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Mapping Global Research on Science Process Skills in Physics Education: A 2000–2025 Bibliometric Study

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Abstract
Science process skills (SPS) are competencies in physics education that enable students to engage in scientific inquiry, critical thinking, and problem-solving. In the context of 21st-century education, strengthening SPS has become important for supporting quality and sustainable science education. This study aims to identify patterns, issues, and research directions related to science process skills (SPS) in physics education from 2000 to 2025. This research focuses on the significance of SPS as a competency for the 21st century, particularly in enhancing the quality of science education in accordance with Sustainable Development Goal (SDG) 4 on Quality Education. Furthermore, the study emphasizes how international collaboration in SPS research plays a role in achieving SDG 17 by fostering partnerships in publications and research networks. The study uses bibliometric analysis, with data sourced from Scopus totaling 377 documents and processed using RStudio software. The analysis covers annual publication trends, keyword networks, collaborations between authors and countries, topic development, and publication sources. The results show a significant rise in publications since 2010, peaking in 2019, along with a shift in research focus from curriculum issues to digital technology integration, STEM/STEAM approaches, and virtual laboratories. International collaborative networks have expanded over time but remain regionally concentrated, particularly in North America and Southeast Asia, while collaborations involving Africa and parts of the Middle East remain limited. These findings demonstrate global growth and structural gaps in the development of SPS research. This study concludes that the development of SPS research is increasingly moving towards innovation in physics education and 21st-century competencies relevant to the SDG 4 agenda, as well as mapping the role of global research collaboration in line with SDG 17. Limitations include reliance on a single data source and metadata quality. Future research should expand data sources and employ comprehensive bibliometric methods.

Keywords: Science Process Skills, Physics Education, 21st Century Skills.
SDGs: Goal 4 (Quality Education), Goal 17 (Partnerships for the Goals).

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INTRODUCTION

Science process skills are a vital part of science education because they help train students to think scientifically in a systematic way (Gizaw & Sota, 2023). Through these skills, students learn to observe, clarify,

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develop hypotheses, carry out experiments, and analyze data, enabling them to understand phenomena more deeply (Bibon, 2022). Science process skills serve as the foundation for developing essential 21st-century skills, including critical thinking, creativity, communication, and collaboration (Ekici & Erdem, 2020; Kurniawan et al., 2023). These skills are essential for students confronting global changes characterized by rapid development and various challenges (Azzahra et al., 2024). Therefore, research that views science process skills as the basis for strengthening 21st-century skills is highly relevant (Mukaromah et al., 2022). It is also important to analyze the development of scientific process skills research through bibliometric analysis, as it provides a comprehensive overview that can guide educational policies and promote learning innovation (Elliyani et al., 2024).

In the past two decades, researchers have increasingly focused on science process skills to meet the demands of 21st-century education (Puspa et al., 2024; Yulianti et al., 2024). This rise in international publications related to science process skills has been significantly influenced by the development of the STEM education concept, inquiry-based learning, and the integration of digital learning in various educational contexts (Jalaludin et al., 2024). This trend indicates that science process skills are not only regarded as fundamental abilities, but also as a means to incorporate modern learning approaches (Romadona et al., 2021). However, most existing studies concentrate primarily on the application of science process skills in classrooms, their relationship with learning outcomes, and their integration with specific teaching models (Mirian, 2023; Nuraini & Muliawan, 2020). There is still a lack of research that distinctly examines the mapping of trends, collaboration, and the direction of global research on science process skills (Kol & Yaman, 2022).

Scopus analysis for the 2019–2024 period identified only a small number of articles meeting the analysis criteria, with research still focused on specific themes (Iqbal et al., 2025). Furthermore, of the hundreds of available publications, only a fraction are indexed in reputable international databases, thus the representation of global research developments is not optimal (Sudirman et al., 2023). Other studies also indicate that research trends on science process skills are fluctuating and still dominated by certain topics, while several important areas remain under-researched (Elliyani et al., 2024). This gap highlights the necessity for a bibliometric study that can provide a more comprehensive overview of the landscape of research on science process skills (Arıcı, 2025).

