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Trends in Digital Based Physics Teaching Material Development and Their Impact on Twenty First Century Learning: A Systematic Literature Review

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ABSTRACT

The rapid advancement of digital technology has transformed physics learning into a more interactive and student-centered process that supports twenty first century competencies. However, studies on digital-based physics teaching materials remain fragmented and have not comprehensively explored publication trends, teaching material types, research methods, research networks, and their impacts on twenty first century learning. Therefore, this research purpose to analyze and visualize trends in the development of digital-based physics teaching materials from 2020 to 2025. This research employed a Systematic Literature Review (SLR) combined with bibliometric analysis using Bibliometrix and VOSviewer software. The data consisted of 34 Scopus-indexed articles selected through the PRISMA procedure based on relevance and publication quality. The findings indicate that research publications on digital-based physics teaching materials increased significantly during the analyzed period, with e-modules emerging as the most dominant type of teaching material. The research also revealed that digital teaching materials positively contribute to improving students' conceptual understanding, critical thinking, higher-order thinking skills, scientific literacy, creativity, collaboration, and learning independence. In conclusion, digital-based physics teaching materials have become strategic learning innovations that support adaptive and technology-integrated physics education in the twenty first century and provide important references for future educational development.

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INTRODUCTION

The continuous development of digital technology has brought substantial changes to educational practices, particularly in science and physics instruction, by facilitating more dynamic and technology-enhanced learning environments (Sanjaya et al., 2021). In response to the demands of twenty-first-century education, learners are expected not only to acquire

scientific knowledge but also to develop essential competencies, including critical thinking, creativity, collaboration, communication, and digital literacy skills (Misbah et al., 2021). Nevertheless, physics learning in many educational settings remains predominantly teacher-centered and dependent on conventional printed materials, which often limit student participation and engagement in the learning process (Mahardika et al., 2025; Sriyanti et al., 2025). Such instructional conditions contribute to persistent difficulties in understanding abstract physics concepts and frequently lead to misconceptions across various topics, including static fluids, thermodynamics, waves, and optics (Gunawan et al., 2024; Mahombar, 2025). Consequently, the development of innovative digital-based physics teaching materials has become increasingly important to support interactive, flexible, and student-centered learning that aligns with contemporary educational needs (Misbah et al., 2021; Sanjaya et al., 2021).

The growing interest in digital-based physics teaching materials is reflected in numerous studies reporting the effectiveness of e-modules, electronic worksheets, multimedia learning resources, and augmented reality applications in enhancing students' conceptual understanding, critical thinking, scientific literacy, and higher-order thinking skills (Afriyanti et al., 2021; Handayani et al., 2021; Komikesari et al., 2020; Nasir & Fakhruddin, 2023; Pane et al., 2021). Furthermore, digital teaching materials have been shown to promote learning motivation, self-directed learning, and greater flexibility in accessing educational resources (Kurniawan & Syafriani, 2020; Nenggala et al., 2024). These findings demonstrate the significant role of digital learning resources in supporting the development of twenty-first-century competencies and improving the quality of physics education.

Despite the considerable growth of studies investigating digital-based physics teaching materials, the majority of existing research has primarily focused on assessing the effectiveness of specific products, instructional approaches, or content domains within physics education. Most of these studies have adopted Research and Development (R&D) methodologies that emphasize product design, validation, and implementation, while providing limited attention to broader aspects such as publication patterns, research collaborations, methodological trends, and contributions to twenty-first-century competencies. In addition, review studies in the field have generally addressed educational technology integration from a general perspective rather than examining the development of digital physics teaching materials through comprehensive bibliometric analysis. Consequently, there remains a lack of systematic understanding regarding the intellectual structure, research evolution, and scientific trends associated with digital-based physics teaching materials in the era of educational digitalization (Mahombar & Mihardi, 2025; Maulana et al., 2024). Therefore, a comprehensive bibliometric investigation is needed to identify research trends, collaboration networks, thematic developments, and potential directions for future innovation in digital physics education research.

