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Bibliometric Analysis of Reflective Practices in Physics Learning: Trends, Challenges, and Future Directions

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ABSTRACT

Objective: *This study aims to provide a comprehensive bibliometric analysis of reflective practices in physics education, identifying global trends, research gaps, and future directions. The focus is to map the development of reflective practices as a key 21st-century skill in physics learning and to highlight their role in strengthening conceptual understanding, metacognitive awareness, and student autonomy.* ***Method:*** *A bibliometric research design was employed using the Scopus database as the primary source. Data were collected from 1995 to 2025, filtered according to inclusion criteria, and analyzed using performance analysis and science-mapping techniques. Tools such as VOSviewer and Biblioshiny were used to visualize publication trends, collaboration networks, and keyword co-occurrences, ensuring validity and replicability.* ***Results:*** *The findings indicate significant growth in publications since 2015, peaking in 2024. Conference proceedings dominate research outputs, while reputable journals play a more minor yet influential role. The United States, China, and Indonesia emerge as leading contributors, with varying levels of international collaboration. Keyword analysis highlights "students," "reflection," and "deep learning" as dominant themes, reflecting a shift toward student-centred and technology-enhanced pedagogies.* ***Novelty:*** *Unlike prior studies that focused mainly on classroom implementation or teacher training, this research systematically maps reflective practices in physics education through bibliometric analysis. It provides the first global overview of research trends and offers strategic recommendations for advancing reflective practices as a transformative approach in 21st-century physics education.*

INTRODUCTION

In the 21st century, physics education is expected not only to equip students with mastery of formulas and problem-solving routines but also to foster critical, reflective, and adaptive thinking skills (Alanazi et al., 2025; Heldalia et al., 2025; Musengimana et al., 2025; Susanti et al., 2021; Worku et al., 2025). Reflection in learning is considered one of the key competencies that helps students make sense of their learning experiences, identify misconceptions, and strengthen metacognitive abilities. This expectation aligns with the modern education paradigm, which emphasizes learning how to learn and shaping lifelong learners (Baker et al., 2021; Mukherjee et al., 2024; Hussein, 2025). Consequently, reflective practices in physics classrooms are envisioned as a bridge to deepen conceptual understanding while cultivating awareness of scientific ways of thinking.

In practice, however, physics learning remains largely dominated by a cognitive orientation, focusing primarily on memorizing formulas and repetitive exercises (Schöllhorn et al., 2022; Sengul, 2024; Li et al., 2023; Hussein, 2025). Teachers often rely on lectures and problem drills, leaving little room for students to reflect on their learning. Recent studies also indicate that although reflective practices have been widely discussed in fields such as general education, teacher training, and nursing, their application in physics education remains relatively scarce (Brang et al., 2025; P.-W. Chiu et al., 2025; Pirker & Dengel, 2021; Tan, 2025; Wei et al., 2025). This reality reveals an apparent mismatch between the aspirations for reflective learning in science education and the actual classroom practices in physics.

The gap becomes more evident when compared with the extensive body of research on reflection in other domains, such as literacy education, cooperative learning, or teacher professional development. (Banda & Nzabahimana, 2021; Dessie et al., 2023; Nicholus et al., 2023; Nasution & Setyaningrum, 2024). Moreover, there is a lack of comprehensive knowledge mapping that would allow researchers and practitioners to understand global trends, methodological challenges, and future directions in reflective practices for physics learning (Judijanto, 2021; Jin & Jian, 2024; Karampelas, 2024; Nurjanah et al., 2025). This absence of bibliometric evidence constitutes the central research gap this study seeks to address.

Several studies have examined the importance of reflection in physics education through practical strategies such as learning journals, digital portfolios, and project-based learning that incorporate self-reflection. Some research has also highlighted the significance of reflective practice in preparing preservice physics teachers to design more meaningful lessons (Menon & Azam, 2021; Kılıç, 2022). These efforts illustrate growing recognition of reflection as a valuable component in physics learning, though such studies are often localized and limited in scale.

The strength of earlier studies lies in their consistent findings that reflective practices provide tangible benefits, including enhanced problem-solving skills, stronger self-regulated learning, and improved critical thinking abilities (Sanjaya et al., 2024; Anders & Speltz, 2025; Kavashev, 2025; Yaşar, 2025). These studies collectively reinforce the notion that reflection is not a supplementary activity but rather an integral part of the learning process. In physics classrooms, reflection has shown potential to help students detect conceptual errors and reconstruct their understanding more effectively through active engagement with their own thought processes.

Nevertheless, prior research suffers from several limitations. First, studies on reflection in physics education are fragmented and lack integration into a holistic framework (Miseliunaite et al., 2022). Second, most existing research is limited to case studies or small-scale interventions, which cannot capture the global research landscape (Beets et al., 2021). Third, there has been no bibliometric analysis that maps publication trends, author collaborations, dominant keywords, and future challenges in reflective practices within physics education (Bitzenbauer, 2021; Ahmed et al., 2023). These shortcomings point to the necessity of a bibliometric approach that can provide a systematic overview and identify knowledge gaps.

Against this background, the present study aims to conduct a bibliometric analysis of scholarly publications on reflective practices in physics education. Specifically, it seeks to analyze research trends, prolific authors and institutions, citation patterns, dominant keywords, and collaborative networks. Beyond descriptive mapping, this study also intends to identify the challenges encountered in applying reflective practices and the opportunities for future development. By doing so, it provides educators, researchers, and policymakers with a clearer understanding of the current state and potential of reflective learning in physics education.

The novelty of this study lies in employing bibliometric analysis to systematically map reflective practices in physics education —an approach that, to the best of our knowledge, has not yet been undertaken. While earlier research has primarily emphasized classroom implementation or teacher training, this study fills a crucial gap by offering a global perspective on reflective practices in physics learning. The findings not only present the state of the art but also provide strategic recommendations for advancing future research. Consequently, this study contributes both theoretically and practically to the development of reflection as an innovative and transformative approach in 21st-century physics education.

RESEARCH METHOD

This study employed a bibliometric research design to systematically map and analyze scholarly publications on reflective practices in physics education (Chiu et al., 2022; Fu et al., 2022; Jian et al., 2023; Korkmaz & Toraman, 2024). Bibliometric analysis was chosen because it enables the identification of publication trends, research networks, influential authors, thematic clusters, and knowledge gaps in a transparent and reproducible manner (Casadei et al., 2023; Donthu et al., 2021; Kumar, 2025; Pessin et al., 2022). The overall workflow comprised data collection, screening, extraction, analysis, and visualization.

The Copus database was selected as the primary source of data due to its comprehensive coverage of peer-reviewed literature in science and education. The search query was constructed using Boolean operators to capture relevant publications, with keywords including: "reflective practice" OR "reflection" OR "reflective learning" AND "physics education" OR "physics learning" AND "bibliometric" OR "scientometric" OR "systematic review." The search was conducted in September 2025, with no geographical restriction, and covered the period 1995–2025.

Table 1. Document screening process

Stage	Description	Number of Documents
Initial search results	All documents retrieved from Scopus	1,140
Time filter	Publications between 1995 and 2025	1,121
Subject area filter	Limited to relevant subject areas	1,092
Document type filter	Articles, conference papers, and reviews	961
Language filter	English only	882

The inclusion criteria for this study were publications written in English, peer-reviewed journal articles, conference papers, or reviews, studies explicitly related to reflection or reflective practices in physics education or closely related STEM education contexts, and documents indexed in Scopus. Conversely, the exclusion criteria comprised non-English documents, editorials, book chapters, or other non-peer-reviewed material, as well as studies that were not directly related to reflection in the context of learning or teaching physics (Guo et al., 2024; Shadiev et al., 2024; Chee et al., 2025).

The final dataset was exported in CSV format for further analysis, with duplicate records carefully removed. Bibliographic information, such as title, authors, keywords, abstract, year of publication, source title, and citations, was standardized, and rigorous data-cleaning procedures were used to ensure accuracy and consistency. Two complementary approaches were then applied: Performance Analysis, which examined publication output by year, most productive authors, institutions, countries, and highly cited documents; and Science Mapping, which explored the intellectual structure of the field through keyword co-occurrence, co-authorship networks, and citation analysis.

To enhance validity and reliability, the search strategy and inclusion criteria were transparently reported, enabling replication (Lakens et al., 2016; Shaheen et al., 2023; Rethlefsen et al., 2024). As this study relied exclusively on secondary data retrieved from publicly available databases, no ethical approval was required. All sources were cited correctly, and the analysis followed academic integrity and responsible research practices (Dobre et al., 2025; Khanna et al., 2025; Taques, 2025).

