



INTERNATIONAL JOURNAL OF
MODERN EDUCATION
(IJMOE)
www.ijmoe.com



TRENDS AND RESEARCH FRONTIERS IN PHYSICS
EDUCATION: A BIBLIOMETRIC ANALYSIS
FROM YEAR 2021-2025

Siti Hidayana Nassiri^{1*}, Muhammad Abd Hadi Bunyamin¹

¹ Faculty of Educational Sciences and Technology, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Malaysia

Email: sitihidayana5@graduate.utm.my; mabhadi@utm.my

* Corresponding Author

Article Info:

Article history:

Received date: 24.07.2025

Revised date: 10.08.2025

Accepted date: 10.09.2025

Published date: 15.10.2025

To cite this document:

Nassiri, S. H., & Bunyamin, M. A. H. (2025). Trends and Research Frontiers in Physics Education: A Bibliometric Analysis from Year 2021-2025. *International Journal of Modern Education*, 7 (27), 625-642.

DOI: 10.35631/IJMOE.727039

This work is licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)



Abstract:

This study explores global trends and research frontiers in physics education from 2021 to 2025 through a bibliometric analysis of 886 publications indexed in Scopus. Using Scopus Analyzer, descriptive statistics and growth patterns were examined, while OpenRefine ensured dataset consistency and VOSviewer facilitated network mapping of co-authorships, citations, and keyword co-occurrence. The findings reveal a steady increase in research output, peaking in 2024 with 200 publications, before a slight drop in 2025 due to indexing delays. The United States emerged as the largest contributor, followed by Indonesia, which demonstrates the growing visibility of Southeast Asian scholarship. Journal analysis highlights Physics Education as the dominant outlet, complemented by regional and interdisciplinary journals that reflect diverse contexts and themes. Keyword co-occurrence analysis identified seven clusters, underscoring research frontiers in technology integration (augmented/virtual reality, e-learning), affective and cognitive constructs (motivation, self-efficacy, critical thinking), STEM and curriculum reform, and traditional physics teaching practices. Co-authorship mapping revealed nine international collaboration clusters, with the United States, Germany, Indonesia, and China as central nodes, alongside smaller yet high-impact contributors such as Finland and the Netherlands. These results demonstrate a field that balances established pedagogical concerns with expanding frontiers shaped by technology and global collaboration. The study contributes to the body of knowledge by offering empirical insights into the specialization, diversification, and internationalization of physics education research, providing guidance for future investigations and policy development.

Keywords:

Physics Education, Teaching Approach, Secondary School, STEM Education, Technology Integration

Introduction

Physics education has undergone significant transformations over the past decades, driven by the need to adapt to evolving educational paradigms and technological advancements. The field, traditionally perceived as abstract and challenging, has seen a surge in research aimed at making it more accessible and engaging for students. This paper, seeks to explore the current trends and emerging frontiers in physics education research, providing a comprehensive overview of the field's evolution and identifying key areas for future investigation.

Recent studies have highlighted the increasing importance of integrating technology into physics education to enhance learning outcomes and student engagement. Technologies such as augmented reality (AR) and virtual reality (VR) have shown significant potential in providing immersive learning experiences that help students grasp complex and abstract concepts more effectively (Prahani & Dawana, 2025). The COVID-19 pandemic further accelerated the adoption of online and blended learning models, which have proven effective in maintaining educational continuity and enriching the learning environment (Tanjung et al., 2025; Prahani et al., 2022). These technological innovations are not only transforming how physics is taught but also how it is perceived by students, making it more relevant and engaging.

Another notable trend in physics education research is the emphasis on interdisciplinary approaches and the integration of various scientific disciplines. Studies have shown that combining physics with mathematics, philosophy, and laboratory activities can enhance students' understanding and retention of concepts (Magazù, 2018; Caccamo & Magazù, 2021). This interdisciplinary approach also aligns with the broader educational goal of developing 21st-century skills, such as critical thinking, problem-solving, and collaboration, which are essential for students to thrive in a rapidly changing world (Prahani & Dawana, 2025). The integration of STEM (Science, Technology, Engineering, and Mathematics) education, particularly through project-based and inquiry-based learning, has been identified as a key strategy in achieving these educational objectives (Yusuf & Widyarningsih, 2019).

Furthermore, the role of assessment in physics education has been a focal point of recent research. Effective assessment strategies are crucial for evaluating student performance and guiding instructional practices. Bibliometric analyses have revealed a growing interest in developing innovative assessment tools and techniques that align with curricular objectives and real-world applications (Nurjanah et al., 2025). These assessments not only measure student achievement but also provide valuable insights into the effectiveness of teaching methods and the learning process.

In conclusion, the landscape of physics education is rapidly evolving, driven by technological advancements, interdisciplinary approaches, and innovative assessment strategies. This bibliometric analysis aims to map out these trends and identify research frontiers that hold the potential to further transform physics education. By understanding these trends, educators,

researchers, and policymakers can better navigate the challenges and opportunities in the field, ultimately enhancing the quality and accessibility of physics education for students worldwide.

Literature Review

The period from 2021 to 2025 has seen significant trends and emerging research frontiers in physics education, driven by technological advancements, the COVID-19 pandemic, and evolving educational needs. One prominent trend is the increasing integration of technology in physics education, particularly through AR and VR. These technologies have shown potential in enhancing students' understanding of abstract concepts and increasing engagement, with Indonesia being a notable contributor to this research area (Prahani & Dawana, 2025). The adoption of AR and VR has fluctuated, but their importance in fostering 21st-century skills is well-recognized, suggesting areas for further exploration, especially in optimizing their use in STEM education (Prahani & Dawana, 2025).

Another key trend is the shift towards online and distance learning, accelerated by the COVID-19 pandemic. The pandemic necessitated a rapid adaptation to online teaching methods, highlighting both the challenges and opportunities in this mode of instruction. Research indicates a significant increase in publication output related to online physics education during this period, with a focus on e-learning, virtual laboratories, and learning analytics (Le et al., 2025). The United States, United Kingdom, and Spain have been the most productive countries in this field, while emerging contributors like Indonesia and Mexico have also made notable contributions (Le et al., 2025). This shift underscores the need for greater international collaboration and the exploration of socio-emotional factors such as student motivation and well-being in online learning environments.

Assessment in physics education has also been a focal point of research, with a growing emphasis on developing innovative assessment techniques and integrating technology into assessment practices. Bibliometric analysis reveals positive growth in publications related to physics education assessment, with key research areas including the development of assessment instruments, predictive modeling for student performance, and the use of technology in assessments (Nurjanah et al., 2025). Despite the growth in publications, there is limited international collaboration, indicating opportunities for expanded cross-border research partnerships. Future research directions include developing adaptive and personalized assessment frameworks and promoting interdisciplinary approaches that bridge assessment and instruction (Nurjanah et al., 2025).