One of the most relevant approaches to addressing this gap is the implementation of a systematic literature review combined with bibliometric analysis. Bibliometric analysis enables researchers to quantitatively analyze scientific publications, identify dominant research themes, map research collaborations, and visualize research networks using specialized software such as Bibliometrix and VOSviewer (Aria & Cuccurullo, 2017; Donthu et al., 2021). Through bibliometric visualization, researchers can identify emerging topics, publication growth patterns, influential journals, and the relationships between keywords in a particular field of study. In the context of digital physics teaching materials, bibliometric analysis can provide a comprehensive overview of how digital learning innovations have evolved and contributed to twenty first century learning. Furthermore, systematic literature review methods allow researchers to synthesize empirical findings from various studies in a structured and transparent manner (Naveed et al., 2023; Rogge et al., 2024). Therefore, the

integration of systematic literature review and bibliometric analysis provides a strong theoretical and methodological foundation for exploring trends and impacts of digital-based physics teaching materials comprehensively.

The novelty of this research lies in its comprehensive bibliometric mapping of digital-based physics teaching materials and their contributions to twenty-first-century learning during the 2020–2025 period. Unlike previous studies that primarily focused on the effectiveness of specific learning products, this research integrates publication trends, teaching material types, research methodologies, thematic networks, and educational impacts within a single analytical framework. Furthermore, the combination of bibliometric visualization and systematic literature review approaches provides a deeper understanding of the intellectual structure and developmental patterns of research in this field. This research therefore offers a comprehensive scientific perspective that can guide future research and innovation in digital physics education.

Based on the background and research gaps identified in previous studies, this research is crucial to provide a comprehensive understanding of the development trends and educational impact of digital-based physics teaching materials in the context of twenty first century learning. Therefore, this research purpose to analyze, map, and visualize publication trends related to the development of digital-based physics teaching materials published between 2020 and 2025 through a bibliometric approach. Specifically, this research examines trends in scientific publications, identifies the types of digital-based physics teaching materials most frequently developed, explores the dominant research methods used, maps research networks and thematic relationships within the field, and investigates the impact of digital-based physics teaching materials development on improving twenty first century learning outcomes. The results of this research are expected to provide valuable references for future researchers in identifying research opportunities and developing innovative digital learning resources in physics education. Moreover, the findings can support educators and educational institutions in designing technology-integrated learning strategies that are more adaptive to modern educational challenges. Ultimately, this research is expected to strengthen the scientific foundation for the sustainable development of digital-based physics teaching materials in improving the quality of physics learning in the twenty first century.

METHODS

The method used was a Systematic Literature Review (SLR), which aims to collect, identify, and comprehensively review relevant research to present the latest literary updates. Data analysis was conducted using content analysis methodology. This process involves analyzing a variety of data, both visual and verbal, which facilitates the reduction of phenomena into predetermined categories, thus enabling a more effective analysis process (Naveed et al., 2023). The publications were then transformed into units of analysis coded with measurable categories. This was done to assess the suitability of these units to the focus of the SLR research (Rogge et al., 2024). Therefore, this research design allows for a comprehensive mapping of knowledge and a more structured and focused presentation of findings in response to the research focus.

The literature search for this research was conducted using the Scopus platform, which provides access to over 22,000 article titles from approximately 5,000 publishers. This procedure allowed researchers to explore research specifically relevant to the topic of developing digital based physics teaching materials for 21st-century learning. This research uses a sample of 34 publication articles taken from the Scopus database, with all publications selected based on the specified keywords “digital physics teaching materials” OR “physics e-modules” OR “interactive physics media” AND “21st century skills” OR “critical thinking”

OR "scientific literacy" AND "physics education". The publications included journal articles and conference proceedings Scopus was chosen over other databases such as Web of Science, Google Scholar, or ERIC because it provides broader coverage of high-quality publications that have undergone peer review, thereby ensuring the reliability of the data and relevance of the selected sources.

The research followed the PRISMA 2020 guidelines. An initial search identified 568 documents, which were screened according to publication type, relevance, and quality criteria. After the screening, eligibility assessment, and quality evaluation stages, 34 highly relevant publications were selected for further analysis. Bibliometric analysis was performed using Bibliometrix 4.5.3 and VOSviewer 1.6.20 to examine publication trends, research methods, teaching material types, thematic relationships, and research impact through network, overlay, and density visualizations (Aria & Cuccurullo, 2017; Donthu et al., 2021). Figure 1 visualizes the systematic screening and selection procedure employed to ensure that only the most appropriate studies were included in the in-depth analysis.