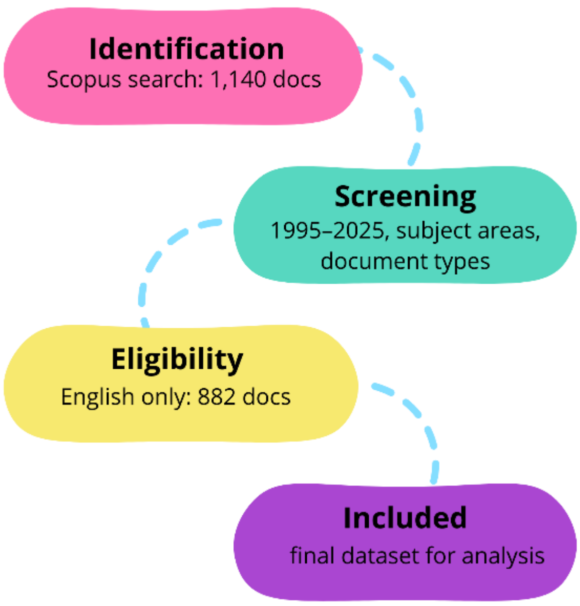

Figure 1. Flowchart of data collection and screening

RESULTS AND DISCUSSION

Results

Figure 2 presents the main bibliometric information for the dataset, including publication output, author collaboration patterns, and document types over the period 1995–2025.

Figure 2. Main information

The data indicate steady growth in publications, with an annual rate of 9.85%, dominated by journal articles (499) and conference papers (381). The average of 3.36 co-authors per document and 15.68% international collaboration reflect a moderately collaborative research landscape. At the same time, the relatively low number of single-authored works highlights the increasing trend toward joint research in this field.

Figure 3 shows the annual distribution of publications on reflective practices in physics education from 1995 to 2025, illustrating the evolution of research interest.

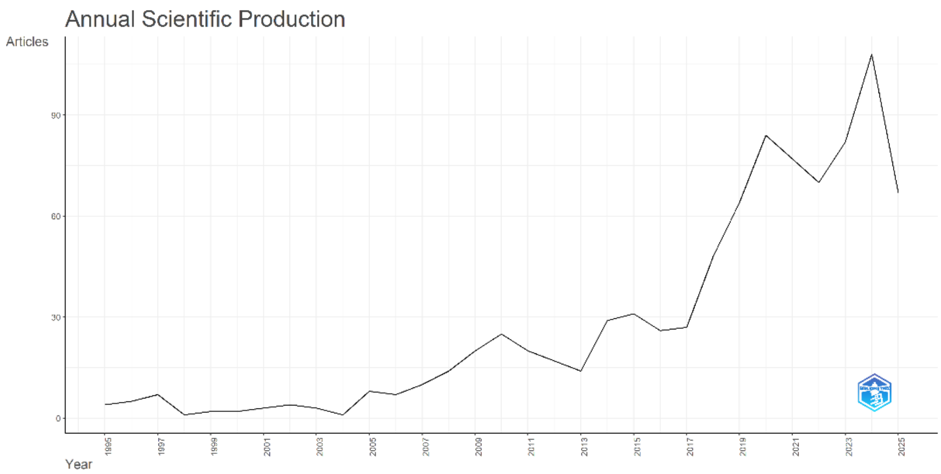

Figure 3. Annual scientific production

The data reveal a relatively modest number of publications in the early years, with fewer than 10 articles per year before 2007. A gradual increase is observed starting in 2008, followed by a sharp rise after 2015. The peak occurred in 2024 with 108 publications, indicating growing scholarly attention toward reflective practices in physics learning. Although 2025 records a slight decline (67 articles), this may be due to incomplete indexing of publications for the current year rather than an actual reduction in research activity.

Figure 4 summarises metrics over the 1995–2025 period, including the mean number of citations per article, the mean citations per year, and the number of citable years for each publication period.

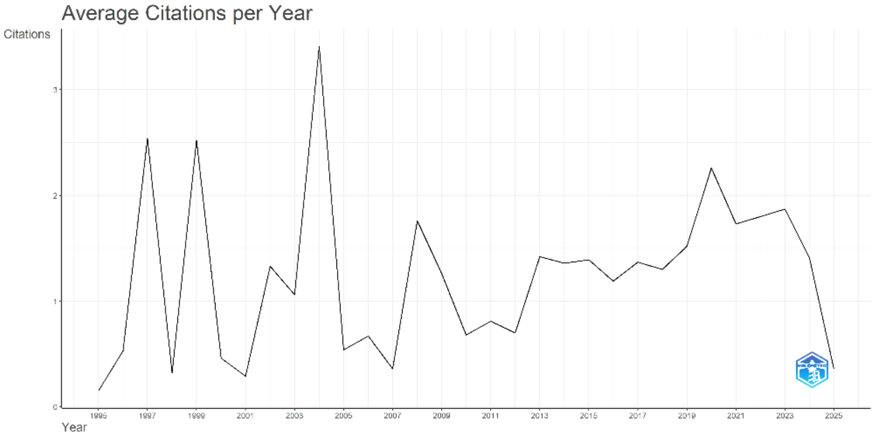

Figure 4. Average citations per year

The results highlight that older publications, particularly those from 1997 (73.71 citations per article) and 2004 (75.00 citations per article), achieved the highest citation averages due to their longer citable years and foundational influence. In contrast, more recent publications, while numerous, show lower average citations (e.g., 2.82 in 2024 and 0.36 in 2025), reflecting the typical citation lag for newly published works. This pattern suggests that earlier studies have established a strong scholarly base, whereas recent outputs are still accruing academic impact (Lehr et al., 2024; Lee & Chi, 2025; Moon et al., 2025).

Figure 5 lists the top publication sources contributing to research on reflective practices in physics education, highlighting the most productive journals and conference proceedings.

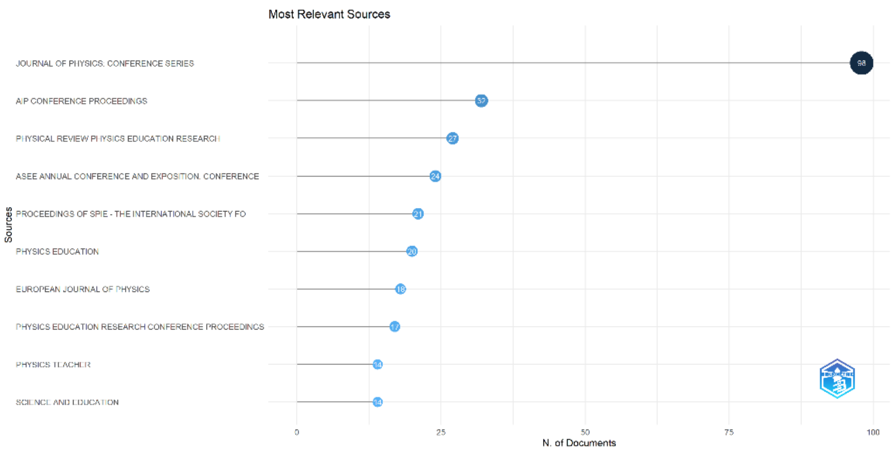

Figure 5. Most relevant sources

The Journal of Physics: Conference Series emerges as the leading source with 98 articles, followed by the AIP Conference Proceedings (32) and Physical Review Physics Education Research (27). The dominance of conference-based outlets suggests that much of the discourse on reflective practices is disseminated at professional meetings and symposia. At the same time, reputable journals such as Physics Education, European Journal of Physics, and Science and Education offer more sustained theoretical and empirical contributions. This distribution reflects both the growing academic interest and the field's dual nature, balancing practice-oriented discussions at conferences with peer-reviewed journal publications for broader scientific visibility.

Figure 6 categorizes publication sources according to Bradford's Law, dividing them into three zones based on their contribution frequency. This distribution helps to identify the core journals and proceedings that serve as the primary outlets for research on reflective practices in physics education.

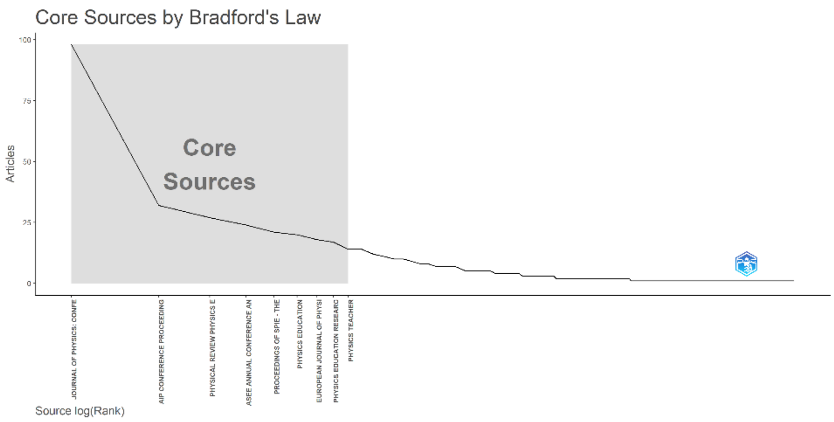

Figure 6. Core sources by Bradford's law

The analysis shows that Zone 1, representing the core sources, is dominated by high-output outlets, including Journal of Physics: Conference Series (98 articles), AIP Conference Proceedings (32), Physical Review Physics Education Research (27), and Physics Education (20). These sources form the field's central knowledge base. Zone 2 includes influential but moderately productive journals, such as the European Journal of Physics, Journal of Research in Science Teaching, and Computers & Education, while Zone 3 consists of a wide range of peripheral journals that contribute only 1 or 2 articles each. This distribution confirms the Bradford pattern: a small number of sources account for a disproportionately large share of publications, underscoring the importance of the core journals and proceedings in shaping the discourse on reflective practices in physics learning.