Moreover, research explicitly connecting science process skills with 21st-century competencies remains relatively limited (Mushani, 2021). Most studies primarily focus on developing instruments for measuring science process skills or evaluating their effectiveness in science education, without directly integrating these skills with higher-order thinking, collaboration, or creativity (Kundera et al., 2025; Ünlü & Dökme, 2022). As noted in the research by Elliyani et al. (2024), publications on science process skills still emphasize classroom applications and measurement tools, while their relationship with 21st-century competencies has not been widely explored. Similar findings were highlighted by Azzahra et al. (2024), who pointed out that the explicit link between science process skills and creative, critical, and collaborative thinking skills remains a significant research gap that requires further investigation. Additionally, comparative research across countries regarding the development of science process skills is still very limited, resulting in a lack of clarity regarding research patterns and priorities in various regions of the world (Hasanah & Shimizu, 2020; Iqbal et al., 2025; Kurniahtunnisa et al., 2024). This issue has created a gap in global understanding of how science process skills enhance 21st-century competencies (Kain et al., 2024).

This study examines the progress of research on science process skills from 2000 to 2025 using a bibliometric approach. It also investigates the evolution of research topics by conducting keyword analysis and co-word mapping to identify emerging topics, including those related to 21st-century competencies (Chen et al., 2023; Fahrudin et al., 2023). Furthermore, collaborative network analysis is used to identify patterns of research collaboration worldwide, providing a snapshot of how research is conducted across countries and regions. Thus, this study offers a clearer picture of global research trends and differences across countries, particularly in understanding the role of science process skills in supporting 21st-century competencies (Linnenluecke et al., 2020; Sudirman et al., 2023). In this context, this study seeks to answer the following research questions:

RQ1: What are the trends in research publications on science process skills in the period 2000–2025 based on bibliometric analysis?

RQ2: What are the research gaps and future research directions based on bibliometric findings?

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METHOD

This study employs bibliometric methods to analyze the growth of publications related to science process skills in the field of physics education from 2000 to 2025. Bibliometric methods were selected because they offer a thorough understanding of research patterns, key keywords, collaboration networks among authors, and trends in research topics based on data from scientific publications (Ninkov et al., 2022).