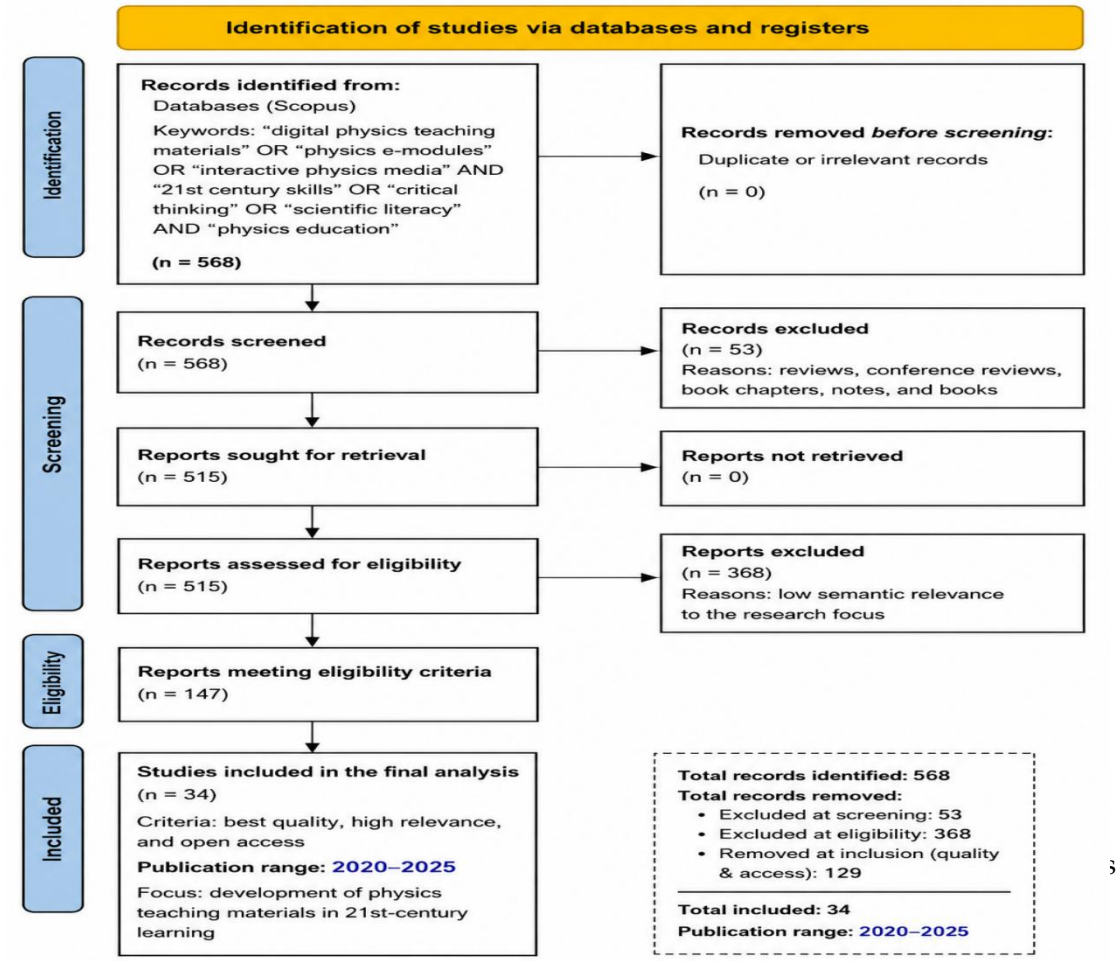

Figure 1. Flowchart of Article Selection Following the PRISMA 2020 Guidelines (Source: Author's Elaboration)

Data analysis was conducted using Bibliometrix version 4.5.3 and VOSviewer version 1.6.20. Bibliometrix is a comprehensive R package for bibliometric analysis (Aria & Cuccurullo, 2017). Bibliometrix was used to obtain information on the development of related literature. On the other hand, VOSviewer is software developed for bibliometric analysis that provides excellent network, overlay, and density visualizations (Donthu et al., 2021). This research used VOSviewer to analyze network maps, using overlay visualization and density visualization.