Figure 7 presents the local impact of publication sources, measured through bibliometric indicators such as the h-index, g-index, m-index, total citations, and number of publications. This analysis provides insights into the relative influence and citation performance of journals and conference proceedings within the field.

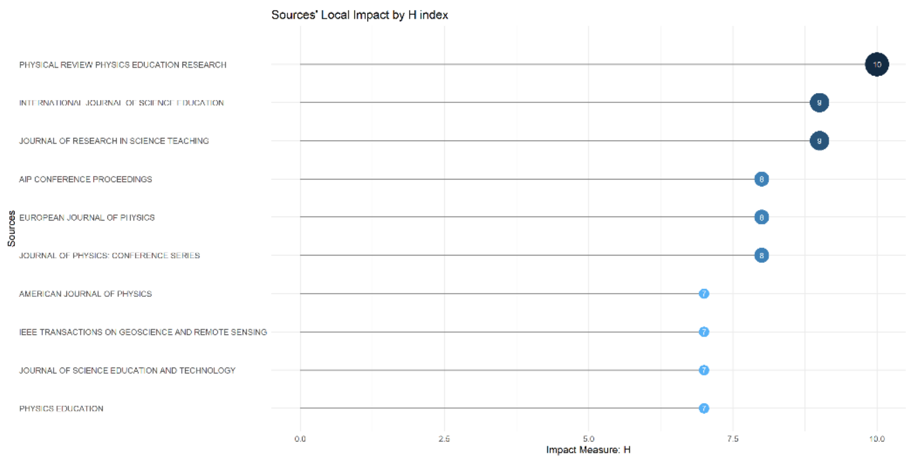

Figure 7. Sources' local impact

The results reveal that Physical Review Physics Education Research (h-index = 10) leads as a core journal with consistent impact despite its relatively recent start in 2016, followed closely by International Journal of Science Education and Journal of Research in Science Teaching, which show strong long-term influence due to their early entry into the field. High citation counts are also noted for interdisciplinary outlets such as IEEE Transactions on Geoscience and Remote Sensing and Science and Education, reflecting the cross-disciplinary relevance of reflective practices in physics education. In contrast, conference proceedings such as Journal of Physics: Conference Series and AIP Conference Proceedings demonstrate wide dissemination with large publication counts but lower citation averages, emphasizing their role in early-stage knowledge sharing rather than long-term citation impact. Overall, the distribution of local impact underscores the complementary roles of leading journals, interdisciplinary outlets, and conference proceedings in shaping the research landscape.

Figure 8 illustrates the longitudinal production trends of the most prominent publication sources in physics education research from 1995 to 2025. The table highlights how journals and conference proceedings have evolved in their output, indicating shifts in dissemination patterns and the growing prominence of specific outlets.

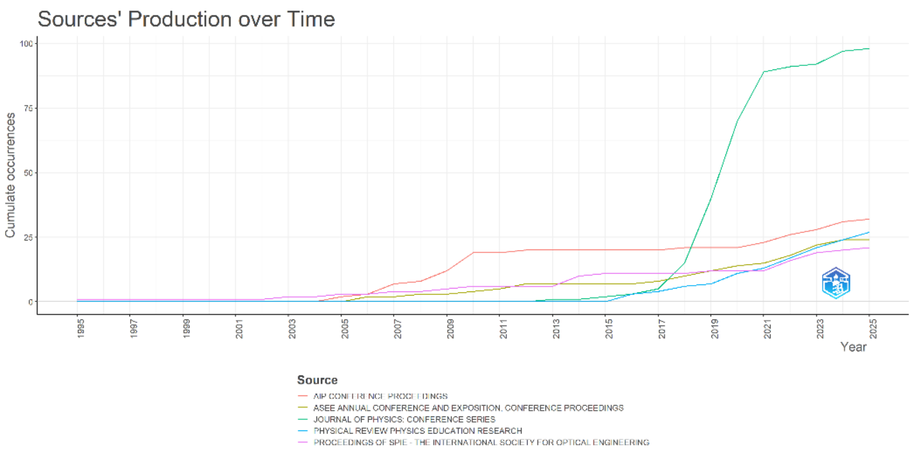

Figure 8. Sources' production over time

The results show that Journal of Physics: Conference Series has experienced a sharp, sustained increase in publications since 2013, becoming the dominant outlet by 2025, with 98 articles. Similarly, Physical Review Physics Education Research, established in 2016, has demonstrated consistent annual growth, reaching 27 publications by 2025. In contrast, AIP Conference Proceedings maintained a stable output of around 20–32 articles annually since the mid-2000s, while ASEE Annual Conference and Exposition Proceedings grew more gradually, reaching 24 contributions in recent years. Meanwhile, Proceedings of SPIE maintained steady but modest production since the mid-1990s. These trends suggest that while specializations are gaining influence and volume, conference proceedings continue to play a crucial role in disseminating knowledge, especially in the early diffusion of emerging research topics.

Figure 9 presents the most relevant authors in physics education research, ranked by the number of publications and adjusted for co-authorship using fractional counting. This metric allows a more balanced assessment of each researcher's contribution.

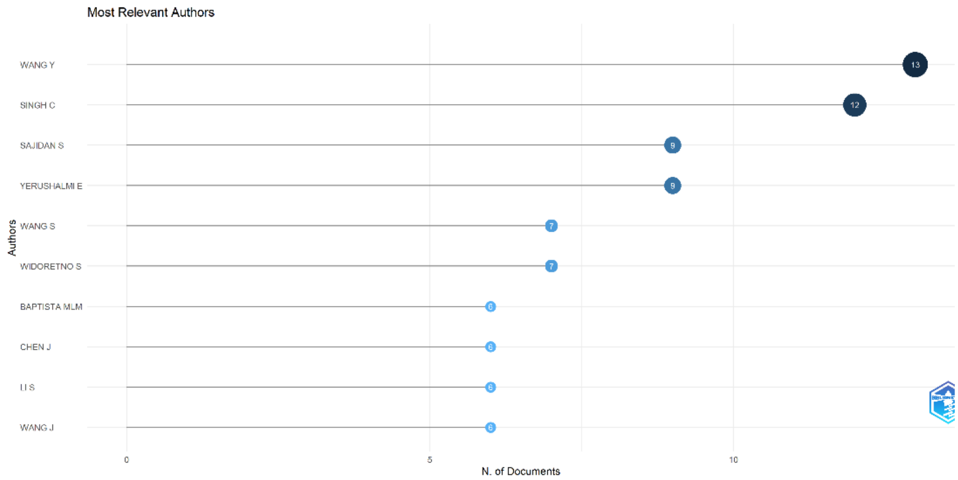

Figure 9. Most relevant authors

The data reveal that Wang Y is the most productive author with 13 publications, although his fractiofractionalizedbution (2.78) indicates frequent collaboration. Singh C follows with 12 publications and a higher fractionalized score (4.58), suggesting more substantial individual contributions per article. Similarly, Yerushalmi E and Sajidan S stand out with nine publications each, with fractionalized values of 2.83 and 1.90, respectively. Other active contributors include Wang S, Widoretno S, Chen J, Li S, and Wang J, whose consistent presence indicates a strong collaborative network across regions. These results highlight the coexistence of prolific contributors who rely heavily on collaboration and those whose impact is reinforced by stronger individual authorship roles.

Figure 10 illustrates the production of the most relevant authors over time, showing publication frequency, total citations (TC), and citations per year (TCpY). This information highlights both the temporal distribution of authors' outputs and the relative impact of their work.

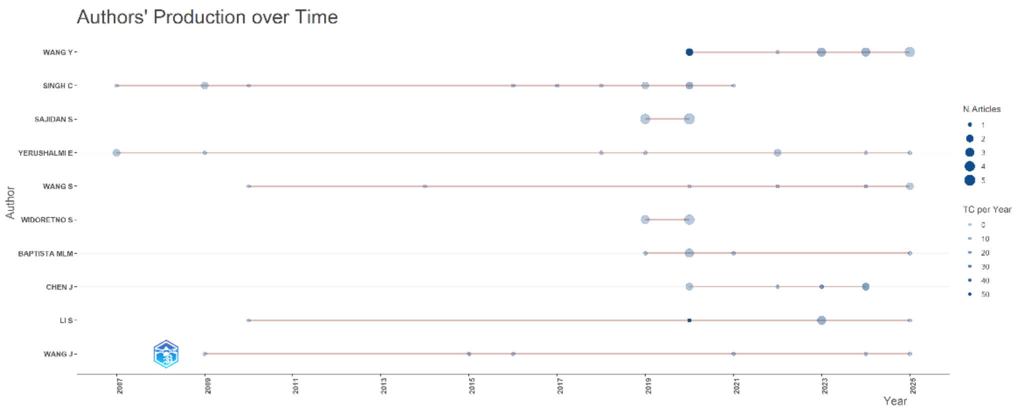

Figure 10. Authors' production over time

The data demonstrate heterogeneous publication patterns among the top authors. For example, Singh C shows consistent contributions from 2007 to 2021, with a notable peak in 2020 (2 publications, 62 citations, TCpY = 10.33). Li S made a remarkable impact in 2020 with a single paper gathering 303 citations (TCpY = 50.50), indicating high influence despite fewer publications. Similarly, Wang Y exhibited firm productivity between 2020 and 2024, with the highest citation impact in 2020 (TCpY = 52.50). In contrast, authors such as Widoretno S and Sajidan S are more visible after 2019 but with lower citation counts, suggesting an emerging role in the field rather than an established influence. Yerushalmi E has made a long-term contribution since 2007, though with a moderate impact. Overall, the trends reveal that certain authors play a pivotal role at specific periods with highly cited works. In contrast, others contribute through steady but less-cited outputs, reflecting both the diversity of research foci and the collaborative nature of physics education research.

