highlights the importance of strengthening cross-national collaboration so that knowledge transfer, innovation development, and the dissemination of best practices in e-book development can proceed more effectively. In the field of physics education, international collaboration has the potential to drive the development of e-books that are more contextual, interactive, and adaptive to students' needs, thereby supporting physics learning that is relevant to global developments in educational technology (Zawacki-Richter, 2021). Interestingly, the analysis results show that keywords related to specific competencies in physics education such as scientific literacy, physics education, conceptual understanding, STEM education and inquiry-based learning, have not yet emerged as dominant themes in the research network. These findings indicate that most research still focuses on the use of e-books as digital learning media in general such as improving access to learning, student engagement, and learning effectiveness while the development of e-books explicitly designed to foster competencies specific to physics education remains relatively limited. In fact, current trends in science education emphasize the importance of digital learning media that not only present content but also facilitate scientific inquiry, problem-solving, and the development of scientific literacy through interactive and contextual learning activities (Ramadhani & Khusniati 2022; Susanti et al., 2022).

The strong relationship between the two clusters in Figure 7 indicates that research on e-books has evolved from a focus solely on the development of digital media toward an evaluation of their impact on students' learning processes and outcomes. This development suggests that e-books are increasingly viewed as part of a digital learning ecosystem capable of enhancing students' learning interactions, motivation, and engagement in the learning process (Septikasari et al., 2021). Nevertheless, the keyword network is still dominated by general terms, such as e-books, e-learning, education, and students, while more specific keywords in physics education such as physics education, scientific literacy, conceptual understanding, problem solving, inquiry-based learning, and STEM education have not yet shown strong connections. These findings indicate that research on e-books is still more focused on the development of learning media in general rather than on the development of specific competencies in physics learning. In fact, a study conducted by Boma et al. (2024) demonstrated that the implementation of interactive physics e-learning can enhance students' scientific literacy skills at the high school level. In addition, Pardede et al. (2024) show that the development of physics e-books based on an inquiry-based approach can create a more contextual learning experience and encourage active student engagement during the learning process.

The results of the Trend Topics analysis show that the focus of research on e-books continues to evolve from merely a medium for conveying information toward a digital learning environment that is more interactive, adaptive, and learner-centered. This shift aligns with developments in educational technology that position digital learning resources as part of a learning ecosystem that supports active, flexible, and personalized

learning tailored to students' needs (UNESCO, 2023; OECD, 2023). Nevertheless, the analysis also reveals that keywords specifically related to physics education such as *physics education*, *scientific literacy*, *conceptual understanding*, *STEM education*, and *problem-solving skills* have not yet emerged as major research topics. This situation indicates that the development of e-books in physics education still has vast room for exploration, particularly through the integration of scientific literacy, STEM-based learning, gamification, and artificial intelligence (AI), which is currently one of the key directions in educational technology development (Adedoyin & Altinay, 2023). Beyond the context of STEM education, interactive e-books also offer significant potential for fostering higher order thinking skills that are essential in physics learning, including critical thinking, problem-solving, conceptual understanding, and scientific reasoning. These competencies are fundamental components of 21st-century learning and are closely related to students' ability to interpret scientific phenomena, evaluate evidence, and apply physics concepts in authentic contexts (OECD, 2023). However, the bibliometric findings indicate that these thinking skills have not yet become prominent themes within e-book research in physics education, suggesting that their integration remains underexplored. In addition, the results of a systematic review conducted by Zawacki-Richter et al. (2019) indicate that the use of smart technology in education is still dominated by research focusing on general aspects of learning, while its implementation in specific academic disciplines, including physics education, remains relatively limited.

The results of the bibliometric analysis show that research on the use of e-books in physics education has experienced a steadily increasing publication trend during the 2015–2025 period, thereby answering RQ1 that this topic is gaining increasing attention in the field of educational technology. This increase has been accompanied by the evolution of research themes from the use of e-books as digital learning media toward their utilization as a learning environment that is more interactive, adaptive, and integrated with developments in educational technology. Furthermore, the analysis results show that publications are distributed across various reputable international journals and involve contributions from various countries, indicating that research on e-books has evolved into a global research agenda in the field of digital learning. To address RQ2, the results of the Word Cloud, Keyword Co-occurrence, Thematic Map, Thematic Evolution, and Trend Topics analyses show that research is still dominated by general keywords, such as e-book, education, learning, students, and e-learning. Conversely, keywords specifically related to physics education such as physics education, scientific literacy, conceptual understanding, STEM education, inquiry learning, and problem-solving skills, have not yet emerged as major themes or formed a strong research network. These findings indicate that e-book development is still more focused on media and learning technology in general than on the development of specific competencies in physics education.