RESULTS AND DISCUSSION

Results

This research purpose to analyze, present, and visualize trends in the development of digital-based physics teaching materials and their impact on twenty first century learning using bibliometric analysis. This objective is divided into six, namely: 1) publication development trends, 2) types of teaching materials, 3) research methods used, 4) network maps, and 5) the impact of using digital-based physics teaching materials on twenty first century learning.

Publication Development Trends

Scientific publication trends provide important insights into the development and research interest in a particular field over time. Analysis of publication trends can reveal the level of scientific attention, research productivity, and dynamics of knowledge development related to digital-based physics teaching materials. Understanding these trends is crucial for identifying periods of growth, stagnation, or emerging research opportunities. Therefore, publication trends on the development of digital-based physics teaching materials from 2020 to 2025 are presented in Figure 2.

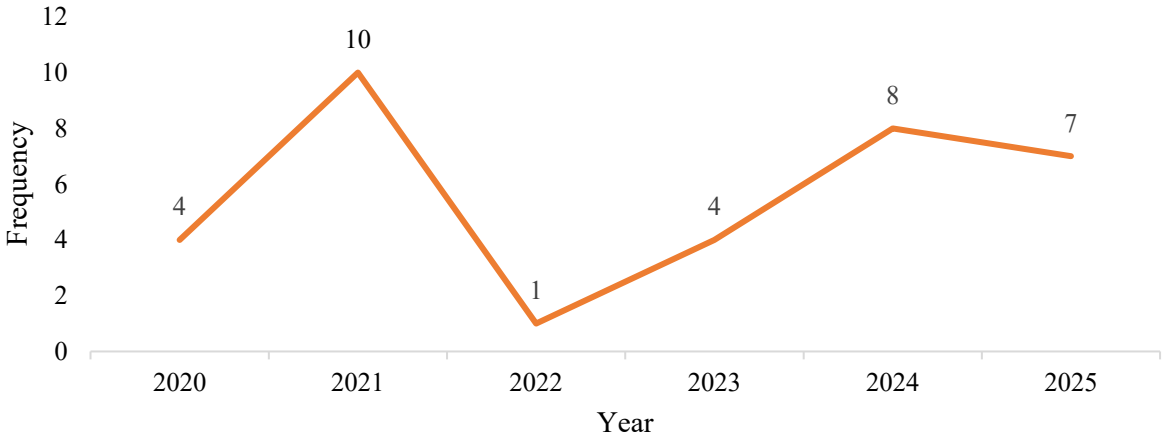

Figure 2. Publication Development Trends from 2020 to 2025
(Source: Author's Elaboration)

Figure 2 reveals a fluctuating publication trend in research on digital-based physics teaching materials during the 2020–2025 period. Despite a sharp decline in 2022, the overall number of publications increased compared to the beginning of the observation period, indicating sustained scholarly interest in this research area. The recovery and growth observed from 2023 to 2025 reflect the continuing importance of developing innovative digital learning resources to support physics education and twenty-first-century competencies. These findings suggest that digital-based physics teaching materials remain a relevant and expanding field of research driven by ongoing technological advancements and educational transformation.

Types of Teaching Materials

Identifying the types of digital-based physics teaching materials developed in previous studies is important for understanding current trends in instructional innovation and technology integration in physics education. Different forms of teaching materials offer distinct advantages in supporting students' conceptual understanding, engagement, and independent learning. An analysis of the distribution of these teaching materials can provide

insights into researchers' preferences and the evolving needs of twenty first century learning environments. The proportions of the various types of digital-based physics teaching materials identified in this research are presented in Figure 3.