Figure 11 presents the distribution of author productivity analysed using Lotka's Law. It compares the observed number and proportion of authors by their publication counts with the theoretical values expected under Lotka's inverse-square law of scientific productivity.

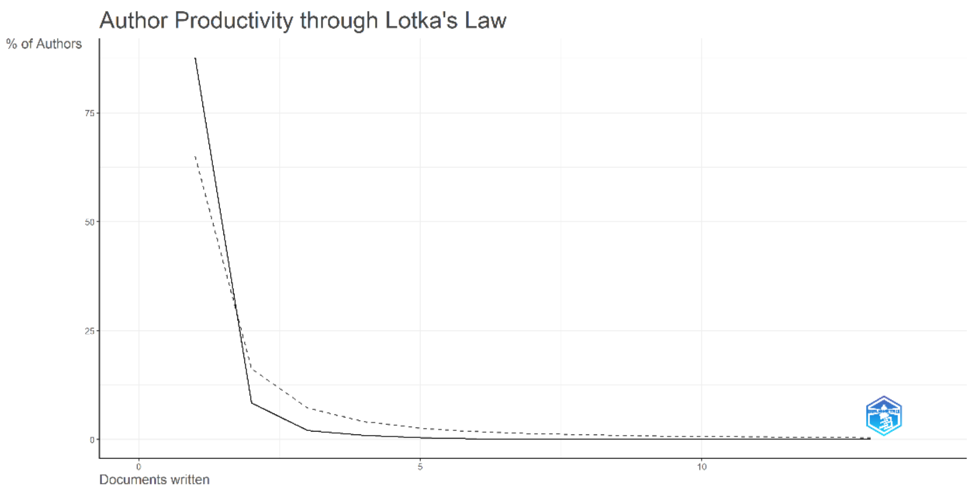

Figure 11. Author productivity through Lotka's law

The findings reveal that the majority of authors (87.8%) contributed only a single publication, while smaller proportions produced multiple works (8.4% with two, 2.1% with three, and less than 1% with higher counts). This distribution closely aligns with the theoretical expectations of Lotka's Law, which predicts that only a few authors are highly prolific, whereas most contribute minimally. The slight deviations observed at higher publication counts (e.g., authors with 12 or 13 documents) indicate the presence of exceptional contributors who maintain sustained productivity over time. Overall, the data confirm that the field of physics education research is characterised by a base of occasional contributors supported by a limited core of highly productive authors.

Figure 12 highlights the local impact of the most influential authors in physics education research, as measured by the h-index, g-index, and m-index, alongside their total citations (TC), number of publications (NP), and the year of their first contribution (PY_start). These indicators provide insights into both the productivity and citation quality of each author's output.

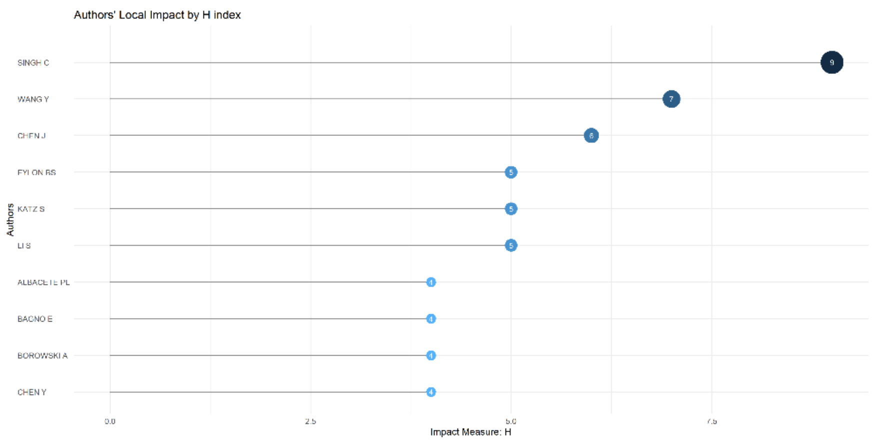

Figure 12. Authors' local impact

The results show that Singh C has the highest h-index (9) and has maintained consistent productivity since 2007, reflecting sustained output and long-term impact. Wang Y, though entering the field later (2020), demonstrates the strongest m-index (1.167) and a significant citation record (363 citations from 13 papers), indicating rapid and influential contributions. Chen J also exhibits a strong performance with balanced productivity (6 publications) and an m-index of 1.000, suggesting steady growth in impact over a short period. Meanwhile, Li S achieves a relatively high citation count (343) with fewer publications, highlighting the quality and influence of specific works. Authors such as Borowski A and Chen Y show promising recent trajectories, with high citation averages despite their later entry into the field. Collectively, these patterns suggest that while long-established figures like Singh C continue to shape the field, newer scholars such as Wang Y and Chen J are emerging as key drivers of current research influence.

Figure 13 presents the most relevant institutional affiliations contributing to physics education research, ranked by the number of published articles. This distribution highlights the global centres of research productivity in the field.

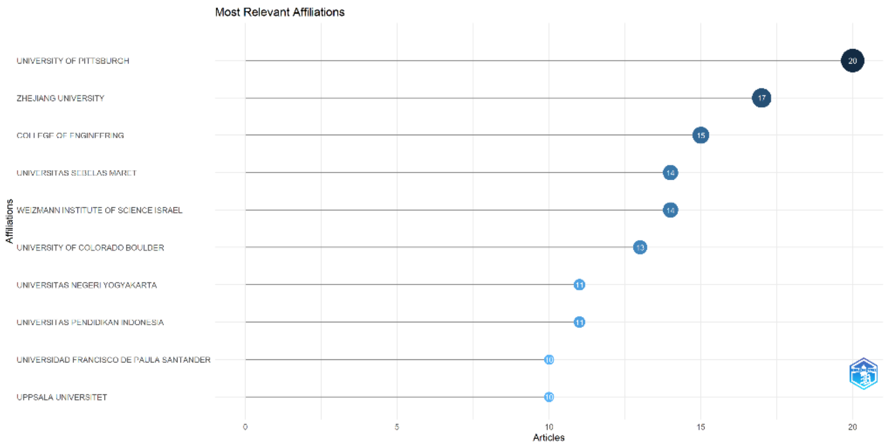

Figure 13. Most relevant affiliations

The data reveal that the University of Pittsburgh leads with 20 publications, followed closely by Zhejiang University (17 articles) and the College of Engineering (15 articles). Notably, Indonesian institutions such as Universitas Sebelas Maret (14), Universitas Negeri Yogyakarta (11), and Universitas Pendidikan Indonesia (11) demonstrate strong contributions, reflecting the growing visibility of Southeast Asian research in physics education. Meanwhile, well-established Western institutions such as the Weizmann Institute of Science (Israel), the University of Colorado Boulder (USA), and Uppsala Universitet (Sweden) also appear as significant contributors, underscoring the field's international and collaborative nature. The presence of both traditional research powerhouses and emerging universities suggests a diversified and expanding global network in physics education research.

Figure 14 outlines the temporal distribution of publications from the most relevant affiliations, showing how their contributions to physics education research have evolved over 1995-2025.

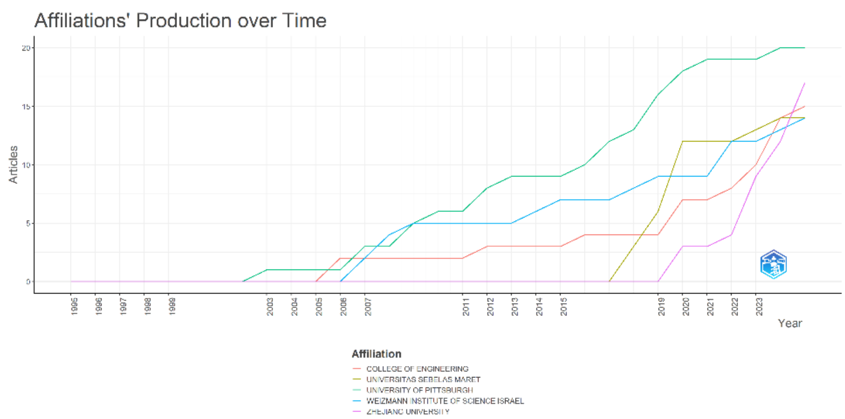

Figure 14. Affiliations' production over time

The results show distinct developmental patterns across institutions. The University of Pittsburgh demonstrates the longest and most consistent trajectory, beginning modestly in 2003 and reaching a stable output of 20 publications by 2024–2025, establishing itself as a global leader. The College of Engineering shows steady but slower growth, with gradual increases after 2006 and a significant rise in recent years, culminating in 15 publications by 2025. The Weizmann Institute of Science (Israel) follows a similar pattern, starting in 2007 and gradually expanding to 14 publications by 2025. By contrast, Asian institutions such as Universitas Sebelas Maret (Indonesia) and Zhejiang University (China) exhibit more recent but rapid growth. Universitas Sebelas Maret entered the field in 2018 and quickly reached 14 publications by 2025, while Zhejiang University began contributing in 2020 and already leads with 17 publications by 2025. These trajectories highlight both the historical dominance of Western institutions and the emerging prominence of Asian universities, pointing to a diversification of global research leadership in physics education.