The use of websites in physics learning has seen increased attention, particularly in the context of collaborative and autonomous learning during the COVID-19 pandemic. A literature review categorizes research on the use of websites into various topics, including knowledge construction, learning environment, and inquiry skills (Sanjaya et al., 2022). The review highlights the positive impact of websites on the physics learning process, especially in collaborative and autonomous learning, while also identifying areas that require further research, such as problem-solving and conceptual change (Sanjaya et al., 2022). This trend reflects the broader move towards leveraging digital tools to enhance the learning experience in physics education.

Lastly, the integration of socio-scientific issues (SSI) in physics education has gained prominence, particularly through interdisciplinary approaches and digital technologies for real-world problem-solving. Research indicates a significant increase in the integration of SSI in science education, with key themes including scientific literacy, climate change, and sustainability (Arifin et al., 2025). This trend emphasizes the need for relevant curricula, teacher training, and international collaboration to advance sustainable science education. The focus on SSI reflects a broader recognition of the importance of preparing students to address complex, real-world issues through their physics education.

In summary, the period from 2021 to 2025 has seen notable trends in physics education, including the integration of AR and VR, the shift towards online learning, advancements in assessment techniques, the use of websites in learning, and the incorporation of socio-scientific issues. These trends highlight the dynamic and evolving nature of physics education, driven by technological advancements and the need to prepare students for a rapidly changing world.

Research Questions

1. What are the research trends in physics education according to the year of publication?
2. Who and how much has been published in the area with regard to the authors and their countries?
3. What does the distribution of physics education publications reveal about the specialization and diversification of research in the field?
4. What are the most cited articles?
5. What is the co-occurrence analysis of author keywords?
6. What is the co-authorship by countries' collaboration?

Methodology

Bibliometric analysis entails the systematic collection, organization, and examination of bibliographic information from scholarly works (Alves et al., 2021; Assyakur & Rosa, 2022; Verbeek et al., 2002). In addition to providing descriptive statistics such as the distribution of journals, publication years, and prolific authors (Wu & Wu, 2017), bibliometrics applies advanced techniques, including document co-citation analysis, to uncover deeper intellectual patterns within a field. A rigorous literature review requires an iterative process of refining keywords, retrieving relevant studies, and conducting detailed analyses to ensure both completeness and reliability (Fahimnia et al., 2015). Guided by this principle, the present study emphasized high-impact publications, as they offer valuable perspectives on the theoretical underpinnings driving research development. To secure the integrity of the dataset, Scopus was selected as the primary database for data retrieval (Al-Khoury et al., 2022; di Stefano et al., 2010; Khiste & Paithankar, 2017). Furthermore, only peer-reviewed journal articles were included to preserve academic quality, while books and lecture notes were intentionally excluded (Gu et al., 2019). Leveraging Elsevier's Scopus, recognized for its comprehensive coverage, publications from 2021 to August 2025 were gathered and prepared for subsequent analysis.

Data Search Strategy

The bibliometric dataset for this study was derived from the Scopus database, using a structured search strategy designed to capture research publications at the intersection of physics and secondary education. The search string applied was shown in Table 1. This initial query retrieved 7,321 documents, representing a wide-ranging collection of works published in

various language journals, document types, range from various countries and addressing physics education in many levels (eg. Secondary until university level). Nevertheless, the inclusion of only articles ensured that the dataset focused on peer-reviewed, citable contributions to the field, while limiting the timespan to 2021–2025 provided a contemporary picture of developments in instructional approaches within physics education.

Following refinement through explicit inclusion and exclusion criteria, the final dataset comprised 886 documents. As shown in Table 2, publications were included if they were written in English, fell within the 2021–2025 time frame, and were published as finalized journal articles. Excluded materials consisted of non-English publications, conference proceedings, book chapters, review articles, and in-press manuscripts, which were omitted to maintain consistency and ensure comparability across studies. These criteria narrowed the focus to high-quality, accessible, and completed works, thereby enhancing the validity of the bibliometric analysis. This refined dataset offers a robust foundation for exploring trends, thematic structures, and emerging frontiers in instructional approaches to physics education at the secondary school level.

Table 1: The Search String

Scopus	TITLE-ABS-KEY ("physics" AND ("secondary school" OR "high school")) AND PUBYEAR > 2020 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SUBJAREA , "SOCT"))
Retrieved on 30 August 2025	
Source: Scopus	

Table 2: The Selection Criterion Is Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2021 – 2025	< 2021
Literature type	Journal (Article)	Conference, Book, Review
Publication Stage	Final	In Press

Data Analysis

VOSviewer is a widely adopted bibliometric software created by Nees Jan van Eck and Ludo Waltman at Leiden University, Netherlands (van Eck & Waltman, 2010; Van Eck & Waltman, 2017). Recognized for its accessibility and effectiveness in analyzing scientific literature, it specializes in producing clear network visualizations, clustering related items, and constructing density maps. The tool is highly versatile, supporting analyses of co-authorship, co-citation, and keyword co-occurrence networks, thus offering scholars a detailed view of research landscapes. Its interactive design, combined with ongoing updates, enables efficient handling of large datasets. Moreover, VOSviewer's capability to calculate bibliometric metrics, adapt visualizations, and work seamlessly with multiple data sources makes it an indispensable asset for researchers aiming to interpret complex academic domains.

A defining strength of VOSviewer lies in its ability to convert extensive bibliometric datasets into easily interpretable visual maps and diagrams. Emphasizing network-based analysis, the software is particularly effective in identifying keyword co-occurrence trends, grouping related

research items, and generating density-based displays. The user-friendly interface supports both beginners and experienced researchers, making exploration of research patterns intuitive and effective. Continuous development ensures the tool remains at the forefront of bibliometric visualization, offering customizable outputs and robust metric calculations. Its flexibility to process different types of bibliometric data, ranging from citation linkages to co-authorship structures, positions VOSviewer as a core tool in mapping intellectual structures and uncovering meaningful insights across research domains.

For this study, datasets containing details such as publication year, title, author, journal, citations, and keywords in PlainText format were retrieved from the Scopus database, covering the period 2021 to August 2025. These were processed with VOSviewer software version 1.6.20, applying clustering and mapping techniques to generate visualizations. Serving as an alternative to the Multidimensional Scaling (MDS) approach, VOSviewer places items in a low-dimensional space where distances mirror the degree of relatedness or similarity (van Eck & Waltman, 2010). While similar in aim to MDS (Appio et al., 2014), VOS differs in its method of normalizing co-occurrence frequencies by employing the association strength (AS_{ij}) measure (van Eck & Waltman, 2007):

$$AS_{ij} = \frac{c_{ij}}{w_i w_j}$$

This index, defined as the ratio between the observed and expected co-occurrences of items *i* and *j* under the assumption of independence, ensures that network maps accurately reflect the strength of conceptual linkages measure (van Eck & Waltman, 2007).

Result and Discussion

RQ1. What are the Research Trends in Physics Education According to the Year of Publication?