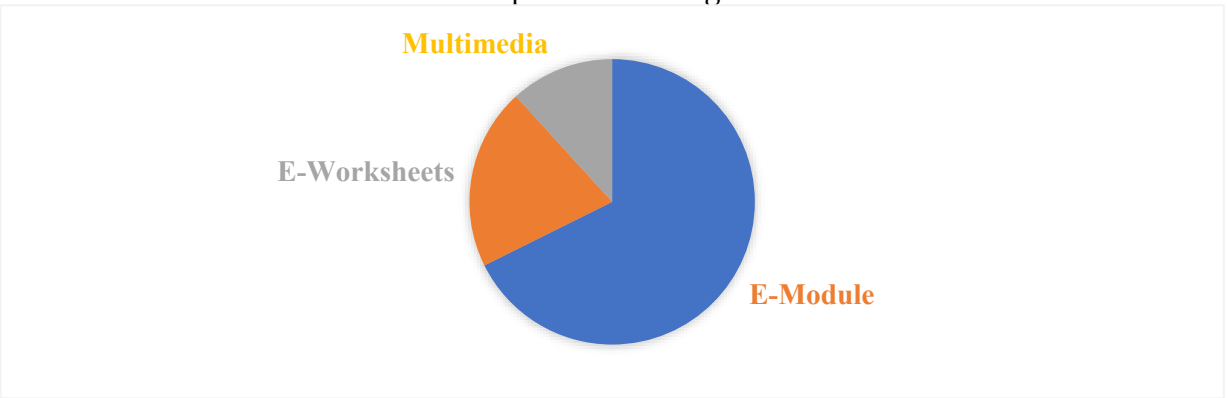

Figure 3. Types of Teaching Materials
(Source: Author's Elaboration)

Figure 3 indicates that E-Modules are the most widely developed type of digital-based physics teaching material, accounting for the majority of the studies analyzed. This finding highlights the growing preference for integrated digital learning resources that combine instructional content, interactive activities, and assessment features within a single platform. E-Worksheets and multimedia-based materials also contribute to the development of digital learning environments, although their adoption remains less extensive than that of E-Modules. Overall, the results suggest that current research is primarily focused on developing comprehensive and interactive teaching materials to support student-centered learning and twenty-first-century educational needs.

Most Frequently Used Research Methods

An analysis of the research methods used in studies on the development of digital-based physics teaching materials is essential for understanding emerging methodological trends in the field. Identifying dominant methods can provide information on the approaches considered most relevant and effective in the development and evaluation of learning products. Furthermore, this analysis can serve as a reference for researchers in determining research designs that align with the desired development objectives. Details of the distribution of research methods found in publications from 2020–2025 are presented in Table 1.

Table 1. Most Frequently Used Research Methods

Research Methods	Research Model	Frequency	Percentage
Research and Development (R&D)	ADDIE Development Model	16	47.06%
	4D Development Model	5	14.71%
	Plomp Development Model	2	5.88%
	Borg & Gall Development Model	2	5.88%
	Rowntree Development Model	1	2.94%
	ASSURE Development Model	1	2.94%
	Formative Development Model	1	2.94%
Quantitative Research	Quasi Experimental	3	8.83%
Qualitative Research	Descriptive Research	2	5.88%
Mixed Methods Research	Sequential Explanatory	1	2.94%

Research Methods	Research Model	Frequency	Percentage
Total		34	100%

Table 1 shows that the Research and Development (R&D) approach is the most dominant method used in studies on digital-based physics teaching materials, indicating a strong emphasis on the design and validation of innovative learning products. Among the development models, ADDIE emerged as the most frequently applied framework, reflecting its systematic and flexible structure for developing technology-enhanced instructional resources. The presence of other models, such as 4D, Plomp, Borg & Gall, and Rowntree, demonstrates the diversity of approaches employed to address different research objectives and educational contexts. Overall, these findings suggest that research in this field is primarily oriented toward instructional innovation, while studies focusing on effectiveness evaluation and learners' experiences remain comparatively limited.

Network Map

To obtain a more comprehensive picture of the development of digital-based physics teaching materials research and its relationship to twenty first century skills, a bibliometric analysis was conducted using VOSviewer software. This analysis aims to identify patterns of relationships between keywords, the intensity of the emergence of research topics, and the development trends of the themes that are the focus of the research during the research period. Through overlay visualization and density visualization, dominant themes can be identified as well as themes that still have opportunities for development in further research. The results of this mapping are presented in Figures 4 and 5 to provide a visual representation of the structure and dynamics of research in the studied field.

