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STEM Trends in Physics Education Research at The Secondary School Level In Indonesia: A Bibliometric Perspective (2010–2024)

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Abstract

Science, Technology, Engineering, and Mathematics (STEM) education has attracted growing global attention, yet its development within physics learning in Indonesia remains unevenly mapped. This study conducts a bibliometric analysis of STEM-oriented physics education in Indonesian secondary schools (2010–2024). Articles were retrieved using Publish or Perish (Google Scholar), curated in Mendeley, and analyzed with VOSviewer. Fifty-four eligible journal articles were identified. The findings indicate that research on STEM-oriented physics learning expanded rapidly, peaking in 2020, and subsequently fluctuated at levels above those observed before 2018. East Java was identified as the most productive province in STEM education research related to physics learning. Furthermore, the University of Jember and the State University of Malang are the two most active institutions in publishing articles in this field. Based on keyword analysis, STEM research in physics learning predominantly focuses on the development of teaching materials, instructional models, learning outcomes, and physics subject content. Among the ten most-cited articles, four discuss STEM project-based learning. This study maps the national research landscape, providing an empirical foundation for researchers, educators, and policymakers to identify gaps, refine STEM strategies, and promote evidence-based practices. Practically, the field would benefit from broader multi-site collaborations (including regions beyond Java), more rigorous methodological reporting, and the systematic adoption of technology-enhanced resources.

Keywords: Bibliometric analysis, physics education, STEM, secondary school.

INTRODUCTION

STEM Education has been globally recognized as a fundamental pillar in driving economic growth (Lee, Chai, & Hong, 2019) and preparing the younger generation to face the challenges of the 21st century (Thu et al., 2021) . Proficiency in STEM is not only relevant in an increasingly complex workforce but also essential in addressing pressing social and environmental issues. STEM education integrates these four disciplines in real-world contexts, enabling students to develop critical thinking, creativity, and collaboration skills necessary to become productive

citizens. Incorporating elements of STEM, either individually or collectively, into everyday practices has the potential to enhance the ease of living (Ozkan & Topsakal, 2023).

Despite the significant potential of STEM education in preparing students for a better future, its global implementation faces various challenges. One of the primary challenges is the disparity in access to adequate resources, including infrastructure, technological tools, and teacher training (Qureshi & Qureshi, 2021). In many developing countries, a lack of infrastructure and trained human resources hinders the successful implementation of an effective STEM curriculum. Furthermore, while the integration of science, technology, engineering, and mathematics is crucial, the practical application of interdisciplinary learning often encounters difficulties. A fragmented curriculum and teachers' unpreparedness to implement interdisciplinary teaching methods pose challenges that must be addressed to achieve optimal STEM learning outcomes (English, 2017; Margot & Kettler, 2019). Collaborative efforts among governments, educational institutions, and the private sector are needed to establish an educational ecosystem that supports sustainability and equity in STEM learning worldwide.

The Indonesian government has implemented several policies to support STEM education, one of which is the implementation of the Kurikulum 2013 (K13), which emphasizes a scientific and project-based learning approach. This curriculum aims to enhance students' critical and creative thinking skills through activities focused on problem-based learning, experiments, and real-life applications of scientific concepts. Additionally, initiatives that support project-based or research-based learning have been strengthened through various programs, such as the ICT-Based Learning Training (PembaTIK), which aims to improve teachers' technological literacy. This program provides training for educators to utilize technology in creating more interactive and project-based learning experiences. On the other hand, micro-credential scholarships in STEM fields and the Kihajar STEM program are also expected to strengthen teachers' competencies and expand access to high-quality STEM education across Indonesia.

The significance of STEM education has driven many countries to implement it. In recent years, several researchers have conducted bibliometric analyses on STEM education worldwide to assess its development. Bibliometric analysis utilizes mathematical and statistical approaches to evaluate the productivity of scientific research (Dervis, 2019). Using bibliometric methods, Thu et al., (2021) found that research on STEM education at the secondary school level first emerged in 2006 and has experienced significant growth since 2016. The United States has been the most active country in researching STEM education (Laksita, Pusporini, & Mutiara, 2024; Phuong et al., 2023; Tas & Bolat, 2022; Thu et al., 2021). Meanwhile, Ha et al., (2020) conducted a bibliometric analysis of STEM education in ASEAN countries, revealing a rising trend in STEM research in the region from 2011 to 2019. Based on the number of published articles, Indonesia ranks third after Malaysia and Thailand in STEM research productivity.