The publication trend from 2021 to 2025 as in Figure 1 shows a steady increase in research on physics education, with outputs rising from 175 documents in 2021 to a peak of 200 in 2024, before dropping to 128 in 2025. The gradual growth between 2021 and 2024 reflects the heightened global emphasis on improving science education, particularly in secondary schools, where instructional innovations such as inquiry-based learning, project-based learning, digital tools, and integrated STEM approaches gained momentum in response to post-pandemic educational reforms. The peak in 2024 can be linked to the maturation of these research efforts, supported by international collaborations and funding initiatives promoting STEM education. However, the decline in 2025 may be explained by two main factors: first, the dataset access date of August 2025 means not all publications for the year had been indexed at the time of data collection, creating an apparent drop; and second, bibliometric records often show lower counts in the most recent year due to indexing delays. Thus, while the decrease in 2025 may seem significant, it is likely an artifact of incomplete indexing rather than an actual reduction in research activity.

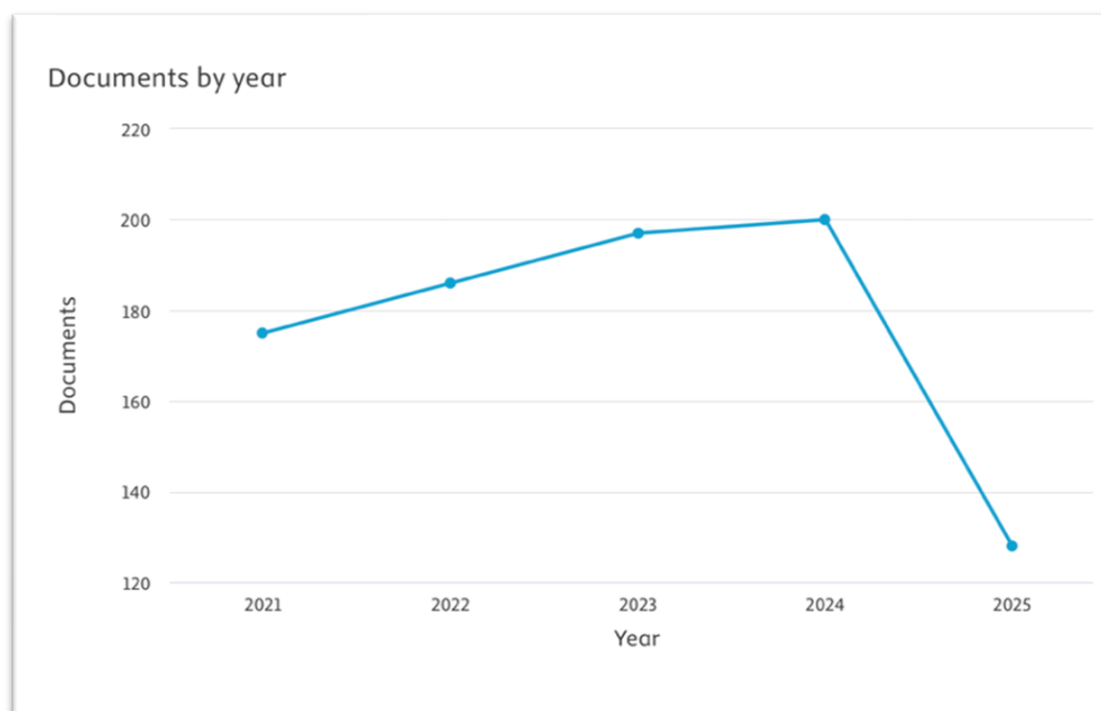


Figure 1: Trend of Research in Physics Education by Years

Source: Scopus Analyzer

RQ2. Who and How Much Has Been Published in The Area with Regard to the Authors and Their Countries?

Publishing by Authors

The analysis of author productivity in physics education research from 2021 to 2025 reveals a diverse set of contributors, with several scholars emerging as highly prolific in this area. Figure 2 shows Bitzenbauer, P. leads with 13 publications, reflecting sustained engagement with instructional approaches in physics education, followed by Kuswanto, H. (9 papers) and a cluster of authors including Balta, N., Kelly, A.M., Lavonen, J., Tóth, K., and Uwamahoro, J. who each contributed 8 publications. This indicates both strong individual productivity and collaborative research networks addressing instructional innovations across different regions. Mid-range contributors, such as Muwonge, C.M. and Testa, I. (7 papers each), as well as Bao, L., Istiyono, E., Jita, L.C., Malmberg, J., Michelini, M., Nzabahimana, J., Samsudin, A., Singh, C., and Suhandi, A. (6 papers each), also play a critical role in shaping the discourse by diversifying perspectives across contexts.

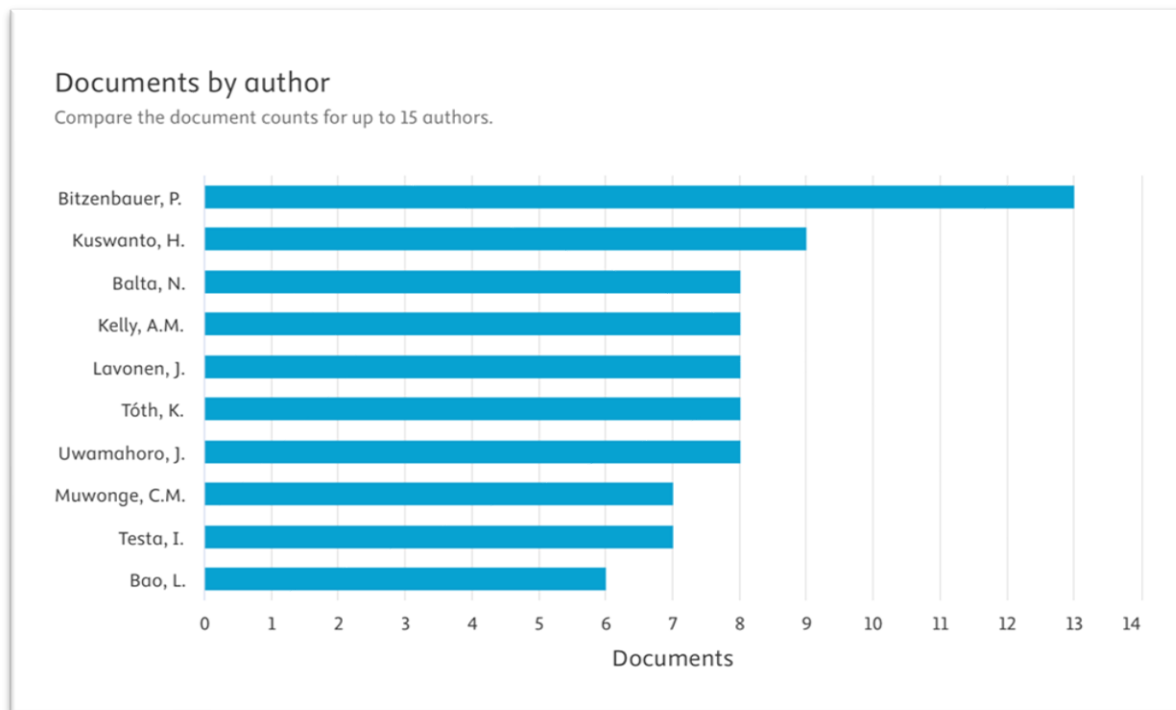


Figure 2: Top Ten Authors in Physics Education

Source: Scopus Analyzer

The distribution of authorship demonstrates a global spread, with significant representation from Europe, Asia, and Africa, reflecting the worldwide concern for improving secondary school physics education. The long tail of contributors with fewer publications (2–5 papers) suggests that the field benefits from both established experts and emerging scholars, ensuring continuity, fresh insights, and the expansion of research themes. This pattern aligns with bibliometric laws such as Lotka's law, where a small group of highly productive authors coexists with a larger pool of occasional contributors, collectively driving the growth and dynamism of the field.