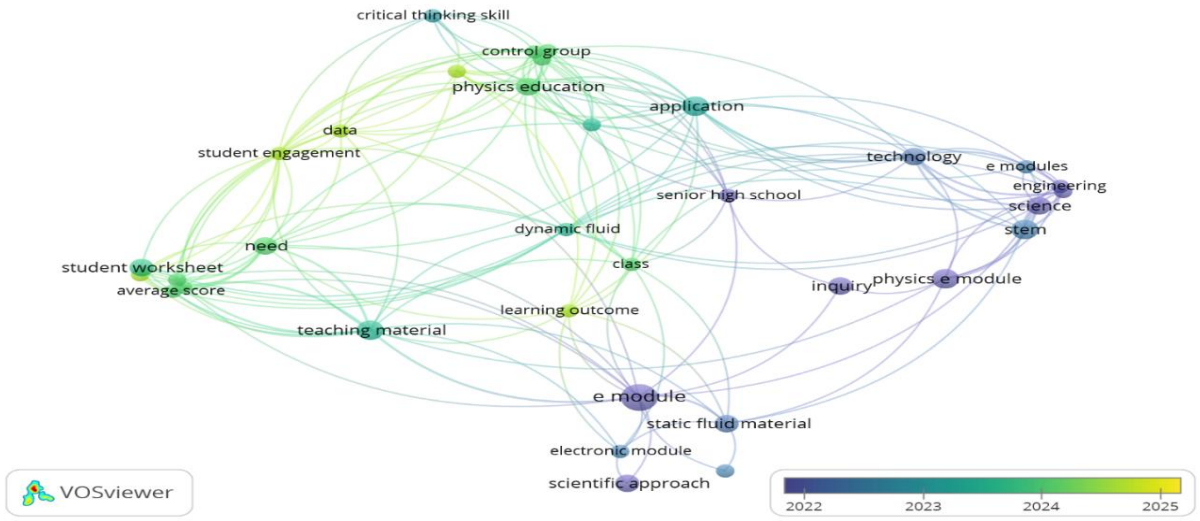

Figure 4. Overlay Visualization
(Source: Author's Elaboration Using VOSviewer)

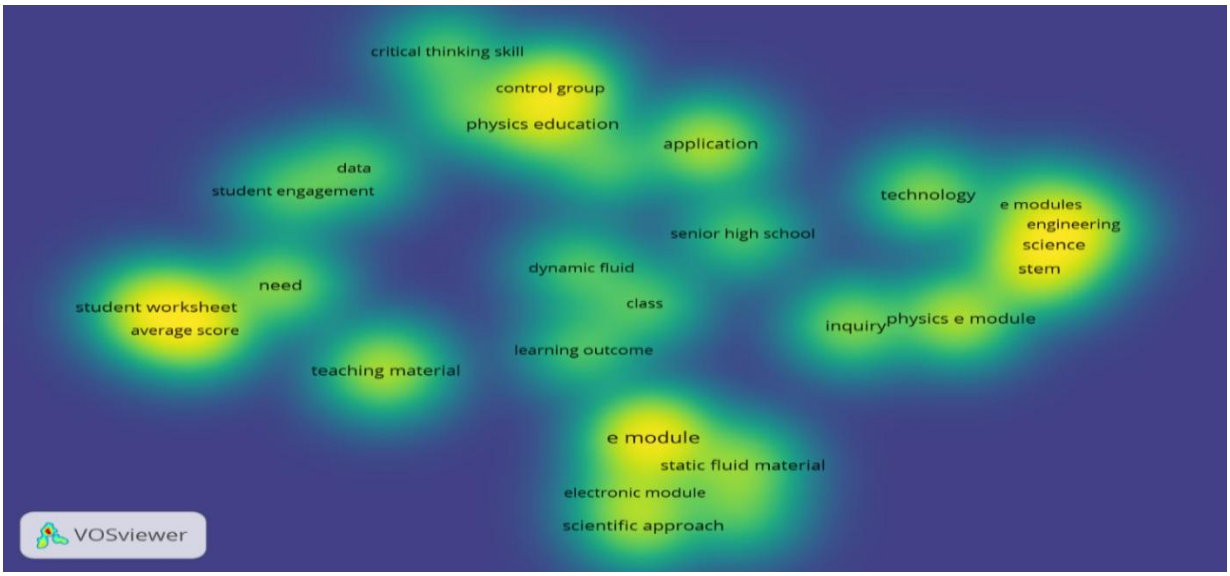

Figure 5. Density Visualization
(Source: Author's Elaboration Using VOSviewer)