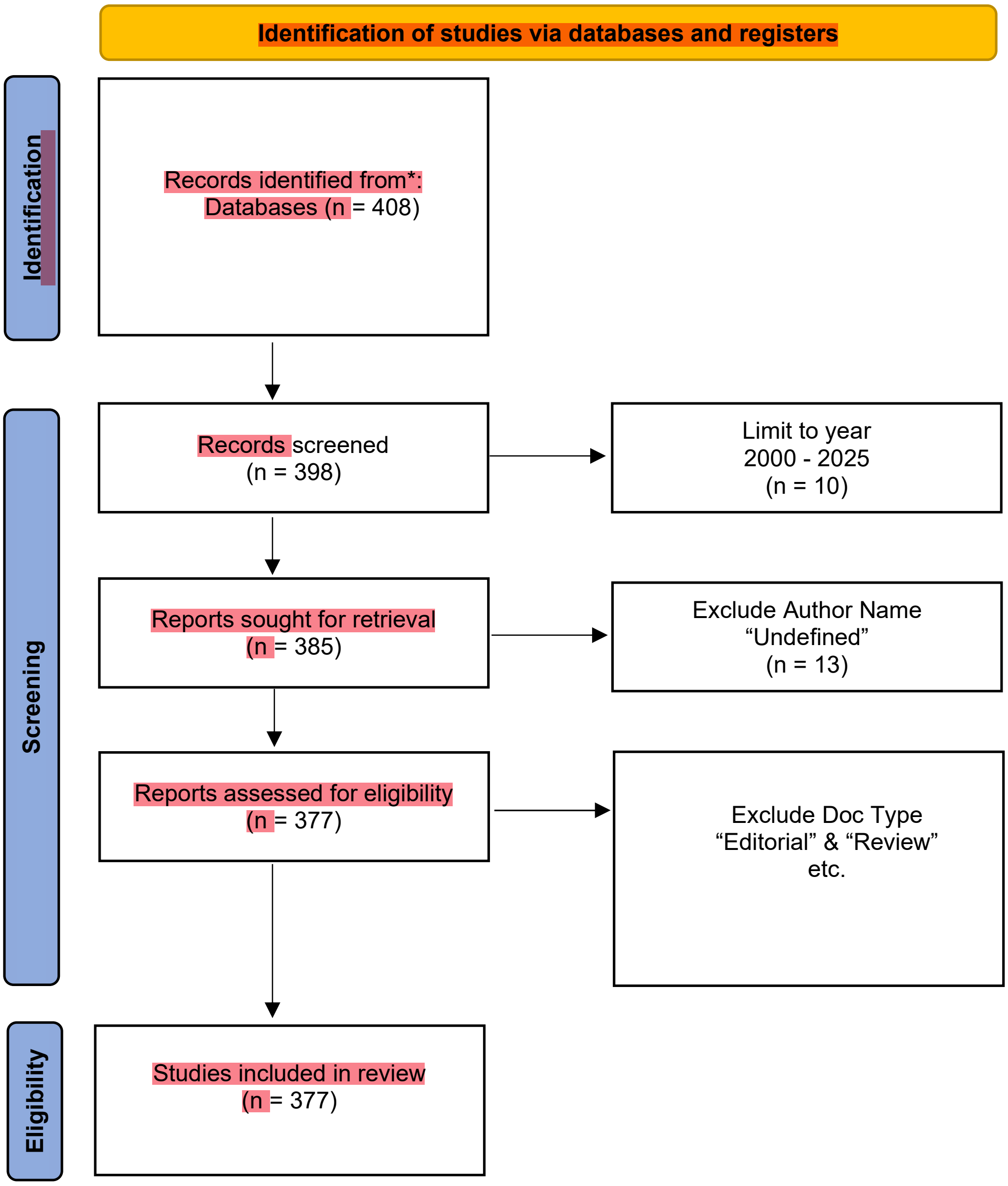

Figure 1. Method Diagram

Data collection was conducted by accessing the SCOPUS International Journal database, covering the period from 2000 to 2025. Documents were identified using two primary keywords on the search page: "Science Process Skill" and "Physics Education". The search process was conducted using the Article Title, Abstract, and Keywords (TITLE-ABS-KEY) search feature to ensure that the retrieved documents were directly relevant to the research topic. Data retrieval was conducted in September 2025 in a single search session to maintain consistency of results, given the dynamic nature of the Scopus database and its regular updates. The search query used was as follows: (TITLE-ABS-KEY ("Science Process Skill") AND TITLE-ABS-KEY ("Physics Education").

The search results were then exported in Microsoft Excel format (.csv) to facilitate data processing. The next stage involved additional filtering based on the relevance of keywords found in the document references.

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The data processing process consisted of three main stages: identification, filtering, and selection of relevant documents. The data collection and analysis process is visualized using the PRISMA diagram in Figure 1. The initial identification phase yielded 408 documents. The next stage was screening to remove duplicate documents, documents with incomplete metadata, and documents with authors listed as "Undefined". Next, a feasibility phase was conducted, excluding several publication types, such as editorials, review articles, and short communications. After completing all stages of the process, 377 documents were deemed suitable for further analysis. The final stage of data analysis was conducted using RStudio software and a thematic literature review approach using the Systematic Content Review (SCR) method. To ensure the repeatability of the study, the entire search process, including the databases used, search queries, search features (TITLE-ABS-KEY), data collection time (September 2025), and filtering criteria, was documented in detail so that other researchers could replicate the search process with the same configuration.