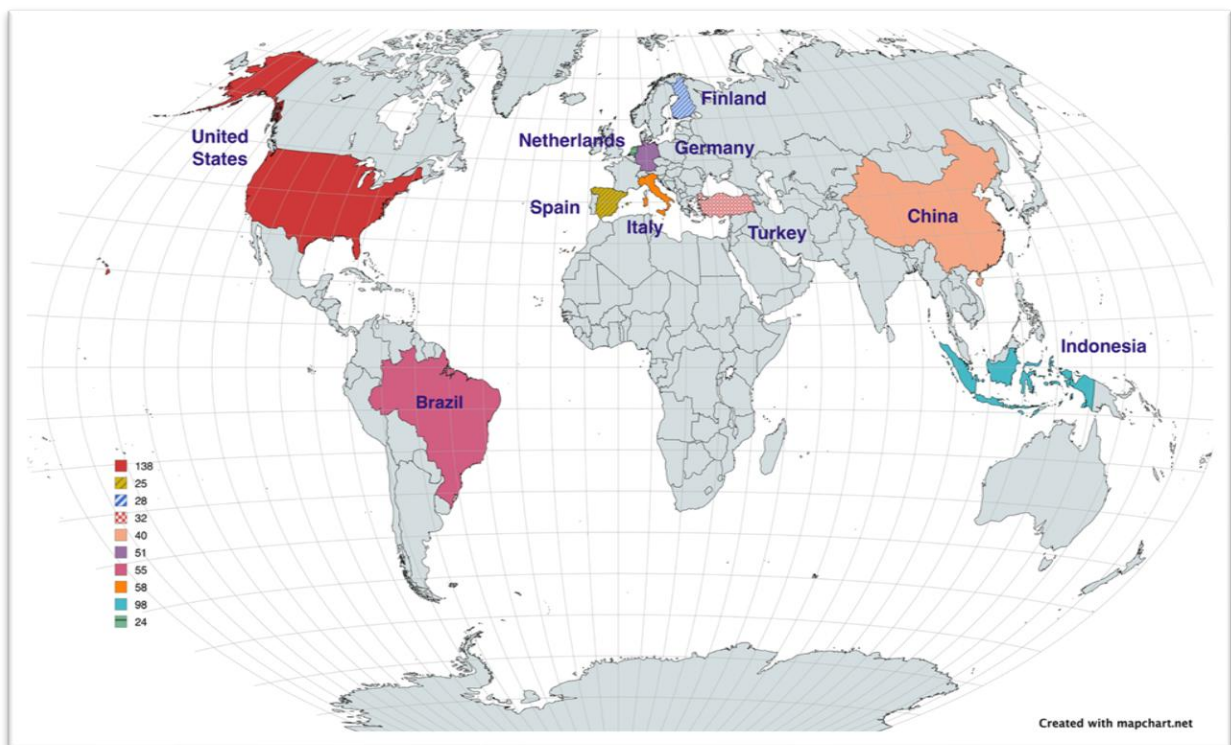
Publishing by Countries

The distribution of the top ten publishing countries shows that research in physics education is both globally dispersed and influenced by strong regional hubs (see Table 3 and Figure 3). The United States leads with 138 documents (15.58%), reflecting its dominance in science education research through well-established networks, funding support, and international collaborations. Following closely is Indonesia with 98 (11.06%), a notable finding that signals the country's growing emphasis on physics and STEM education reforms. The high output from Indonesia also demonstrates the region's increasing academic visibility, supported by national initiatives to strengthen science education and the rising number of indexed regional journals that disseminate this work internationally. European contributions are also significant, with Italy (58, 6.55%), Germany (51, 5.76%), and Spain (25, 2.82%) maintaining strong positions. These outputs indicate the well-rooted traditions of science education in Europe, where research on instructional practices, digital integration, and teacher professional development are well established.

Table 3: Top Ten Countries Contributed in Physics Education

Country/Territory	Number of Publications	Percentage (%)
United States	138	15.58
Indonesia	98	11.06
Italy	58	6.55
Brazil	55	6.21
Germany	51	5.76
China	40	4.51
Turkey	32	3.61
Finland	28	3.16
Spain	25	2.82
Netherlands	24	2.71

Source: Scopus Analyzer

**Figure 3: Top Ten Countries Contributed to Physics Education**

Source: mapchart.net

Meanwhile, countries like **Brazil (55, 6.21%)**, **China (40, 4.51%)**, and **Turkey (32, 3.61%)** illustrate the active engagement of emerging economies in shaping the global discourse in physics education. Brazil's prominence reflects Latin America's broader educational reforms, while China's presence shows its strategic investments in technology-enhanced education. Interestingly, **Finland (28, 3.16%)** and the **Netherlands (24, 2.71%)**, though smaller in scale compared to the US and Indonesia, contribute disproportionately high-quality research, consistent with their strong reputations in educational innovation and teacher training. Collectively, these top ten countries account for a substantial share of publications, underscoring both the leadership of advanced economies and the rising contributions of

developing nations in diversifying perspectives and driving forward instructional approaches in physics education worldwide.

RQ3. What does the Distribution of Physics Education Publications Reveal about the Specialization and Diversification of Research in the Field?

The distribution of publications across journals demonstrates both specialization and diversification in physics education research (see Figure 4). The journal *Physics Education* dominates with 150 articles, reflecting its longstanding focus and international reputation as a leading outlet for classroom practices, instructional strategies, and curriculum innovations in physics teaching. Specialized venues such as *Physical Review Physics Education Research* (63 articles) and *Physics Teacher* (48 articles) also attract high contributions, emphasizing both empirical studies and practitioner-oriented work. Regional journals, including the *Revista Brasileira de Ensino de Fisica* (32 articles) and *Jurnal Pendidikan IPA Indonesia* (12 articles), highlight strong participation from Latin America and Southeast Asia, where national reforms in science and STEM education are generating significant scholarly outputs. Broader interdisciplinary outlets like *Education Sciences* (28) and *Frontiers in Education* (14) show that physics education research is increasingly intersecting with wider educational debates, particularly on digital learning, inquiry-based instruction, and 21st-century skills.