The overlay visualization presented in Figure 4 reveals a noticeable shift in research trends on digital-based physics teaching materials, moving from technology-oriented themes toward pedagogical dimensions and learning outcomes. Early studies conducted during the 2022–2023 period predominantly focused on topics such as technology, e-module, STEM, science, and engineering, whereas more recent studies from 2024–2025 increasingly emphasized themes including physics education, student engagement, learning outcomes, application, control group, and needs analysis. Complementing this trend, the density visualization in Figure 5 highlights student worksheet, e-modules, science, STEM, physics education, and e-module as the most intensively investigated topics, as indicated by their high-density concentrations. Collectively, these findings suggest that contemporary research has evolved beyond the mere development of digital learning products and is increasingly directed toward examining their pedagogical effectiveness in fostering twenty-first-century skills, enhancing student engagement, and improving learning outcomes.

The Impact of Using Digital Based Physics Teaching Materials on Twenty First Century Learning

To understand the contribution of digital-based physics teaching materials to the development of student competencies, an analysis of the impacts reported in the articles that were the object of the research was conducted. This analysis focused on various aspects of twenty first century learning that experienced improvements after the implementation of digital teaching materials in the physics learning process. Identifying these impacts is important to demonstrate the extent to which digital teaching material innovations are able to support the achievement of learning objectives relevant to the demands of modern education. The results of the analysis regarding the distribution of the impacts of the use of digital-based physics teaching materials on various aspects of twenty first century learning are presented in detail in Table 2.

Table 2. The Impact of Using Digital Based Physics Teaching Materials

No	Twenty First Century Learning Aspect	Frequency	Percentage	Indicators of Findings
1	Conceptual Understanding	17	50%	Increased post-test scores, reduced misconceptions, and improved

No	Twenty First Century Learning Aspect	Frequency	Percentage	Indicators of Findings
				ability to explain physics concepts scientifically.
2	*Critical Thinking*	4	11.77%	Students demonstrated stronger logical reasoning, data analysis skills, and better performance on HOTS-oriented questions.
3	HOTS Skills	3	8.8%	Improvement in students' abilities to analyze, evaluate, and create solutions for physics-related problems.
4	Scientific Literacy	3	8.8%	Students were able to interpret scientific data and apply scientific concepts in everyday contexts.
5	4C Skills	2	5.9%	Students became more active in discussions, teamwork, and communicating ideas effectively through digital media.
6	Science Process Skills	1	2.94%	Students showed improvement in observing, measuring, and drawing scientific conclusions.
7	Learning Outcomes	1	2.94%	Average learning outcomes and classical learning mastery increased significantly.
8	Learning Independence	1	2.94%	Students became more active in accessing learning resources independently and showed higher learning motivation.
9	Creativity Skills	1	2.94%	Students were able to develop projects, simple media, or creative solutions based on physics concepts.
10	Teaching Skills of Pre-Service Physics Teachers	1	2.94%	Pre-service teachers became more capable of designing interactive lessons and effectively utilizing digital media.
	Total	34	100%	

Table 2 demonstrates that the most prominent impact of digital-based physics teaching materials on twenty-first-century learning is reflected in students' conceptual understanding, which accounts for 17 articles (50%) of the analyzed studies. This finding suggests that digital teaching materials effectively support the comprehension of abstract and complex physics concepts through the integration of visualization, simulations, and interactive multimedia features, thereby facilitating deeper knowledge construction and reducing misconceptions. Furthermore, substantial contributions were identified in the areas of critical thinking, Higher-Order Thinking Skills (HOTS), and scientific literacy, indicating that digital learning resources play an important role in fostering analytical reasoning, problem-solving abilities, and the application of scientific concepts in authentic contexts. Although aspects such as 4C skills, science process skills, learning independence, creativity, learning outcomes, and pedagogical

competencies of prospective physics teachers were reported less frequently, the overall findings confirm that digital-based physics teaching materials possess considerable potential to support the holistic

Discussion

The increasing publication trend on digital-based physics teaching materials reflects the growing recognition of digital technologies as essential components of contemporary physics education that support the development of twenty-first-century competencies (Misbah et al., 2021; Pane et al., 2021). This trend is consistent with the global transformation of educational practices that increasingly emphasize flexible, technology-enhanced, and student-centered learning environments (Nasbey et al., 2024; Susilawati et al., 2025). The recovery of publication productivity after 2022 suggests that digital innovation in physics education remains a strategic research priority despite post-pandemic educational transitions (Asfiya et al., 2024; Ashnam et al., 2022). Furthermore, the emergence of research involving artificial intelligence, virtual laboratories, and adaptive learning systems indicates a shift toward more personalized and data-driven physics learning experiences (Utami et al., 2025; Wahyuddin et al., 2026; Wijaya, 2025).