Figure 15 reports the distribution of corresponding authors by country, including the number of articles, percentage share, and collaboration type measured through single-country publications (SCP) and multiple-country publications (MCP). The MCP percentage provides an indicator of the extent of international collaboration.

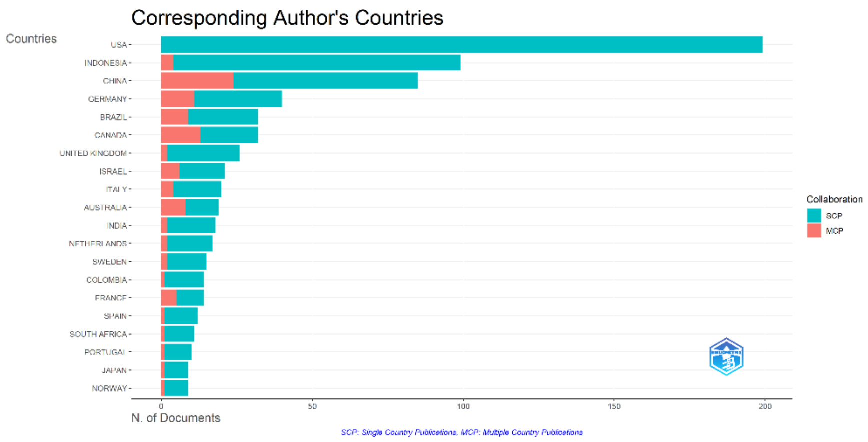

Figure 15. Corresponding author's countries

The results show that the USA dominates with 199 publications (22.6%), all of which are single-country outputs, reflecting firm domestic productivity but limited international collaboration. Indonesia ranks second with 99 articles (11.3%), of which only 4.0% involve international co-authorship, suggesting a growing but still nationally centred research base. By contrast, China (85 articles, 28.2% MCP) and Germany (40 articles, 27.5% MCP) display more internationally collaborative profiles. Smaller but influential contributors such as Canada (40.6% MCP), Australia (42.1% MCP), and Hong Kong (71.4% MCP) highlight regions where international networking is central to research visibility. In Europe, Italy, France, the Netherlands, Sweden, and the UK contribute modestly in volume but maintain active collaborations. Interestingly, countries such as Austria, Algeria, and Estonia show 100% MCP, indicating their publications in this field are entirely produced through international partnerships. Overall, the data confirm a dual structure: large-volume producers such as the USA and Indonesia emphasise work. At the same time, smaller and emerging contributors rely heavily on international collaboration to strengthen their scientific impact.

Figure 16 presents the top 10 countries in physics education research, ranked by the frequency of published documents.

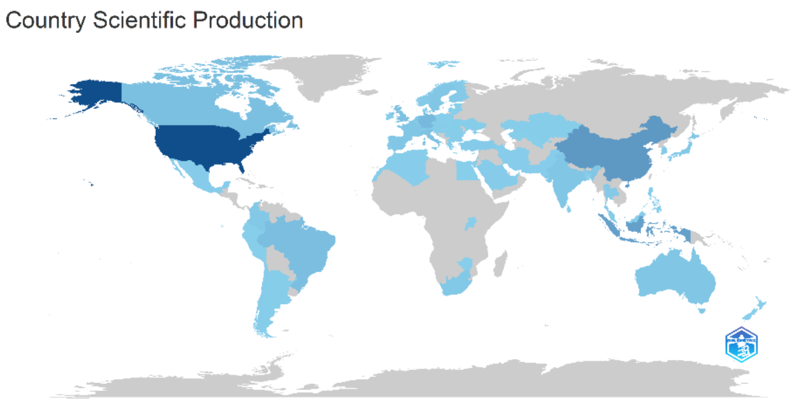

Figure 16. Countries' scientific production

The findings confirm that the USA leads the field with 505 publications, far surpassing all other countries and underscoring its central role in shaping global research directions. China (200) and Indonesia (171) emerge as strong contributors, reflecting the growing prominence of Asian research communities over the past few years. European nations such as Germany (79), the UK (48), Italy (45), the Netherlands (33), and Sweden (31) demonstrate steady contributions, indicating established but regionally distributed efforts. Meanwhile, countries in the Global South, particularly Brazil (58), are playing an increasingly significant role, especially in advancing education-related research in Latin America. Collectively, the distribution illustrates a concentration of output in North America and Asia, balanced by emerging voices from Europe and South America, suggesting a more diversified global landscape of physics education research.

Figure 17 displays the longitudinal trends of scientific production from the top contributing countries between 1995 and 2025, illustrating both early leadership and the emergence of new research hubs in physics education.

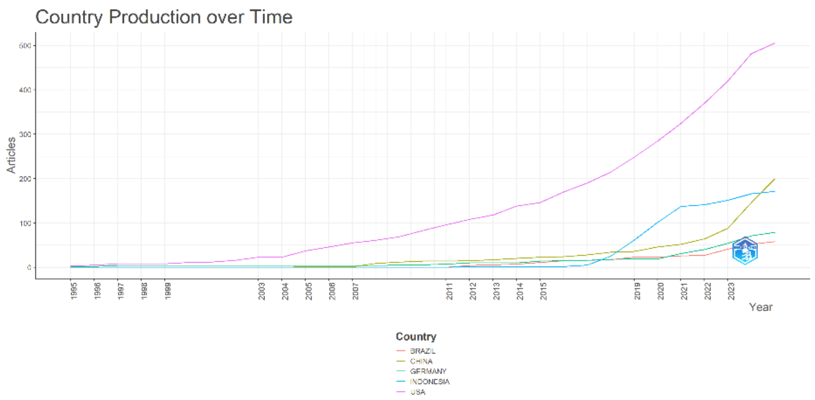

Figure 17. Countries' production over time

The USA consistently leads the field, showing steady growth from 3 publications in 1995 to 505 in 2025, maintaining its role as the global research hub. Germany also demonstrates a gradual but continuous rise, particularly after 2015, reaching 79 publications in 2025. By contrast, China and Indonesia illustrate late but rapid acceleration. China's contributions, which were negligible until 2005, expanded significantly in the last decade, peaking at 200 publications in 2025. Similarly, Indonesia's growth has been especially striking: from virtually no publications before 2012, it experienced a surge after 2018, reaching 171 publications by 2025 and establishing itself as a key regional leader in Southeast Asia. Brazil shows a comparable emerging trend, beginning only in 2012 but steadily growing to 58 publications in 2025, consolidating its role in Latin America. Collectively, these trajectories suggest a shift from traditional Western dominance toward a more globally distributed research landscape, with Asia and South America playing increasingly important roles in advancing physics education research.

Figure 18 presents the most cited countries in physics education research, listing their total citations (TC) and average citations per article, which provide a measure of both overall influence and per-publication impact.

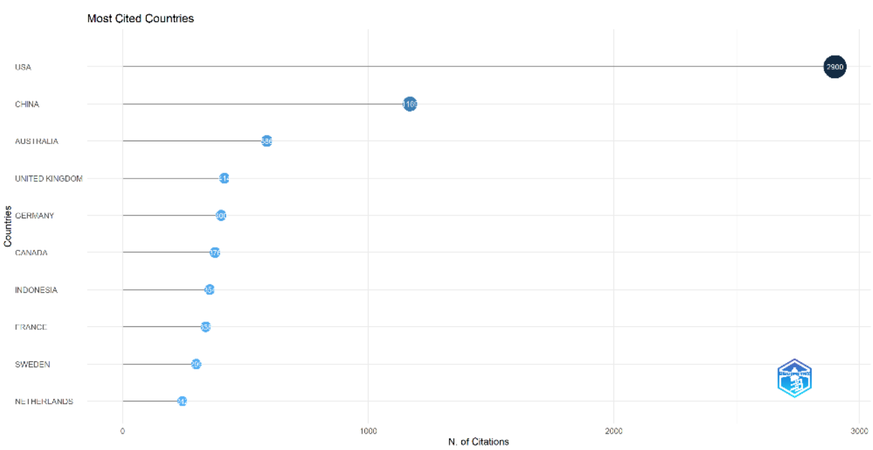

Figure 18. Most cited countries

The USA leads with the highest citation volume (2,900 citations, 14.6 per article), confirming its long-standing dominance in the field. China follows with 1,169 citations (13.8 per article), reflecting both high productivity and growing influence. Interestingly, several countries demonstrate disproportionately high average citations per article, signalling substantial impact despite smaller outputs. For example, Australia (30.8), Finland (25.7), France (24.1), Estonia (22.0), and Sweden (19.9) each surpass the USA in citation density, suggesting that their contributions, though fewer in number, carry substantial scholarly weight. Emerging contributors such as Indonesia (354 citations, 3.6 per article) and Brazil (131 citations, 4.1 per article) show increasing visibility but comparatively lower citation rates, indicating room for growth in global impact. Exceptional cases like Lithuania (49 citations from a single article, 49.0 average) and Brunei (20.0 average) illustrate how individual landmark papers can significantly elevate a country's citation profile. Collectively, these patterns highlight a dual structure: established countries (USA, China, UK, Germany) ensure volume and continuity, while smaller but highly cited contributors (Australia, Finland, France, Sweden) amplify the field's intellectual influence through concentrated high-impact research.