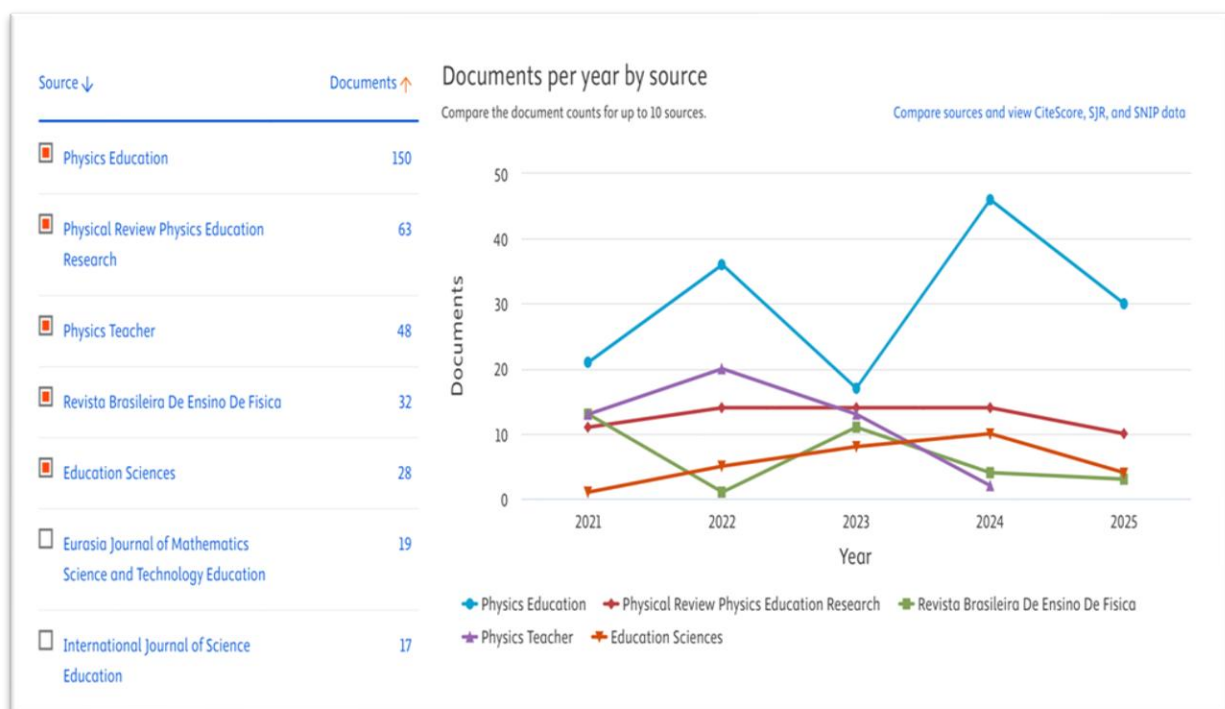


Figure 4: Top Five Distribution of Publications Across Journals by Year

Source: Scopus Analyzer

The variation in publication frequency across sources can be explained by differences in journal scope, visibility, and indexing status, leading journals in science education naturally attract higher submissions, while regional and emerging journals provide platforms for localized studies and innovations. This pattern illustrates a balance between global scholarly consolidation around established journals and the expansion of research dissemination through diverse regional and interdisciplinary outlets.

RQ4. What are the Most Cited Articles?

The most cited articles in this dataset highlight two major frontiers in contemporary physics education research: the integration of emerging technologies (such as augmented and virtual reality) and the early exploration of artificial intelligence tools like ChatGPT (refer Table 4). The top-cited study by Cai et al. (2021), published in the British Journal of Educational Technology with 139 citations, underscores the impact of augmented reality (AR) on students' self-efficacy and conceptions of learning in physics. Its high citation count reflects both the global momentum in immersive learning research and the journal's wide readership. Similarly, Bitzenbauer (2023) achieved rapid influence with his article in Contemporary Educational Technology (112 citations) on ChatGPT applications in physics education. This indicates a strong scholarly interest in AI-driven tools, especially as educators grapple with their opportunities and challenges in classroom practice. These two papers stand out not only for their citation impact but also for pioneering topics at the intersection of technology innovation and pedagogical transformation, which are highly relevant in the post-pandemic educational landscape.

Table 4: The Most Cited Authors

Authors	Title	Year	Source Title	Cited by
Cai et al., 2021	Effects of learning physics using Augmented Reality on students' self-efficacy and conceptions of learning	2021	British Journal of Educational Technology	139
Bitzenbauer, 2023	ChatGPT in physics education: A pilot study on easy-to-implement activities	2023	Contemporary Educational Technology	112
Holly et al., 2021	Designing VR Experiences – Expectations for Teaching and Learning in VR	2021	Educational Technology and Society	93
Papakostas et al., 2023	Exploring Users' Behavioral Intention to Adopt Mobile Augmented Reality in Education through an Extended Technology Acceptance Model	2023	International Journal of Human-Computer Interaction	82
Ingvavara et al., 2022	The use of a personalized learning approach to implementing self-regulated online learning	2022	Computers and Education: Artificial Intelligence	73

The next cluster of highly cited works continues this technological emphasis. Holly et al. (2021), with 93 citations, explored the design of VR learning environments, reflecting the growing recognition of immersive technologies in shaping student engagement and conceptual understanding. Papakostas et al. (2023) examined the adoption of mobile augmented reality

through an extended Technology Acceptance Model, receiving 82 citations, which highlights the role of acceptance and usability factors in successful integration of educational technologies. Other impactful works include Ingkavara et al. (2022) on personalized online learning (73 citations) and Georgiou et al. (2021) on immersive VR for physics education (55 citations). Together, these studies demonstrate a clear research trajectory where physics education increasingly intersects with digital transformation. The rapid uptake of citations, especially for articles published as recently as 2023, signals both the timeliness of these topics and the urgency with which the academic community is investigating digital and AI-mediated instructional approaches. This suggests that future research will continue to prioritize AI, AR/VR, and personalized learning ecosystems, as they represent both the innovation frontier and pressing challenges in modern physics education.

RQ5. What is the Co-occurrence Analysis of Author Keywords?

Co-occurrence analysis of author keywords, as implemented in VOSviewer, is a bibliometric technique used to identify the relationships between frequently used keywords in a body of literature. In this approach, keywords that appear together in the same documents are assumed to share a thematic or conceptual link. By mapping these co-occurrences, VOSviewer creates a network visualization where nodes represent keywords and links represent the strength of their co-occurrence. The closer two keywords are positioned on the map, the stronger their connection, reflecting how often they appear together across publications. This allows researchers to detect research hotspots, emerging themes, and the intellectual structure of a field, offering insights into how different concepts interact within physics education literature.