RESULTS AND DISCUSSION

Bibliometric analysis shows a significant increase in publications on science process skills (SPS) in physics education from 2001 to 2025, particularly in 2019, as shown in Figure 2 below.

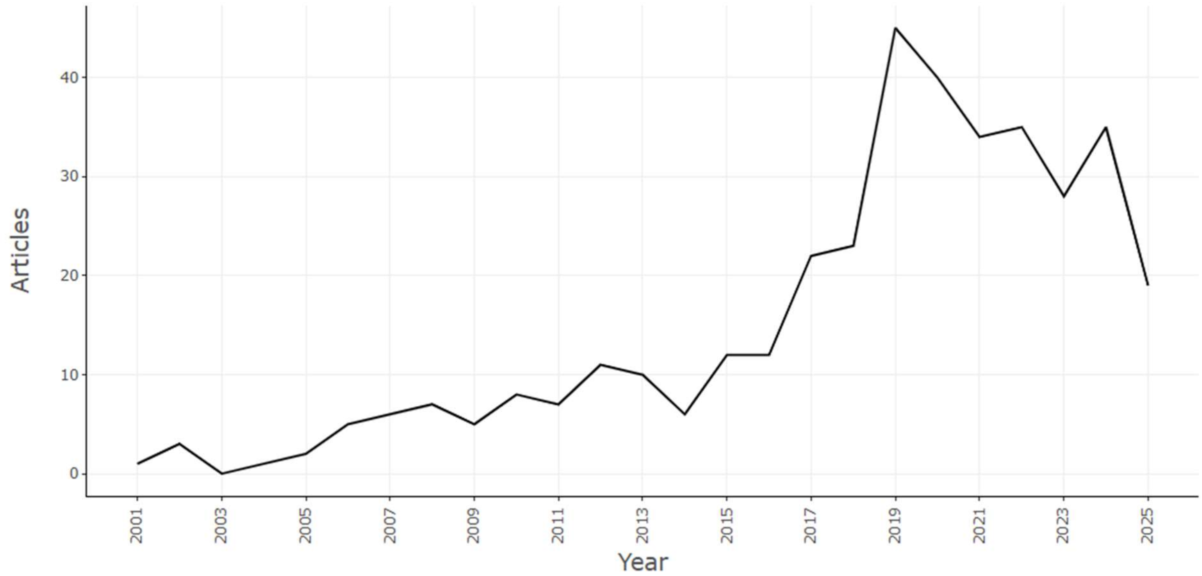

Figure 2. Research Trends from the Scopus Database

Based on Figure 2, in the initial period (2001–2005), the number of publications was still relatively low and unstable, ranging from 0 to 5 articles per year. A more stable increase began to appear in 2007, with an average of 5–10 articles per year until 2015. A sharp increase only occurred after 2016, reaching its peak in 2019 with more than 40 articles published. Subsequently, the publication pattern experienced a slight decline, although it remained at a higher level than in previous decades. In 2025, there was a further decline to around 20 articles. In general, this publication dynamic reflects significant progress, especially after 2015, which shows an increase in international awareness of the development of scientific process skills in physics learning.

This increase was influenced by several interrelated factors. First, the shift in the global educational paradigm from content-based learning to competency-based learning has encouraged the placement of SPS as the primary foundation of scientific literacy and problem-solving skills, so that SPS is viewed not only as a procedural skill but also as a means to develop higher-order scientific thinking skills (Pfefferová & Plesch, 2025). Second, the integration of 21st-century skills frameworks into national and international curricula reinforces the urgency of developing SPS (Azzahra et al., 2024). Skills such as critical thinking, creativity, collaboration, and communication are directly linked to SPS indicators, such as observation, data interpretation, hypothesis formulation, and experimentation (Lestari & Oktaviani, 2023).