The increasing trend in STEM research reflects significant global attention toward STEM education. However, no prior study has specifically examined the research trends in STEM-based physics education in Indonesia. This study aims to provide a comprehensive bibliometric analysis of STEM implementation in secondary-level physics education (SMP and SMA) in Indonesia from 2010 to 2024, utilizing VOSviewer to examine research trends. By identifying relevant publications and mapping frequently studied topics, this analysis assesses the extent to which STEM has been integrated into physics education. It specifically addresses three key questions: (1) the evolution of STEM research in physics education, reflected in publication trends and growth patterns; (2) dominant research themes identified through keyword co-occurrence and bibliographic coupling; and (3) collaboration patterns among researchers and institutions engaged in STEM research on physics education in Indonesia.

METHOD

This study employs a bibliometric methodology that integrates data retrieval, reference management, and network visualization

using Publish or Perish, Mendeley, and VOS viewer (version 1.6.20). Bibliometric analysis is a quantitative study that uses statistical and mathematical techniques to analyze the characteristics of published literature. Publish or Perish was utilized to extract bibliographic data and citation metrics from academic databases such as Google Scholar, enabling the identification of relevant literature based on specific search queries (Harzing, 2007). The retrieved references are systematically managed and organized using Mendeley to facilitate accurate data handling and citation tracking. Subsequently, the VOS viewer, developed by van Eck and Waltman (2010), was employed to construct and visualize bibliometric maps, including co-authorship networks, keyword co-occurrence, and citation relationships (Husaeni & Nandiyanto, 2022; Hutami et al., 2023; Jaya et al., 2024).

Publish or Perish was utilized to retrieve publication data from Google Scholar for the period 2010–2024. In the context of this research title, the term "secondary school" encompasses both junior high school (SMP) and senior high school (SMA) in Indonesia. The search parameters included "Journal" or "Jurnal" in the publication name field and "Science, Technology, Engineering, and Mathematics (STEM) Learning" AND "SMA" AND "SMP" in the title words field, yielding 165 relevant publications. The retrieved data were exported in CSV (Microsoft Excel) and RIS file formats for further analysis. The CSV file was processed in Microsoft Excel to filter publications that met the criteria for peer-reviewed journal articles published between 2010 and 2024. The filtered records were then sorted based on citation count to identify the most influential studies in the field. The RIS file was imported into Mendeley, where bibliographic metadata-including title, author(s), year of publication, journal or conference name, abstract, and keywords-were systematically refined and completed. The curated RIS file was subsequently exported for bibliometric visualization using VOSviewer (ver. 1.6.20).

The bibliometric visualization generated by VOSviewer facilitated the identification of research trends and thematic connections within the dataset. By analyzing co-occurrence networks, this study provides insights into key research themes, their interrelations, and potential directions for further exploration in STEM-based physics education. The workflow of bibliometric mapping applied in this research is depicted in Figure 1.

Figure 1. Workflow of Bibliometric Mapping

RESULT AND DISCUSSION

The search results indicate that 54 publications related to the implementation of STEM education in physics learning at the junior and senior high school levels in Indonesia were published between 2010 and 2024 (Figure 2). Between 2010 and 2014, no STEM-related articles were published. However, in 2015, two articles on STEM education were published in the Jurnal Pendidikan Sains Indonesia. The number of publications then declined to only one article in 2016 and 2017. A notable increase in publications began in 2018, and from 2019 onwards, the number of published articles remained consistently above four per year. A significant surge occurred in 2020, with a total of 11 articles published. These STEM-related articles were published across 31 different journals. These findings indicate a notable increase in STEM-related publications in physics education in Indonesia since 2018, with a peak reached in 2020. This trend aligns with the results of a global bibliometric study conducted by Laksita, Pusporini, and Mutiara (2024), which analyzed 139 publications from 2003 to 2024 and reported a consistent upward trajectory in school-based STEM education research worldwide, particularly dominated by contributions from the United States, China, and Australia. Their findings demonstrate that global attention to STEM education has accelerated significantly after 2016, reflecting a shift in educational research priorities toward interdisciplinary and innovation-driven learning approaches. Accordingly, these findings indicate that interest in STEM research within the

Indonesian educational context follows a similar trajectory to global trends in STEM research.

This parallel development may be attributed to Indonesia's increasing policy emphasis on 21st-century skills and inquiry-oriented curricula, particularly through the 2013 Curriculum (K13) and subsequent national initiatives such as PembaTIK and Kihajar STEM. The simultaneous global and national rise in STEM-related studies also reflects a shared educational response to technological advancement, digital transformation, and the demand for interdisciplinary competencies in the post-industrial era. Moreover, the growing number of STEM publications in Indonesia suggests greater research awareness and institutional support, especially in teacher education programs, indicating that STEM is becoming an established framework within physics education discourse both globally and nationally.