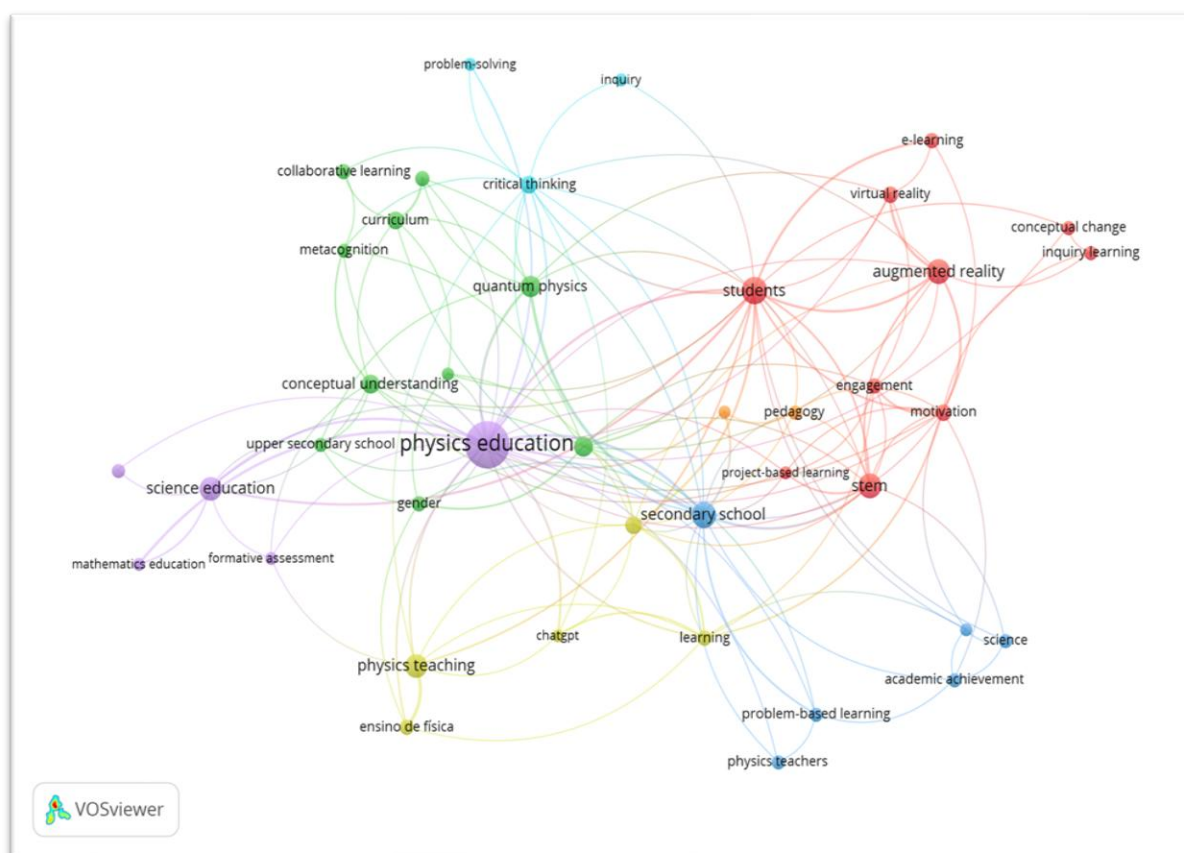


Figure 5: Network Visualization Map of Keywords' Co-occurrence

Source: VOSviewer

For this study (refer Figure 5), the visualization was generated using the full counting method, which means each co-occurrence between keywords is counted equally regardless of the number of times they appear within a single document. A minimum occurrence threshold of 7 was set, meaning only keywords that appeared at least seven times across the dataset were included. Out of a total of 2,672 unique keywords, 51 met this threshold and were included in the analysis. To further structure the map, a minimum cluster size of 1 was applied, ensuring that even smaller groups of related keywords could be represented. Based on this configuration, four distinct clusters emerged, each grouping keywords that share strong conceptual associations within the literature.

The findings contribute to the body of knowledge by highlighting both the consolidation of core themes and the diversification of emerging topics in physics education. Keywords such as “physics education” (162 occurrences, link strength 139), “students” (48), and “secondary school” (59) dominate, demonstrating the central concern with teaching practices and learner contexts. Simultaneously, the prominence of terms like “augmented reality” (24), “virtual reality” (11), and “e-learning” (10) underscores the rapid integration of technology into instructional practices. Affective and cognitive constructs such as “motivation”, “self-efficacy”, “critical thinking”, and “conceptual understanding” point to the field’s increasing attention to how students learn and engage with physics. Furthermore, the inclusion of “STEM”, “curriculum”, and “gender” indicates the intersection of physics education with broader educational reforms and equity considerations. Altogether, these clusters reveal a research landscape that balances traditional instructional concerns with innovative, technology-driven, and learner-centered approaches, thereby enriching the global discourse on physics education.

RQ6. What is the Co-authorship by Countries’ Collaboration?

Co-authorship analysis by countries’ collaboration, as performed in VOSviewer, maps the patterns of international cooperation in academic publishing. In this approach, each country is represented as a node, with the size of the node proportional to the number of publications, while the links between nodes represent co-authorship connections across countries. The total link strength indicates the intensity of collaboration, showing how often authors from different countries co-publish within the dataset. This analysis is valuable for identifying global research networks, detecting which countries serve as collaboration hubs, and understanding how knowledge flows internationally. In physics education research, such collaboration often reflects shared educational reforms, international funding opportunities, and cross-cultural comparative studies.

In this study, the co-authorship map was generated using the full counting method, where each co-authorship link is given equal weight regardless of the number of authors involved. A minimum threshold of 5 publications per country was applied, meaning only countries with at least five documents were included. Out of a total of 90 publishing countries, 47 met the threshold. Additionally, the minimum cluster size was set to 1, which ensured that even smaller, less connected networks could still be visualized. Based on this configuration, the analysis produced 9 clusters, each representing groups of countries that collaborate more frequently with one another. These clusters can highlight regional partnerships (e.g., European collaborations), North-South academic exchanges, or cross-continental networks anchored by leading contributors.