Table 19 presents the most globally cited documents in physics education research and related fields, listing their total citations, yearly citation rates, and normalised scores to account for differences in publication age.

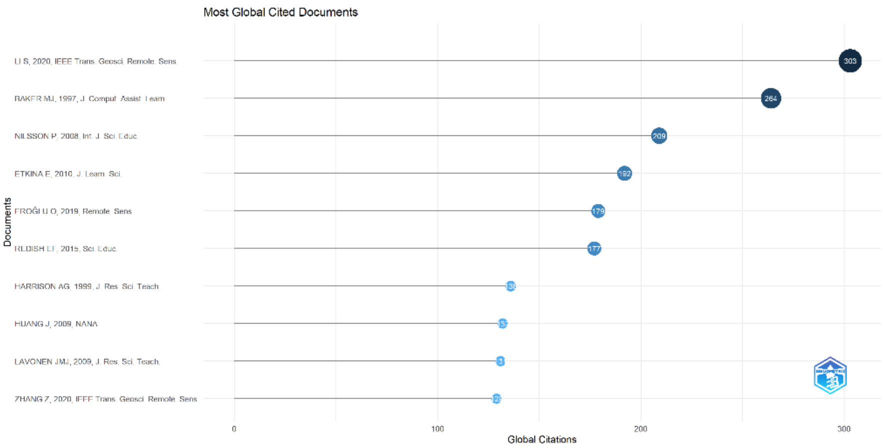

Figure 19. Most globally cited documents

The data show that the most influential article is Li S (2020) in IEEE Transactions on Geoscience and Remote Sensing (303 citations, 50.50 citations per year), reflecting both high volume and exceptional citation velocity. Baker MJ (1997) follows with 264 citations in Journal of Computer Assisted Learning, demonstrating long-term impact despite a lower annual citation rate (9.10). Similarly, Nilsson P (2008) and Etkina E (2010) represent highly impactful contributions to science education and the learning sciences, with strong normalised counts (6.60 and 17.78, respectively), signalling sustained scholarly relevance. Remote sensing applications are also evident, as seen in Eroğlu O. (2019), with an impressive annual citation rate (25.57) and a high normalised impact (16.80). Notably, Redish EF (2015) in Science Education exemplifies physics education's core influence, with 177 citations and a solid normalised of 11.60. Older landmark works such as Harrison AG (1999) retain foundational importance, while more recent entries, such as Zhang Z (2020), show rapid uptake with 21.50 citations per year. Overall, the table highlights a mix of enduring classics and fast-rising contemporary contributions, illustrating the dual structure of knowledge building in the field: long-lasting theoretical foundations complemented by recent high-impact innovations.

Figure 20 lists the most frequently occurring words in the dataset, reflecting the dominant themes and conceptual emphases in physics education research.

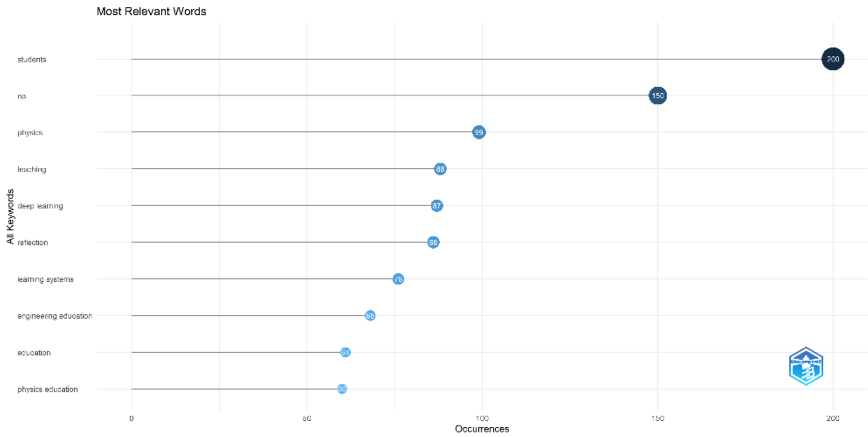

Figure 20. Most frequent words

The results indicate that the word "students" (200 occurrences) is the most frequent, underscoring the centrality of the learner in physics education research. Other high-frequency terms include "physics" (99), "teaching" (88), and "education" (61), which collectively highlight the focus on instructional contexts. Interestingly, more specialised areas such as "deep learning" (87), "reflection" (86), and "learning systems" (76) reveal an emphasis on pedagogical innovation and the integration of technology-enhanced learning environments. The presence of "engineering education" (68) and "physics education" (60) further emphasises the field's disciplinary orientation, bridging physics content knowledge with broader educational practices. Overall, the frequent words indicate strong alignment with student-centred learning, reflective teaching practices, and the growing role of advanced computational or digital systems in shaping physics and engineering education.

Figure 21 presents a word cloud of the most frequent terms in the dataset, with font size proportional to word frequency. This visualisation provides an overview of the dominant themes in physics education research.

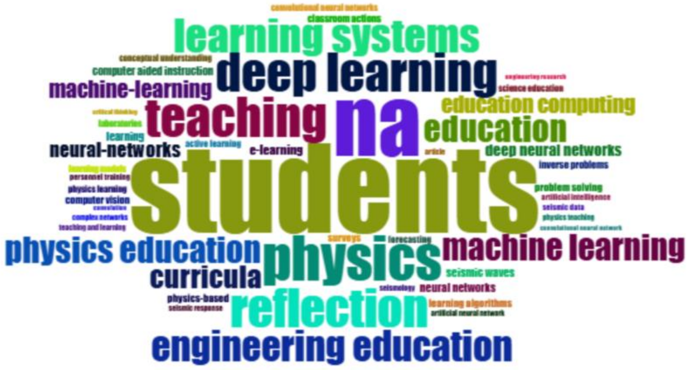

Figure 21. Wordcloud

The word cloud confirms the centrality of "students", which is the most frequent term (200 occurrences), reflecting the field's strong learner-centred orientation. Terms such as "physics", "teaching", and "education" reinforce the disciplinary and instructional context. At the same time, emerging emphases like "deep learning", "reflection", and "learning systems" suggest growing attention to advanced pedagogical strategies and technology integration. The prominence of “engineering education” and “physics education” highlights the disciplinary scope, bridging subject-matter knowledge with broader educational practices. Overall, the word cloud demonstrates how physics education research increasingly blends traditional teaching concerns with innovative, student-focused, and technology-supported approaches.

Figure 22 illustrates a treemap of the most frequent terms in the dataset, with each block proportional to its frequency. This representation enables a comparative view of thematic dominance in physics education research.

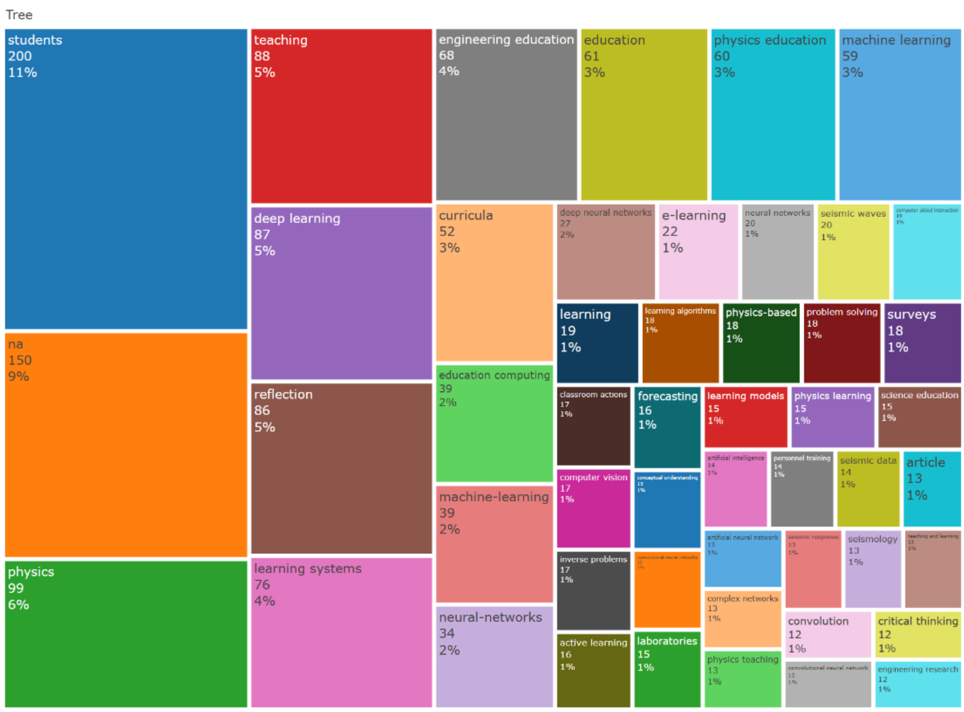

Figure 22. Treemap

The treemap highlights “students” as the most dominant theme (200 occurrences), occupying the largest block, followed by “na" (150), which likely reflects a text-mining artifact or placeholder term. Core disciplinary terms such as "physics" (99), "teaching" (88), and "education" (61) appear prominently, reinforcing the field's instructional and academic orientation. Notably, innovative pedagogical concepts, including "deep learning" (87), "reflection" (86), and "learning systems" (76), occupy substantial areas, indicating a strong research interest in technology-enhanced and reflective teaching approaches. The inclusion of "engineering education" (68) and "physics education" (60) underscores the disciplinary breadth, bridging physics, engineering, and educational practice. Overall, the treemap confirms the prominence of student-centred learning, pedagogical innovation, and the integration of disciplinary and technological perspectives in the field.