Table 1 indicates a pronounced concentration of STEM and physics-education publications within a limited set of outlets. Jurnal Pembelajaran Fisika accounts for 10 of 24 articles (41.7%), followed by Jurnal Pendidikan: Teori, Penelitian, dan Pengembangan with 4 articles (16.7%), whereas each of the remaining five journals contributes 2 articles (8.3% per outlet). Consequently, the two leading journals together comprise 58.3% of the analyzed corpus. Most STEM-related articles are published in lower-indexed journals. Only one article is indexed in Sinta 1, while a few others appear in Sinta 2-indexed journals. This situation reflects the lack of attention given to STEM research in physics education, which may subsequently affect the overall quality of STEM research in this field.

Figure 3 presents the six institutions with the highest number of STEM-related publications, with Universitas Jember clearly leading (11 publications), followed by Universitas Negeri Malang (6) and Universitas Negeri Padang (4); the remaining institutions, Universitas Syiah Kuala, Universitas Negeri Semarang, and SMA Negeri 2 Jember, contribute 2 publications each. Based on this, it can be stated that STEM–physics education output centres on Universitas Jember, with moderate contributions from several state universities, indicating research hubs that merit further investigation. This concentration of research productivity in Universitas Jember may stem from the strong commitment of its faculty to STEM-based curriculum development and the presence of active research groups that consistently collaborate with secondary school teachers. The pattern also suggests that institutional support and localized research ecosystems play a crucial role in sustaining publication output. However, the limited participation of institutions outside Java indicates a geographic imbalance that may hinder the national dissemination of STEM pedagogical innovation. Therefore, future policies and research funding should promote cross-institutional collaborations and capacity-building programs in underrepresented provinces to achieve a more equitable and nationally integrated STEM research landscape.

Figure 4 illustrates the distribution of author affiliations across Indonesian provinces. Only 14 out of 38 provinces have institutions that have published STEM-related articles. East Java (n = 24) has the highest number of institutions contributing to STEM research publications, followed by West Sumatra (n = 6), Aceh (n = 5), Central Java (n = 4), and West Java (n = 2). Meanwhile, Jambi, North Sumatra, Special Region of Yogyakarta, Lampung, West Nusa Tenggara, Maluku, North Maluku, and East Kalimantan each have one institution publishing in this field. STEM research in physics education is largely dominated by institutions in East Java Province. Universitas Jember and Universitas Negeri Malang are the two most active institutions in this field. Several studies are the result of collaborations between university researchers and senior high school teachers (Dewi, Lesmono, Hadiyanto, & Harimukti, 2020; Putri, Lesmono, & Ismanto, 2020). Outside Java, North Sumatra and Aceh have recorded the highest number of publications, respectively. However, several provinces have only one or no STEM-related publications at all.

This geographical disparity highlights the uneven distribution of research capacity and access to academic resources across Indonesia. Provinces in Java benefit from higher institutional density, stronger research cultures, and more extensive funding and collaboration opportunities, which collectively foster higher publication output. Conversely, the limited research activity in eastern

and peripheral regions may be linked to infrastructural constraints, limited access to digital databases, and insufficient professional development opportunities for teachers and researchers. These findings underscore the need for national initiatives that decentralize research support, strengthen regional research networks, and promote mentorship programs connecting leading STEM institutions with emerging universities across Indonesia. Such measures would facilitate a more inclusive and balanced growth of STEM-based physics education research nationwide.

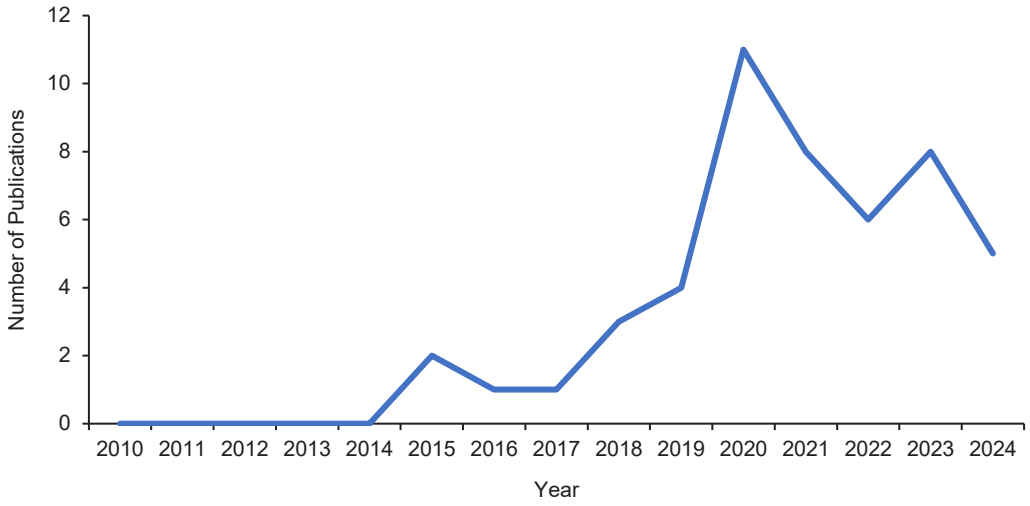

Figure 2. Number of STEM Research Publications in Physics Education from 2010 to 2024