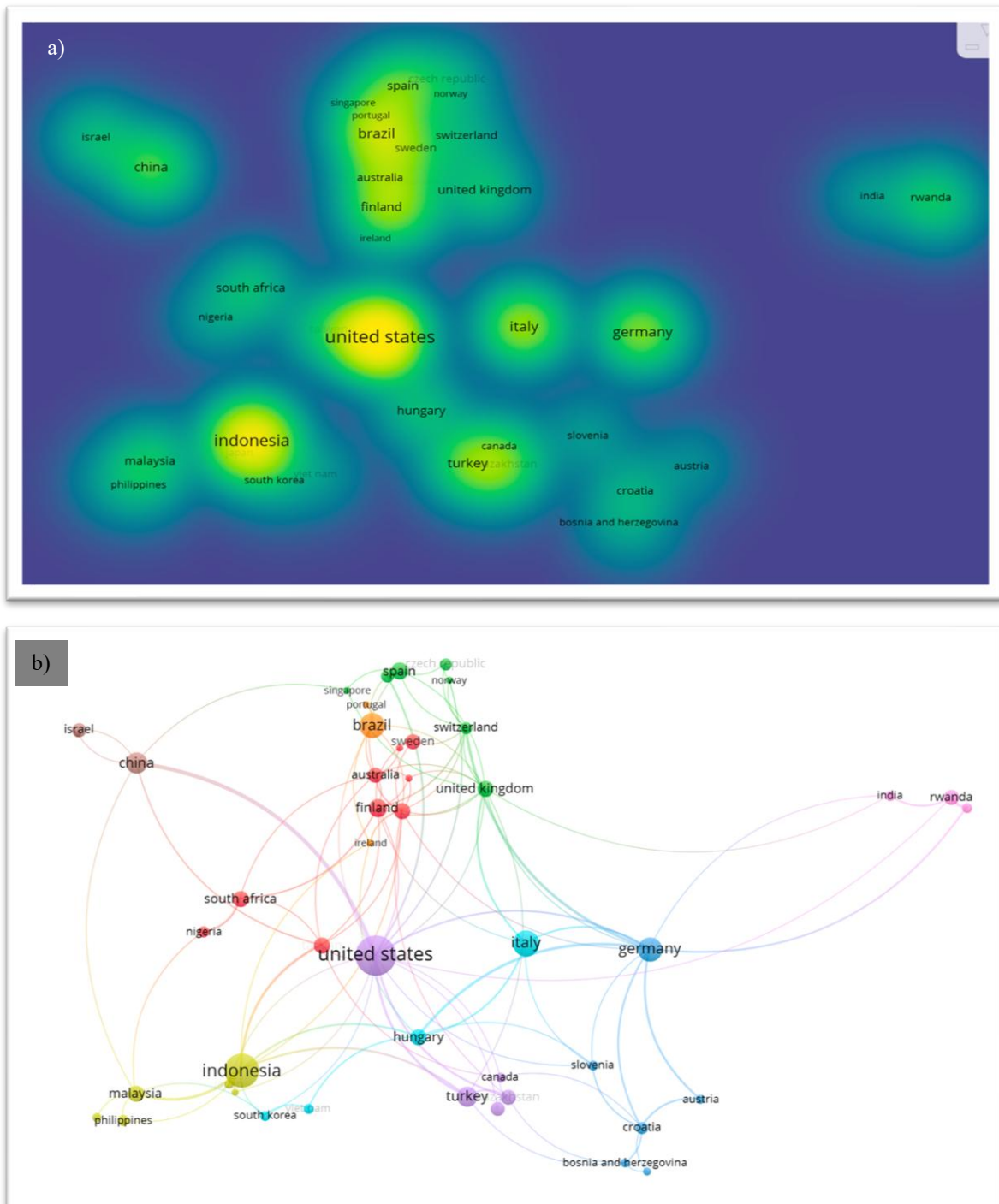


Figure 6: Visualisation Map of Co-authorship by Countries' Collaboration by Density Visualisation; and b) Network Visualisation

Source: VOSviewer

The findings contribute to the body of knowledge by illustrating both dominance and diversity in international research on physics education (refer Figure 6). The United States leads with 138 documents, 779 citations, and the highest link strength (40), underscoring its role as a global hub for collaboration. Other strong contributors include Germany (513 citations, link strength 32), Indonesia (383 citations, link strength 25), and China (364 citations, link strength

18), reflecting both established and emerging research powers. Smaller but highly connected countries like Finland, Switzerland, and the Netherlands show high citation impact relative to their output, signaling the influence of their research quality and strong partnerships. The generation of nine clusters indicates a vibrant global research network, where knowledge in physics education is shaped not only by high-output nations but also by dynamic collaborations across continents. This underscores the importance of international partnerships in diversifying perspectives, enhancing methodological innovations, and addressing global challenges in physics and STEM education.

Conclusion

This bibliometric analysis demonstrates that physics education research between 2021 and 2025 is marked by both consolidation around established pedagogical themes and diversification into innovative, technology-driven approaches. Traditional areas, such as instructional strategies, conceptual understanding, and student-centered learning, remain foundational, but the prominence of emerging topics—particularly artificial intelligence, augmented and virtual reality, and online learning—signals a clear shift in the research agenda. The increasing focus on socio-emotional constructs such as motivation, self-efficacy, and critical thinking further illustrates the field's responsiveness to broader educational goals, including the development of 21st-century skills.

At the global level, the findings highlight uneven yet complementary contributions across countries and regions. While the United States retains dominance in publication volume and international collaboration, Indonesia's rapid rise illustrates how emerging economies are shaping new directions in STEM and physics education. Similarly, regional and interdisciplinary journals are creating diverse publication outlets that expand scholarly discourse beyond traditional platforms. The co-occurrence and co-authorship networks reveal a vibrant, interconnected field that benefits from both established academic hubs and growing contributions from developing regions. Together, these trends point toward a future in which physics education research will be increasingly collaborative, technologically integrated, and globally inclusive, offering pathways for innovation in teaching, learning, and policy.

Acknowledgements

The authors would like to thank Universiti Teknologi Malaysia (UTM) for the financial support given through UTM Fundamental Research Grant (UTMFR) with grant reference number: PY/2022/04389 (cost centre: Q.J130000.3801.22H44)

References

- Arifin, Z., Sukarmin, S., & Saputro, S. (2025). Trends and research frontiers in socioscientific issues for sustainable science education: A systematic and bibliometric analysis from 2014 – 2024. *Journal of Pedagogical Research*, 9(1), 407 – 434. <https://doi.org/10.33902/JPR.202530575>
- Assyakur, D. S., & Rosa, E. M. (2022). Spiritual Leadership in Healthcare: A Bibliometric Analysis. *Jurnal Aisyah : Jurnal Ilmu Kesehatan*, 7(2). <https://doi.org/10.30604/jika.v7i2.914>
- Bitzenbauer, P. (2023). ChatGPT in physics education: A pilot study on easy-to-implement activities. *Contemporary Educational Technology*, 15(3). <https://doi.org/10.30935/cedtech/13176>