The predominance of E-Modules demonstrates that researchers increasingly perceive digital teaching materials as comprehensive learning environments rather than merely electronic versions of printed resources (Diani et al., 2021; Nenchi et al., 2021; Simamora et al., 2020). The widespread adoption of E-Modules can be attributed to their ability to integrate multimedia elements, assessment tools, and interactive learning activities within a single platform that enhances learner autonomy and engagement (Linda et al., 2021; Syukri et al., 2024). The continued development of E-Worksheets and multimedia resources further indicates the importance of active learning and visualization in facilitating conceptual understanding in physics education (Karim et al., 2024; Muliyati et al., 2023). These findings support the argument that effective digital learning environments should combine interactivity, visualization, and inquiry-based activities to maximize learning effectiveness (Handayani et al., 2021; Mahombar, 2024b).

The dominance of the Research and Development approach highlights the strong orientation of current studies toward producing innovative instructional products that directly address educational needs and classroom challenges (Haryanto et al., 2021; Saputra et al., 2024). The extensive use of the ADDIE model suggests that researchers favor systematic instructional design frameworks capable of ensuring the quality, usability, and effectiveness of digital teaching materials (Haryanto et al., 2021; Susanti et al., 2023). However, the limited application of qualitative and mixed-methods approaches indicates that the complexity of students' experiences, perceptions, and learning interactions remains insufficiently explored (Putri & Syafriani, 2020; L. Sari et al., 2021). Therefore, future studies should integrate product development with comprehensive pedagogical evaluations to generate a more holistic understanding of how digital teaching materials influence learning processes and outcomes (Desnita et al., 2025; Mahombar, 2024a).

The finding that conceptual understanding represents the most frequently reported impact confirms that digital teaching materials are particularly effective in addressing the abstract nature of physics concepts through visualization, simulation, and interactive representations (Mahardika et al., 2025; Majid et al., 2020). Beyond conceptual mastery, the positive effects on critical thinking, HOTS, scientific literacy, and collaboration demonstrate that digital learning resources contribute significantly to the development of competencies required in twenty-first-century education (Hariyanti et al., 2025; Pane et al., 2021). The growing emphasis on student engagement and learning outcomes observed in the bibliometric

network analysis further suggests that research is shifting from technology adoption toward evidence-based evaluations of educational effectiveness (Herliana et al., 2025; S. Y. Sari et al., 2023). Consequently, digital-based physics teaching materials should be viewed not only as technological innovations but also as pedagogical instruments capable of fostering meaningful learning, learner autonomy, and lifelong learning skills in modern educational contexts (Mahombar et al., 2023; Neyarasmi & Mardatillah, 2025; Nurlatifah et al., 2025).

CONCLUSION

This research confirms that the development of digital-based physics teaching materials has become an increasingly important area of research in response to the demands of twenty-first-century learning and the growing integration of technology in education. The findings indicate a substantial increase in research productivity during the 2020–2025 period, with E-Modules emerging as the most widely developed form of digital teaching material due to their capacity to support interactive, flexible, student-centered, and independent learning experiences. Furthermore, digital-based physics teaching materials have demonstrated significant potential to enhance students' conceptual understanding, critical thinking, higher-order thinking skills, scientific literacy, creativity, collaboration, and learning autonomy. The bibliometric visualization also reveals a research trend toward the integration of STEM approaches, interactive technologies, and student engagement, highlighting a shift from technology adoption toward the optimization of learning outcomes and twenty-first-century competencies. Overall, this research provides a comprehensive overview of publication trends, research themes, and educational impacts of digital-based physics teaching materials, offering valuable insights for educators, researchers, and curriculum developers in designing innovative and adaptive physics learning environments for the future.

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