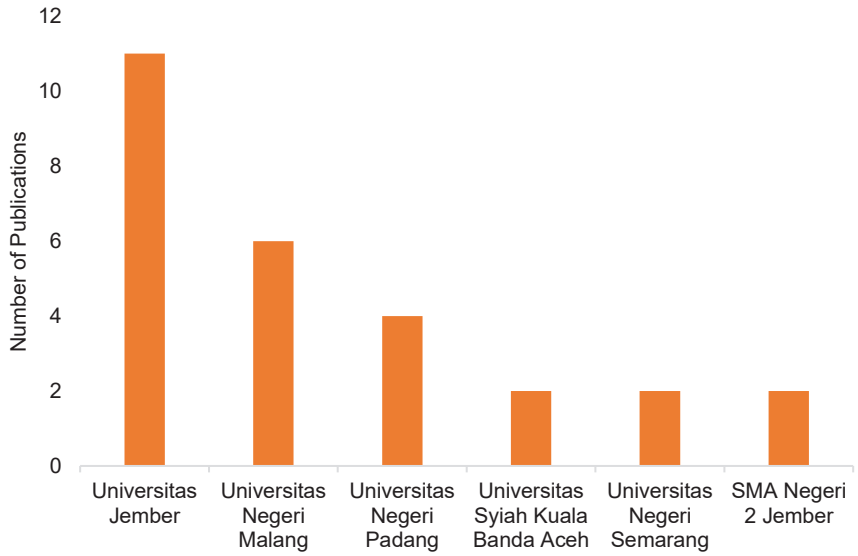

Figure 3. The Six Most Productive Institutions in STEM and Physics Education

Table 1. The Seven Most Productive Journals in STEM and Physics Education

Journals	Number of Articles	Sinta Index
Jurnal Pembelajaran Fisika	10	5
Jurnal Pendidikan: Teori, Penelitian, dan Pengembangan	4	3
Jurnal Pendidikan Sains Indonesia	2	2
Unnes Physics Education Journal	2	3
Jurnal Pendidikan Matematika dan Sains	2	3
Briliant : Jurnal Riset dan Konseptual	2	3
Jurnal Literasi Pendidikan Fisika	2	4

Noted: Sinta (Science and Technology Index), developed by the Ministry of Research, Technology, and Higher Education of Indonesia, ranks scientific journals, researchers, and institutions based on citation impact, with journals categorized from Sinta 1 (highest) to Sinta 6 (lowest).

Among the total of 133 authors, 32 engaged in collaborative research with other scholars, as depicted in Figure 6. The visualization identifies seven distinct clusters, each represented by a different colour. Several authors have contributed to multiple STEM-related articles, including Albertus Djoko Lesmono (n = 8), Lailatul Nuraini (n = 4), and Parno (n = 3). Over the past decade, Albertus Djoko Lesmono from Universitas Jember has been the most prolific author in publishing STEM-related articles. Seven out of his eight articles were published in 2020, with the remaining one published in 2024. One of his studies, published in Jurnal Pembelajaran Fisika, holds the highest citation count (Kanza, Lesmono, & Widodo, 2020). In all of his publications, Lesmono collaborated with two or three co-authors, consistently occupying the second authorship position. Lailatul Nuraini, one of his frequent collaborators, was also an active contributor to STEM-related publications. One of their joint studies explored the impact of problem-based learning with a STEM approach on student learning outcomes. Additionally, Nuraini, along with other authors, published an article in Jurnal Pembelajaran Fisika that has accumulated a total of 68 citations (Wijayanto, Supriadi, & Nuraini, 2020). Figure 6 depicts a centralized, locally bounded co-authorship network centred in Jember. Working more across different research groups and institutions would make the network more connected, add a wider range of expertise, and increase the overall scientific impact. The dominance of a single regional cluster indicates that collaboration patterns in STEM-physics education research are still concentrated within localized academic communities rather than being distributed nationally. This limited interconnectivity may restrict innovation, methodological diversity, and the dissemination of findings to broader educational contexts. The strong collaborative nucleus in Jember suggests an effective institutional culture of teamwork and mentorship, yet similar structures are less evident elsewhere. Encouraging cross-provincial partnerships, co-authored publications with researchers from other universities, and integration into national research consortia could substantially strengthen network density and visibility. In the long term, a more interconnected authorship network will enhance the exchange of ideas, foster interdisciplinary approaches, and elevate Indonesia's overall contribution to the global discourse on STEM education.