- Caccamo, M. T., & Magazù, S. (2021). Physics Education for Students: An Interdisciplinary Approach. In *Physics Education for Students: An Interdisciplinary Approach*. Bentham Science Publishers. <https://doi.org/10.2174/97898149985121210101>
- Cai, S., Liu, C., Wang, T., Liu, E., & Liang, J.-C. (2021). Effects of learning physics using Augmented Reality on students' self-efficacy and conceptions of learning. *British Journal of Educational Technology*, 52(1), 235–251. <https://doi.org/10.1111/bjet.13020>
- di Stefano, G., Peteraf, M., & Veronay, G. (2010). Dynamic capabilities deconstructed: A bibliographic investigation into the origins, development, and future directions of the research domain. *Industrial and Corporate Change*, 19(4), 1187–1204. <https://doi.org/10.1093/icc/dtq027>
- Fahimnia, B., Sarkis, J., & Davarzani, H. (2015). Green supply chain management: A review and bibliometric analysis. In *International Journal of Production Economics* (Vol. 162, pp. 101–114). <https://doi.org/10.1016/j.ijpe.2015.01.003>
- Georgiou, Y., Tsivitanidou, O., & Ioannou, A. (2021). Learning experience design with immersive virtual reality in physics education. *Educational Technology Research and Development*, 69(6), 3051–3080. <https://doi.org/10.1007/s11423-021-10055-y>
- Gu, D., Li, T., Wang, X., Yang, X., & Yu, Z. (2019). Visualizing the intellectual structure and evolution of electronic health and telemedicine research. *International Journal of Medical Informatics*, 130. <https://doi.org/10.1016/j.ijmedinf.2019.08.007>
- Holly, M., Pirker, J., Resch, S., Brettschuh, S., & Gütl, C. (2021). Designing VR Experiences – Expectations for Teaching and Learning in VR. *Educational Technology and Society*, 24(2), 107–119. <https://www.scopus.com/inward/record.uri?eid=2-s2.0-85104036105&partnerID=40&md5=3f4ad46e5391cdf49f242ab25254ad5d>
- Ingvavara, T., Panjaburee, P., Srisawasdi, N., & Sajjanaroj, S. (2022). The use of a personalized learning approach to implementing self-regulated online learning. *Computers and Education: Artificial Intelligence*, 3. <https://doi.org/10.1016/j.caeai.2022.100086>
- Khiste, G. P., & Paithankar, R. R. (2017). Analysis of Bibliometric term in Scopus. *International Research Journal*, 01(32), 78–83.
- Küchemann, S., Steinert, S., Revenga, N., Schweinberger, M., Dinc, Y., Avila, K. E., & Kuhn, J. (2023). Can ChatGPT support prospective teachers in physics task development? *Physical Review Physics Education Research*, 19(2). <https://doi.org/10.1103/PhysRevPhysEducRes.19.020128>
- Le, H. T., Nguyen-Dinh, C. H., Van, H. T., & Nguyen, M. D. (2025). The Evolution of Online Physics Education: Insights from a Bibliometric Study. *International Journal of Learning, Teaching and Educational Research*, 24(4), 221 – 249. <https://doi.org/10.26803/ijlter.24.4.11>
- Liu, Q., Yu, S., Chen, W., Wang, Q., & Xu, S. (2021). The effects of an augmented reality based magnetic experimental tool on students' knowledge improvement and cognitive load. *Journal of Computer Assisted Learning*, 37(3), 645–656. <https://doi.org/10.1111/jcal.12513>
- Magazù, S. (2018). New trends in physics education research. In *New Trends in Physics Education Research*. Nova Science Publishers, Inc. <https://www.scopus.com/inward/record.uri?eid=2-s2.0-85066502558&partnerID=40&md5=0cf64c38bd812621038f6e5972a7bf72>

- Nurjanah, S., Sultan, J., Arriza, L., Suardi, I. K., Ramadhani, S., Seran, D. S. F., & Rashid, S. (2025). Assessment in physics education research: Trends, patterns, and future directions. *Review of Education*, 13(1). <https://doi.org/10.1002/rev3.70043>
- Papakostas, C., Troussas, C., Krouska, A., & Sgouropoulou, C. (2023). Exploring Users' Behavioral Intention to Adopt Mobile Augmented Reality in Education through an Extended Technology Acceptance Model. *International Journal of Human-Computer Interaction*, 39(6), 1294–1302. <https://doi.org/10.1080/10447318.2022.2062551>
- Prahani, B. K., Amiruddin, M. Z. B., Suprpto, N., Deta, U. A., & Cheng, T.-H. (2022). The Trend of Physics Education Research during COVID-19 Pandemic. *International Journal of Educational Methodology*, 8(3), 517–533. <https://doi.org/10.12973/ijem.8.3.517>
- Prahani, B. K., & Dawana, I. R. (2025). Exploring the potential of technology in physics education: current research and innovation trends to support 21st century skills. *Perspektivy Nauki i Obrazovania*, 73(1), 349–361. <https://doi.org/10.32744/pse.2025.1.23>
- Sanjaya, L. A., Bunyamin, M. A. H., Meganingtyas, D. E. W., & Haeruman, L. D. (2022). Trends of Web-Based Instructional (WBI) in Physics Learning: A Literature Review. In W. F.C., T. null, S. A., B. E., I. W., N. H., P. T.B., B. F., M. D., & S. L.A. (Eds.), *Journal of Physics: Conference Series* (Vol. 2377, Issue 1). Institute of Physics. <https://doi.org/10.1088/1742-6596/2377/1/012082>
- Sun, J. C.-Y., Ye, S.-L., Yu, S.-J., & Chiu, T. K. F. (2023). Effects of Wearable Hybrid AR/VR Learning Material on High School Students' Situational Interest, Engagement, and Learning Performance: the Case of a Physics Laboratory Learning Environment. *Journal of Science Education and Technology*, 32(1), 1–12. <https://doi.org/10.1007/s10956-022-10001-4>
- Tanjung, Y. I., Diliarosta, S., Arsih, F., & Fadillah, M. A. (2025). Developing the Physics Learning Management System (PLMS) to Support Blended Learning Models. *International Journal of Information and Education Technology*, 15(1), 18–29. <https://doi.org/10.18178/ijiet.2025.15.1.2214>
- Tsivitanidou, O. E., Georgiou, Y., & Ioannou, A. (2021). A Learning Experience in Inquiry-Based Physics with Immersive Virtual Reality: Student Perceptions and an Interaction Effect Between Conceptual Gains and Attitudinal Profiles. *Journal of Science Education and Technology*, 30(6), 841–861. <https://doi.org/10.1007/s10956-021-09924-1>
- van Eck, N. J., & Waltman, L. (2007). Bibliometric Mapping Of The Computational Intelligence Field. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, 15(05), 625–645. <https://doi.org/10.1142/S0218488507004911>
- van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84(2), 523–538. <https://doi.org/10.1007/s11192-009-0146-3>
- van Eck, N. J., & Waltman, L. (2017). Citation-based clustering of publications using CitNetExplorer and VOSviewer. *Scientometrics*, 111(2), 1053–1070.
- Verbeek, A., Debackere, K., Luwel, M., & Zimmermann, E. (2002). Measuring progress and evolution in science and technology - I: The multiple uses of bibliometric indicators. *International Journal of Management Reviews*, 4(2), 179–211. <https://doi.org/10.1111/1468-2370.00083>

- Wu, Y. C. J., & Wu, T. (2017). A decade of entrepreneurship education in the Asia Pacific for future directions in theory and practice. In *Management Decision* (Vol. 55, Issue 7, pp. 1333–1350). <https://doi.org/10.1108/MD-05-2017-0518>
- Yusuf, I., & Widyaningsih, S. W. (2019). HOTS profile of physics education students in STEM-based classes using PhET media. In A. B. D. Nandiyanto, A. G. Abdullah, S. null, S. null, I. Permana, & R. R. Agustin (Eds.), *Journal of Physics: Conference Series* (Vol. 1157, Issue 3). Institute of Physics Publishing. <https://doi.org/10.1088/1742-6596/1157/3/032021>