Figure 23 presents the temporal evolution of the most frequent terms in the dataset between 1995 and 2025. This longitudinal perspective reveals how the central concepts in physics education research have emerged, stabilised, and declined over the past three decades.

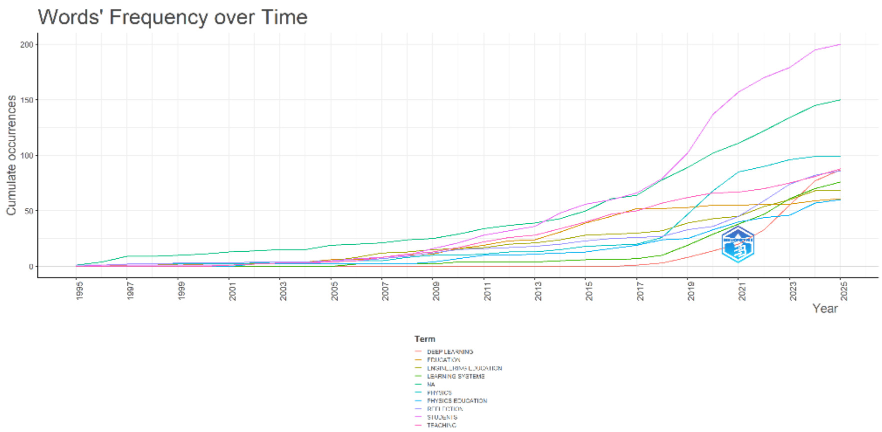

Figure 23. Words' frequency over time

The frequency analysis shows a gradual increase in the term "students", from negligible mentions in the mid-1990s to a peak of 200 occurrences in 2025. This confirms the centrality of student-focused research in physics education. Similarly, "teaching" and "education" display steady growth, especially after 2010, signifying the persistent emphasis on instructional strategies and educational frameworks. Interestingly, "deep learning", "reflection", and "learning systems" emerged later (post-2017) and demonstrated rapid acceleration, particularly after 2020. For example, deep learning rose from a single occurrence in 2017 to 87 in 2025, highlighting the growing influence of artificial intelligence and computational models in education. Reflection also became a prominent theme (from 15 in 2010 to 86 in 2025), indicating stronger attention to metacognition and self-regulated learning.

Meanwhile, disciplinary identifiers such as "physics" and "physics education" show consistent, though more gradual, increases, reflecting their foundational yet stable role in the field. Engineering education similarly rose in prominence, doubling its frequency between 2010 (16) and 2025 (68), suggesting an expanding interdisciplinary nexus between physics and engineering. Overall, the longitudinal trends underscore a shift from a foundational disciplinary focus toward student-centred, reflective, and technology-enhanced learning paradigms. The acceleration after 2018 is especially notable, coinciding with broader global trends in digitalisation and educational innovation.

Table 24 presents trending topics over time, based on first appearance (Q1), median year, and most recent concentration (Q3). This allows us to track the evolution of research foci, from earlier foundational studies toward contemporary technology-driven themes.

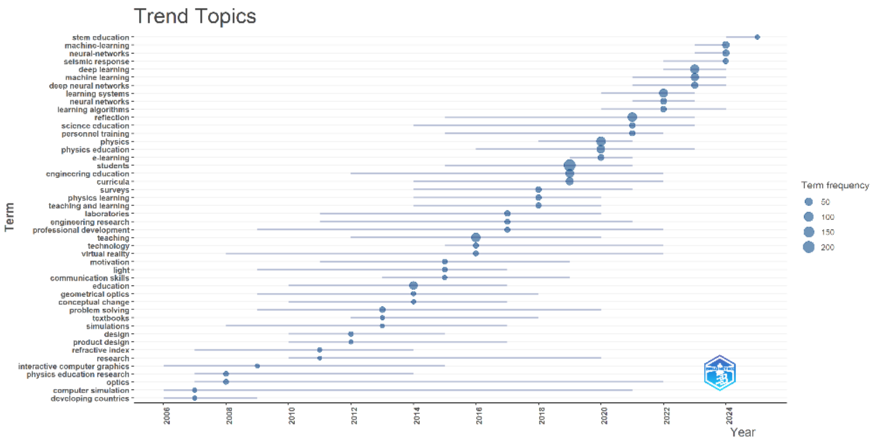

Figure 24. Trend topics

The data indicate a clear transition in research focus, moving from early interests in computer simulations, optics, and problem-solving toward more recent emphases on machine learning, deep learning, and STEM education. This shift reflects how physics and engineering education research has evolved from traditional conceptual frameworks to technology-driven, AI-oriented approaches, aligning with global trends in digital transformation and educational innovation.

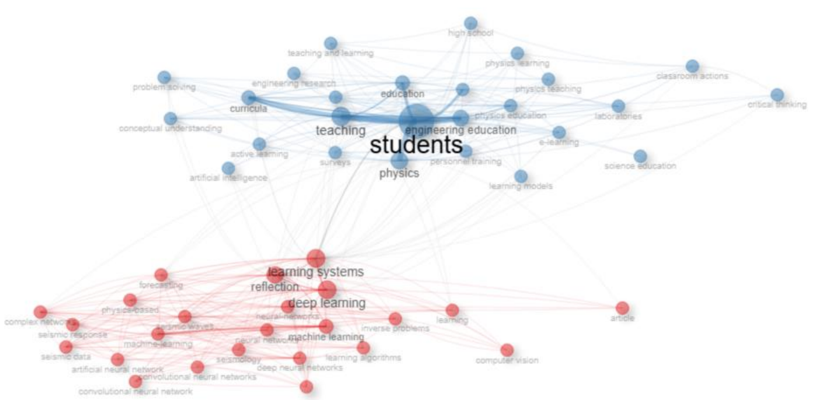

Figure 25. Co-occurrence network

The co-occurrence network highlights two main clusters: the first centres on advanced computational methods such as deep learning, machine learning, and neural networks, which demonstrate strong centrality and connectivity in recent physics-related research. The second cluster emphasises context, dominated by terms such as students, teaching, physics education, and curricula, reflecting the intense focus on pedagogy and instructional design. Together, these clusters reveal the field's dual orientation—advancing both cutting-edge computational approaches and innovative educational practices.

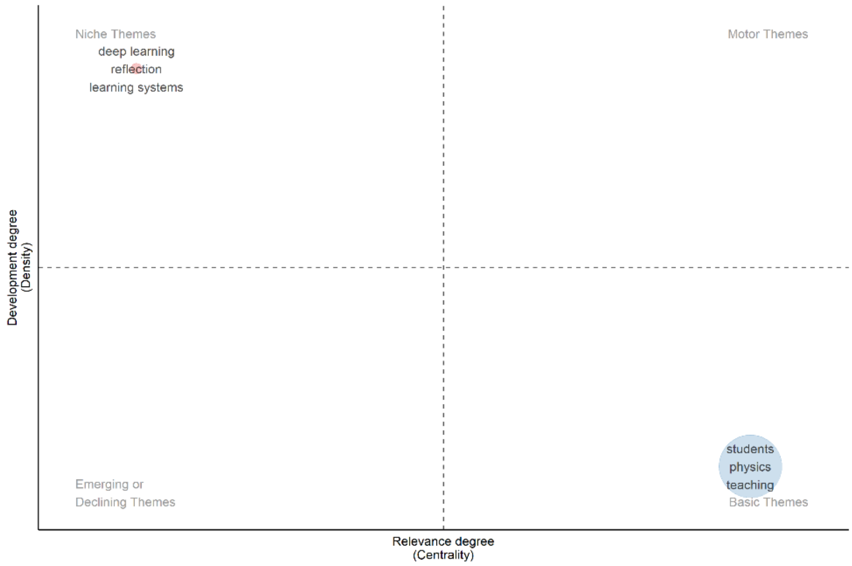

Figure 26. Thematic map

The thematic map highlights two main research clusters: the deep learning cluster, which encompasses advanced computational technology topics (such as machine learning, neural networks, convolutional neural networks, and their applications in seismic waves and remote sensing), and the students/education cluster, which emphasiemphasizesgical themes (including physics, teaching, curricula, problem solving, and STEM education). Together, these clusters demonstrate that research developments are progressing in parallel between technological innovation and educational innovation.