Table 2 shows a highly skewed citation distribution among the ten most-cited STEM–physics education articles (total 757 citations; mean 75.7, median 58.5). Jurnal Pembelajaran Fisika contributes 232 citations (30.6%) and Unnes Physics Education Journal 196 (25.9%), while the remaining journals each contribute a single entry with markedly lower tallies. Citation impact within this corpus is concentrated in a small number of articles and outlets, especially those publishing practice-oriented, STEM-integrated instructional interventions at the secondary level. The two most-cited articles from this analysis both focus on STEM Project-Based Learning (STEM PBL). As described by Han, Capraro, & Capraro (2015), STEM PBL is a teaching strategy that integrates multiple disciplines, emphasizes collaboration, incorporates technology, and adopts a student-centred approach. Research on STEM PBL continues to expand, as its implementation has been recognized for fostering essential 21st-century skills,

particularly critical thinking (Capraro & Slough, 2013). The literature suggests that PBL strategies allow students to engage with physics content in meaningful ways and promote collaborative problem-solving skills (Pangesti & Triyanta, 2022). This approach encourages students to work on projects that reinforce their understanding of physics concepts and require the application of critical thinking and creativity to solve complex problems.

Table 2. The Top Ten Most-Cited Articles

Author (Year)	Title	Journal	Cited
(Kanza, Lesmono, & Widodo, 2020)	Analisis Keaktifan Belajar Siswa Menggunakan Model Project Based Learning dengan Pendekatan STEM Pada Pembelajaran Fisika Materi Elastisitas Di Kelas XI MIPA 5 SMA Negeri 2 Jember	Jurnal Pembelajaran Fisika	164
(Pangesti, Yulianti, & Sugianto, 2017)	Bahan Ajar Berbasis STEM (Science, Technology, Engineering, and Mathematics) untuk Meningkatkan Penguasaan Konsep Siswa SMA	Unnes Physics Education	158
(Ismail, Permanasari, & Setiawan, 2016)	STEM Virtual Lab: An Alternative Practical Media To Enhance Students' Scientific Literacy	Jurnal Pendidikan IPA Indonesia	88
(Wijayanto, Supriadi, & Nuraini, 2020)	Pengaruh Model Pembelajaran Project Based Learning Dengan Pendekatan STEM Terhadap Hasil Belajar Siswa SMA	Jurnal Pembelajaran Fisika	68
(Sumardiana, Hidayat, & Parno, 2019)	Kemampuan Berpikir Kritis pada Model Project-Based Learning disertai STEM Siswa SMA pada Suhu dan Kalor	Jurnal Pendidikan: Teori, Penelitian, dan Pengembangan	66
(Rahmatina, Jannah, & Annisa, 2020)	Pengembangan Bahan Ajar Berbasis Science, Technology, Engineering, and Mathematics (STEM) di SMA/MA	Jurnal Phi: Jurnal Pendidikan Fisika dan Fisika Terapan	51
(Widayoko, Latifah, & Yuliati, 2018)	Peningkatan Kompetensi Literasi Saintifik Siswa SMA dengan Bahan Ajar Terintegrasi STEM pada Materi Impuls dan Momentum	Jurnal Pendidikan: Teori, Penelitian, dan Pengembangan	51
(Marwani & Sani, 2020)	Pengaruh Model Project-Based Learning Berbasis STEM Terhadap Kemampuan Berfikir Kreatif Siswa Padamateri Pokok Fluida Statis Di Kelas XI SMAN Negeri 4 Tebing Tinggi T.P 2019/2020	Jurnal Inovasi Pembelajaran Fisika (INPAFI)	48
(Syahiddah, Putra, & Supriadi, 2021)	Pengembangan E-Modul Fisika Berbasis STEM (Science,Technology, Engineering, and Mathematics) Pada Materi Bunyi di SMA/MA	Jurnal Literasi Pendidikan Fisika	38
(Santoso & Mosik, 2019)	Kefektifan LKS Berbasis STEM (Science, Technology, Engineering and Mathematic) untuk Melatih Keterampilan Berpikir Kritis Siswa pada Pembelajaran Fisika SMA	Unnes Physics Education Journal	38

Figure 4. Distribution of Authors in STEM and Physics Education Across Provinces in Indonesia