Overall, the results of the bibliometric analysis indicate that research on e-books has grown substantially over the past decade and has evolved from conventional digital

learning media toward more interactive, adaptive, and technology-enhanced learning environments. However, analyses of Keyword Co-occurrence, Thematic Map, Thematic Evolution, and Trend Topics reveal that the current research landscape remains dominated by general themes related to e-books, education, learning, and students. Topics specifically associated with physics education, such as scientific literacy, conceptual understanding, STEM education, inquiry-based learning, and problem-solving skills, have not yet become primary research focuses. These findings suggest that current e-book development still emphasizes technological and instructional design aspects, while the integration of discipline-specific competencies in physics learning remains relatively limited. Consequently, current e-book requirements extend beyond multimedia and interactivity features to include learning designs that foster scientific literacy, higher-order thinking skills, conceptual understanding, and adaptive learning experiences aligned with 21st-century competencies.

Furthermore, the bibliometric findings indicate that previous studies have predominantly evaluated e-books in terms of usability, learning motivation, and general learning outcomes, whereas relatively few studies have explored their role in developing specific competencies in physics education. This research gap highlights the need for future studies to develop and evaluate interactive e-books that integrate scientific literacy, STEM approaches, inquiry-based learning, gamification, and artificial intelligence-supported features within authentic physics learning contexts. The findings of this study provide practical implications for researchers, educational media developers, educators, and policymakers by offering a strategic reference for determining research priorities, designing innovative physics learning media, and strengthening the implementation of digital learning approaches that support 21st-century competencies.

CONCLUSION

Fundamental Finding: This study demonstrates that research on the use of e-books in physics education has shown a consistent upward trend during the 2015–2025 period, reflecting the growing importance of digital learning technologies in educational research. The bibliometric analysis reveals that the field has expanded through increased publication productivity, broader international contributions, and the evolution of research themes. Nevertheless, the thematic structure remains dominated by general topics related to e-books, learning, and education, while physics-specific themes, such as scientific literacy, conceptual understanding, STEM education, and problem-solving skills, have not yet become major research focuses. These findings highlight a significant research gap and indicate that the integration of interactive e-books with competencies specific to physics education remains underexplored.
Implication: The findings provide a comprehensive overview of the current research landscape and offer valuable guidance for researchers, educators, and instructional media developers in identifying future research priorities. They emphasize the need to develop interactive e-books that integrate scientific literacy and innovative learning

approaches to better support 21st-century competencies in physics education.. **Limitation:** This study is limited by the use of a single scientific database and publications indexed between 2015 and 2025. Consequently, the findings may not fully represent the entire global body of literature on e-books in physics education. **Future Research:** Future studies are recommended to integrate multiple databases, such as Scopus, Web of Science, and Dimensions, and to combine bibliometric analysis with systematic literature review approaches. Such efforts are expected to provide a more comprehensive understanding of the evolution of e-book research and to support the development of innovative, evidence-based interactive e-books for physics education.

AUTHOR CONTRIBUTIONS

Muhammad Ghiyats Naufal: Conceptualization, Methodology, Data Curation, Formal Analysis, Investigation, Visualization, Writing Original Draft, and Writing, Review & Editing. **Abdul Kholiq:** Supervision, Methodology, Validation, Writing, Review & Editing, and Funding Acquisition. **Tantri Ilvia Suci:** Validation, Investigation, and Project Administration. **Cahyo Febri Wijaksono:** Formal Analysis, Data Curation, and Review & Editing.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ETHICAL COMPLIANCE STATEMENT

This manuscript complies with research and publication ethics. The authors affirm that the work is original, conducted with academic integrity, and free from any unethical practices, including plagiarism.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors acknowledge the use of digital tools, including AI-based technologies, as support in the research and writing stages of this article. Specifically, Deepl was employed for translated language. All outputs generated with digital assistance were critically evaluated and revised to ensure academic rigor and ethical standards were upheld. The final responsibility for the manuscript rests entirely with the authors.

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*Muhammad Ghiyats Naufal (Corresponding Author)
Department of Physics, Faculty of Mathematics and Natural Science, State University Of Surabaya,
Jl. Ketintang, Ketintang, Kec. Gayungan, Surabaya, Jawa Timur 60231
Email: muhammadnaufal.22042@mhs.unesa.ac.id

Abdul Kholiq
Department of Physics, Faculty of Mathematics and Natural Science, State University Of Surabaya,
Jl. Ketintang, Ketintang, Kec. Gayungan, Surabaya, Jawa Timur 60231
Email: kholiq@unesa.ac.id

Tantri Ilvia Suci
Department of Physics, Faculty of Mathematics and Natural Science, State University Of Surabaya,
Jl. Ketintang, Ketintang, Kec. Gayungan, Surabaya, Jawa Timur 60231
Email: tantriilvia.22019@mhs.unesa.ac.id

Cahyo Febri Wijaksono
Deutsche Zentrum für Hochschul- und Wissenschaftsforschung (DZHW)
Lange Laube 12, Hannover, Lower Saxony, Germany
Email: wijaksono@dzhw.eu