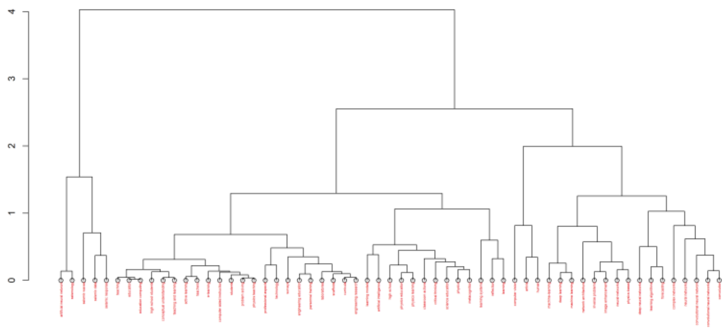

Figure 27. Factorial analysis topic dendrogram

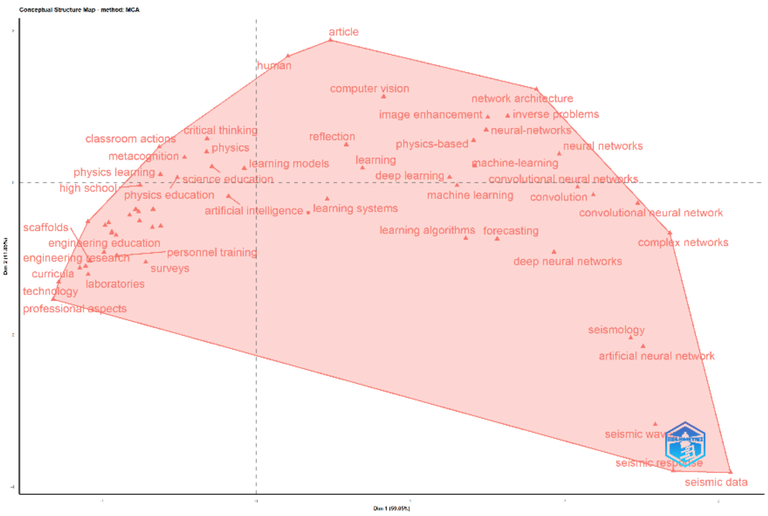

Figure 28. Factorial analysis word map

The results of the factorial analysis reveal two main poles: on one side, education-related themes such as students, teaching, curricula, engineering education, laboratories, conceptual understanding, and physics education appear with negative values on Dim1–Dim2, while on the other side, computational technology-oriented themes such as deep learning, machine learning, neural networks, convolutional neural networks, seismic data, and complex networks dominate with high positive values. This pattern indicates a clear separation between pedagogical and technological research orientations, yet both remain within a single overarching cluster that complements each other in advancing science and physics education.

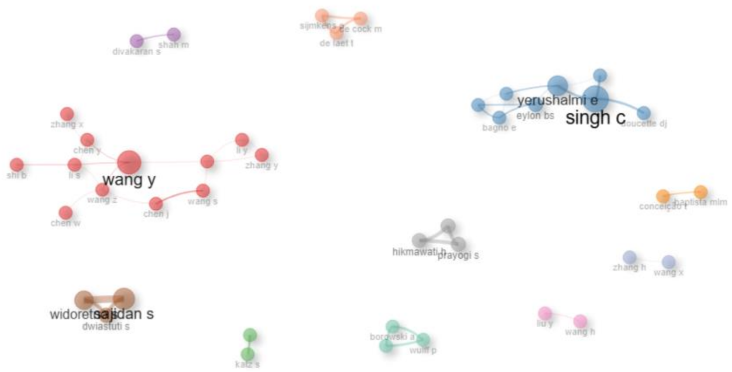

Figure 29. Collaboration network

The collaboration network analysis reveals several distinct clusters of researchers. The strongest cluster (Cluster 1) is dominated by Chinese authors, including Wang Y, Wang S, Li S, Chen J, Chen Y, Zhang Q, and Zhang Y, who exhibit high centrality values, indicating strong interconnectedness and influence in collaborative research. Another key cluster (Cluster 2) centres on Singh C, Yerushalmi E, Eylon BS, and Bagno E, and represents a strong tradition in physics education research collaborations. Smaller clusters (Clusters 3–11) involve authors such as Katz S, Albacete PL, Shah M, Divakaran S, Baptista MLM, Sajidan S, Widoretno S, and others, often working in more localised, specialised settings. Overall, the network reflects both large-scale collaborations among prolific Chinese scholars and regionally focused groups that contribute to global discourse in physics and education.

Discussion

The findings of this study reveal that reflective practices in physics education still face a significant gap between theory and classroom implementation. Theoretically, reflection is regarded as a key 21st-century skill that strengthens conceptual understanding, enhances metacognitive awareness, and fosters learner autonomy. However, the bibliometric analysis shows that previous studies have mostly emphasised aspects of memorisation, and the integration of reflection remains sporadic and has yet to become mainstream. This highlights that although reflection has been proven effective in other fields, such as literacy and teacher education, its application in physics learning remains poorly documented.

Furthermore, the bibliometric results indicate a notable increase in publications since 2015, peaking in 2024. This reflects the growing global attention toward reflection in physics education, although most outputs are still dominated by conference proceedings rather than reputable journals. The dominance of conference-based outlets such as the Journal of Physics: Conference Series shows that reflective discourse is often presented in practical academic forums but is not yet fully integrated into long-term scholarly discussions. This distribution suggests that research in this field is still developing and requires stronger representation in high-quality international journals to more firmly and sustainably establish its scientific contribution.

In terms of collaboration, the results demonstrate an expanding network of international researchers, with significant contributions from the United States, China, and Indonesia. Interestingly, while the U.S. leads in publication volume, its international collaboration rate remains relatively low. In contrast, countries with fewer minor publication counts, such as Germany, Canada, and Australia, display higher levels of global engagement. This points to two distinct patterns: highly productive countries with a domestic focus, and moderately productive countries that excel in international networking. Such dynamics underscore the importance of building more substantial global synergies to ensure that reflective practices in physics are not fragmented locally but have a broader international impact.

Keyword analysis reveals that terms such as "students," "teaching," "deep learning," and "reflection" have emerged as dominant themes, especially since 2018. This shift indicates a transition from purely conceptual focuses toward pedagogical innovation supported by technology and reflective approaches. The integration of deep learning and machine learning into physics education research signifies a transformation toward more digital, personalised data-driven teaching methods. However, reflection should not be seen merely as an add-on; instead, it should be integrated as an essential part of technology-based pedagogy. In other words, reflection must be aligned with technological innovations to ensure it retains its core function as a tool for developing students' self-awareness and critical thinking.

Finally, this study underscores that reflective practices in physics education represent a fertile area for further development. The bibliometric findings show that a knowledge base is beginning to take shape, though still limited in scope. The key challenge ahead is to connect fragmented small-scale empirical studies into a larger conceptual framework through collaborative research and reputable publications. In practice, this implies that physics educators intentionally design learning environments that encourage reflection, whether through learning journals, digital portfolios, or reflective discussions. Theoretically, this study provides a foundation for advancing future research. At the same time, it offers guidance for teachers, researchers, and policymakers on integrating reflection as an innovative and transformative approach in 21st-century physics education.

CONCLUSION

Fundamental Finding: This study confirms that reflective practices in physics education are increasingly acknowledged but still fragmented compared to other fields. The bibliometric results show significant growth of publications, especially after 2015, with a peak in 2024. However, the dominance of conference proceedings indicates that this area is still developing and needs stronger representation in high-quality journals. **Implication:** The findings suggest that reflection should be integrated as a central element in physics classrooms rather than as an optional activity. Teachers can adopt strategies such as reflective journals, digital portfolios, and structured discussions to enhance conceptual understanding and metacognition. For researchers, the trends emphasise the importance of producing rigorous studies and publishing in reputable journals to expand the global visibility of this topic. **Limitation:** This study is limited to Scopus-indexed data, potentially excluding relevant works from other databases. Moreover, bibliometric analysis maps publication and citation patterns but does not directly assess the pedagogical impact of reflective practices in real classrooms. **Future Research:** Future studies should go beyond bibliometric analysis by combining it with empirical investigations in diverse classroom contexts. Research could also explore the role of emerging technologies, such as AI and digital learning platforms, to strengthen reflective practices. Expanding international collaborations will be essential to transform reflection in physics education into a coherent and impactful global research area.

AUTHOR CONTRIBUTIONS

Hanan Zaki Alhusni contributed to the conceptual framework, methodology development, data collection, data analysis, and manuscript drafting. **Binar Kurnia Prahani** was responsible for research design, supervision, validation, and critical review of the manuscript. **Titin Sunarti** contributed to sourcing references, literature review, and supporting data interpretation. **Madlazim** provided oversight in project administration, validation, and final manuscript editing. All authors have reviewed and approved the final version of this submission.

CONFLICT OF INTEREST STATEMENT

The authors confirm that there are no conflicts of interest, either financial or personal, that may have influenced the content or outcome of this study.

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 preparation of this article. Specifically, AI-assisted software was used for language refinement, bibliographic organisation, and clarity improvement in academic writing. Reference management tools were also utilised to ensure proper citation formatting and consistency. All outputs generated with digital or AI assistance were carefully reviewed, verified, and revised by the authors to maintain academic rigour and ethical integrity. The final responsibility for the content of this manuscript rests solely with the authors.

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