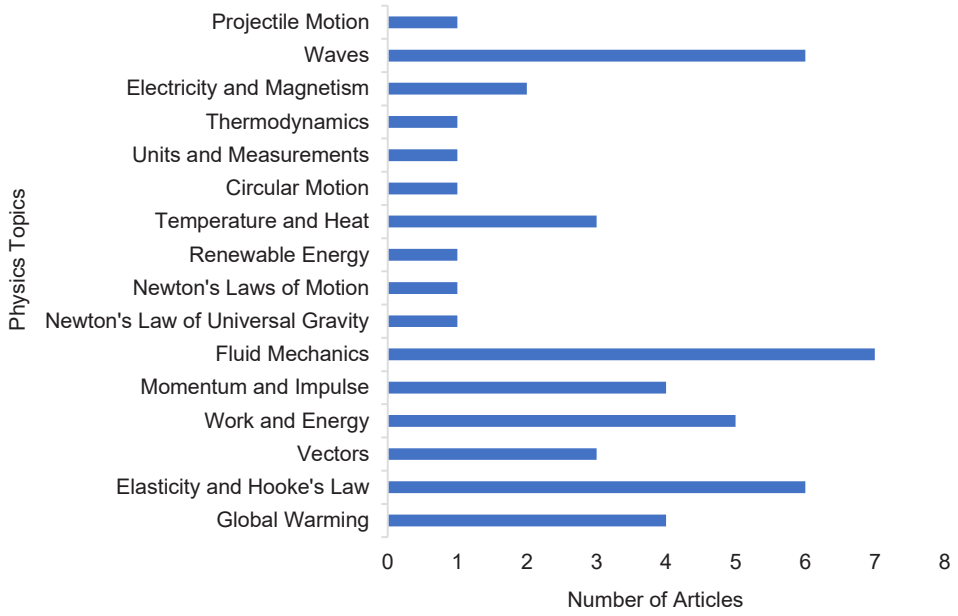

Figure 5. The Physics Topics Emerging in STEM Research

Table 3 presents the complete set of keywords, categorized into thirteen clusters. The clustering indicates a strong practice-proximal orientation, where instructional models are frequently combined with resource development (e-modules/student worksheet and digital media (virtual labs), reflecting an emphasis on classroom-deployable interventions rather than purely theoretical contributions. The prominence of outcomes such as critical thinking, scientific literacy, process skills, and scientific communication signals attention to 21st-century competencies targeted by STEM initiatives (Capraro & Slough, 2013; English, (2017). Content coverage concentrates on foundational mechanics and contextual environmental themes, consistent with upper-secondary curricula. At the same time, the presence of blended/hybrid and model-based learning suggests diversification beyond PBL and adaptation to digital ecosystems. Overall, the keyword map portrays a research agenda centred on PBL/inquiry-driven STEM interventions

supported by e-modules, student worksheets and virtual labs, aiming to advance concept learning and higher-order scientific competencies in core physics topics and environmental contexts.

The bibliometric mapping in Figure 7 demonstrates that STEM-based research in physics education is characterized by the systematic integration of pedagogy, content, skills, and resources. The size of each circle represents the frequency of keyword occurrences within the articles (van Eck & Waltman, 2010). The network visualization map presented in Figure 7 reveals thirteen distinct clusters, each represented by a different colour.

Table 3. List of 13 Clusters with Their Corresponding Keywords

Claster	Keywords
1	*Approach STEM, berpikir kreatif, elasticity, learning model, learning outcomes, mathematical creativity, PBL model with STEM, project-based learning*
2	*Global warming, module, physics learning, scientific communication, STEM-PjBL, work and energy*
3	*Student learning outcome, cognitive learning outcome, creative thinking skills, model-based learning, problem-based learning, vector*
4	*Analisis kebutuhan bahan ajar, e-modul, hybrid learning, need analysis, scaffolding*
5	*Critical thinking, elasticity and hooke, learning, physics, textbook*
6	*Conceptual understanding, impulse and momentum, inquiry learning, sains*
7	*Critical thinking skills, generic science skills, Student Worksheet(LKPD), STEM*
8	*e-module, renewable energy, sound, STEM-PBL*
9	*Blended learning, fluid, teaching material*
10	*Media learning science, scientific literacy, virtual lab*
11	*Bahan ajar elektronik, hasil belajar*
12	*Mastery of concepts, teaching materials*
13	*Guided inquiry, science process skills*

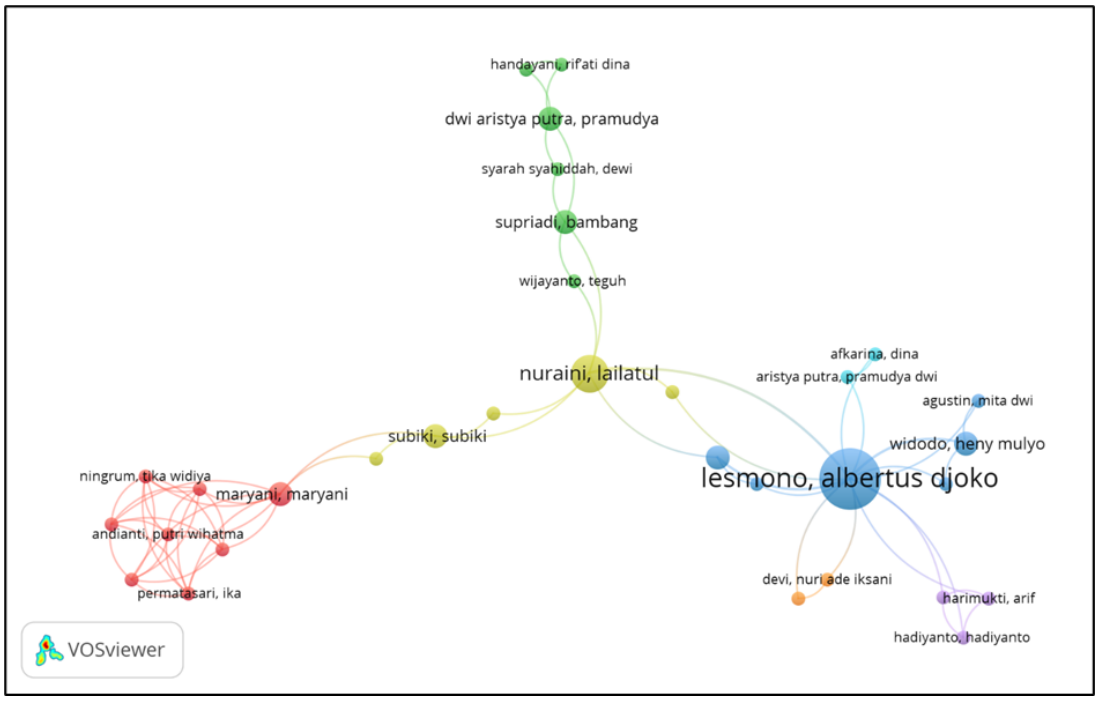

Figure 6. Relationship between Authors

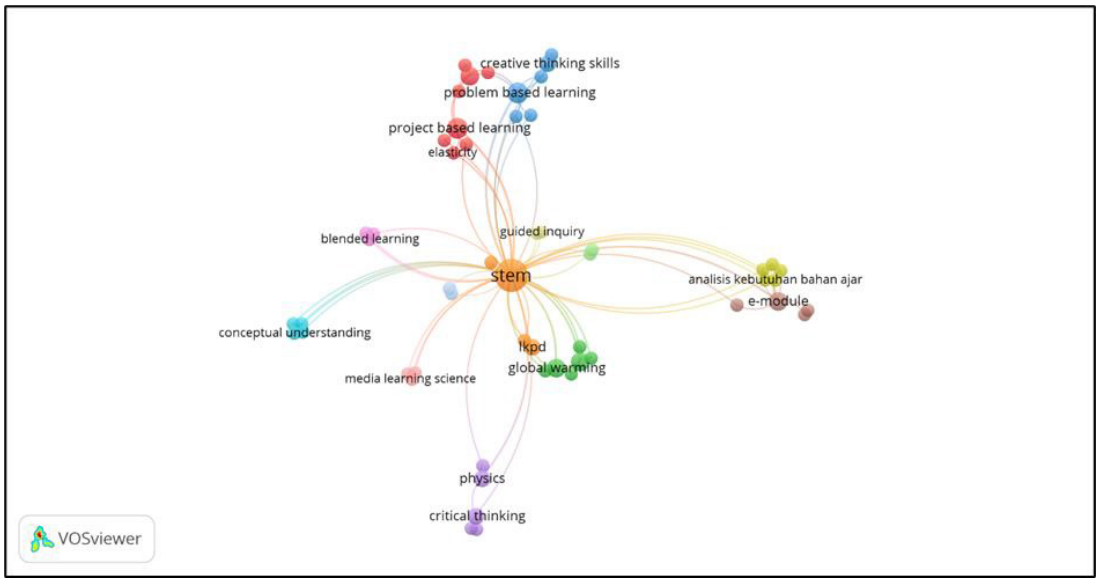

Figure 7. Relationship between Keywords in STEM Research on Physics Education

First, keywords such as learning outcomes, mathematical creativity, creative thinking skills, critical thinking skills, and cognitive learning outcomes suggest that researchers are particularly interested in examining the impact of STEM education on student learning outcomes. Second, keywords such as project-based learning, PBL model with STEM, STEM-PJBL, problem-based learning, and learning model highlight a research trend focused on the implementation of instructional models in physics education. Third, several keywords—such as e-module, teaching material, student worksheet (SW), teaching material needs analysis, and textbook—indicate that researchers also explore teaching materials used in STEM education. Fourth, STEM-based physics education is applied to specific topics, as reflected in keywords such as global warming, work and energy, vector, elasticity and Hooke's law, and fluid mechanics (Figure 5). The findings reveal that research within STEM education predominantly emphasizes applied physics topics, with fluid mechanics, waves, and elasticity and Hooke's law emerging as the most frequently investigated areas. In contrast, fundamental concepts such as Newton's laws, thermodynamics, and projectile motion are less represented, indicating a scholarly tendency to prioritize contextually relevant and application-oriented domains over foundational theoretical constructs. This pattern suggests that STEM research in Indonesian physics education is strongly driven by curriculum relevance and real-world applicability rather than by theoretical exploration. The dominance of project-based and application-oriented topics reflects the pedagogical shift toward contextual learning, aligning with the 2013 Curriculum (K13) that emphasizes inquiry, experimentation, and problem-solving (Lee, Chai, & Hong, 2019; English, 2017). However, the underrepresentation of fundamental physics concepts indicates potential research gaps that may limit the comprehensive integration of STEM across all physics domains. To build a more balanced research landscape, future studies should extend STEM-based interventions to include abstract or mathematically intensive topics, such as dynamics,electromagnetism, and thermodynamics, supported by digital simulations and virtual laboratories (Ismail, Permanasari, & Setiawan, 2016; Jiang et al., 2024). Doing so would not only diversify the range of learning contexts but also enhance students' higher-order thinking and conceptual reasoning skills in both applied and theoretical physics domains.

The integration of STEM into instructional models has become a prominent trend in physics education research. Although project-based learning dominates, researchers have also

incorporated STEM into inquiry-based and problem-based learning approaches. Several studies included in this bibliometric analysis indicate that STEM inquiry-based learning and STEM problem-based learning can enhance students' scientific process skills (Aprilia & Anggaryani, 2023) and conceptual understanding (Khotimah, Supriana, & Parno, 2020) in physics education.

Another notable research trend is the development of teaching materials. Nearly 46% of the articles analyzed focus on the development of instructional modules, student worksheets, and educational videos. However, none of the analyzed studies explore the integration of augmented reality (AR) or virtual reality (VR). Given the significant potential of AR and VR in facilitating the comprehension of abstract physics concepts, this presents a research gap. Previous systematic reviews have also highlighted the benefits of AR and VR in STEM education (Jiang, Zhu, Chugh, Turnbull, & Jin, 2024).

Based on the critical synthesis of the ten most-cited studies, it can be concluded that future research STEM in physics education should address several key gaps, including the tendency of existing studies to focus on single learning outcomes, the absence of standardized and psychometrically validated assessment tools, the short-term scope of interventions that overlook long-term retention and the limited integration of local cultural wisdom into STEM content (Pamungkas, Harun, & Manaf 2023), and the underutilization of virtual laboratories in hybrid learning models (Khaeruddin & Bancong, 2022).

Therefore, this study proposes a novelty that lies in the development of a multivariate, integrative PBL-STEM framework combining validated instructional resources, hybrid modalities that blend virtual and hands-on experiments, and culturally contextualized learning materials, supported by robust assessment instruments capable of simultaneously measuring cognitive, affective, psychomotor, literacy, and metacognitive skills. By incorporating technology-enhanced self- and peer-assessment, this approach is expected to yield both sustained learning impacts and scalable, contextually relevant innovations that contribute significantly to the advancement of STEM education theory and practice.

CONCLUSION

This bibliometric study of STEM-oriented physics education in Indonesian secondary schools (2010–2024) shows a growing yet uneven landscape. Publication activity rose sharply to a 2020 peak and has remained above pre-2018 levels, but outputs are concentrated in a small number of journals and institutions, with no straightforward correspondence between topical volume and journal tier (Sinta 2–5). Citation impact is similarly skewed, clustering around a few practice-proximal studies (STEM-PBL/inquiry, e-modules/student worksheet, virtual laboratories). Co-authorships form seven clusters with a locally bounded, Jember-centred core–periphery pattern, while keyword mapping (13 clusters) highlights classroom-deployable interventions aimed at concept learning and higher-order scientific competencies within core physics topics and environmental contexts.

Practical implications follow directly from this study. First, researchers and academics should broaden inter-cluster and inter-institutional collaboration through multi-site (≥3 schools/regions) and, where feasible, longitudinal designs to strengthen generalizability and network cohesion. Second, authors and institutions are encouraged to commit to open materials, data or code to enhance transparency, reuse, and cumulative knowledge building. Third, teachers and school leaders should prioritize proven practice-proximal implementations (STEM-PBL/inquiry, e-modules, student worksheet, virtual labs) with standardized assessments of scientific literacy and critical thinking embedded in design-based research cycles. Fourth, policy makers and funders should support thematic, multi-province consortia, including under-represented domains such as electricity, magnetism, waves, optics, and computational/data literacy and adopt normalized impact metrics alongside implementation indicators

to evaluate scale and durability of effects. Taken together, the field is growing but unevenly distributed across outlets, institutions, authors, and themes. Expanding collaborative networks, raising methodological standards, and diversifying content domains constitute the most leverageable steps to strengthen scientific quality and broaden the educational impact of STEM research in physics education.

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