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Next, the keyword network visualization is shown in the form of a Sankey diagram in Figure 3 below. In this visualization, the left side (ID) represents the original keywords used by the authors, the middle section (KW_Merged) shows keywords that have been normalized or combined based on similar meaning, while the right side (DE) shows the standardized descriptor keywords in the database. The connecting lines in the diagram represent the frequency of co-occurrence of two keywords in a single publication, with thicker lines indicating more frequent co-occurrence of two keywords, thus indicating a stronger conceptual relationship.

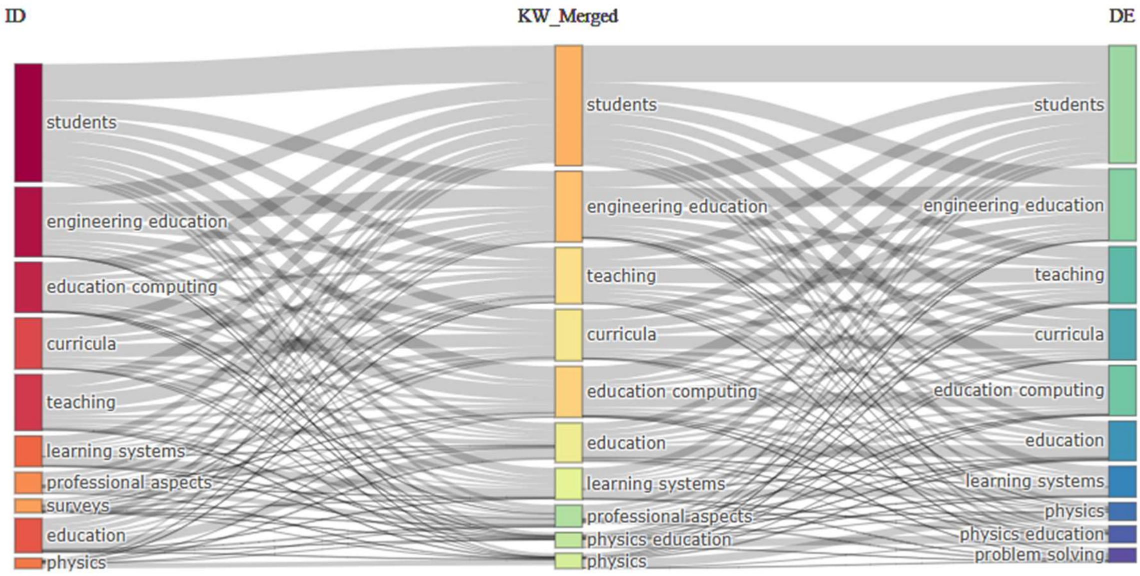

Figure 3. Thematic Structure of Science Process Skills Research

The visualization results show that the keywords "students," "engineering education," "teaching," and "curricula" have the highest number of connections, indicating their role as central to the research theme. The strong relationships between these keywords indicate that the research focuses heavily on developing student competencies through learning approaches, curriculum, and the integration of educational technology. In addition, keywords such as "learning systems" and "educational computing" show medium connectivity, while the relationship with keywords such as "physics education" and "problem solving" shows that the development of science process skills is still widely studied in the context of science learning and strengthening analytical thinking skills.

This trend is further supported by research from Iqbal et al. (2025), which indicates rapid growth in SPS research over the past decade, especially concerning contemporary science learning. Additionally, the shift in focus from curriculum-related keywords to topics such as STEM, virtual laboratories, and engineering education aligns with a study by Sakdiah et al. (2022) showing that the STEAM approach effectively improves students' science process skills and scientific attitudes in a vocational physics program. This suggests that current research is increasingly integrating technology, creativity, and digital experimentation as fundamental elements of modern science education.

Furthermore, figure 4 bellow shows the distribution of research terms, indicating that the focus of studies related to Science Process Skills has undergone dynamic development since 2007.

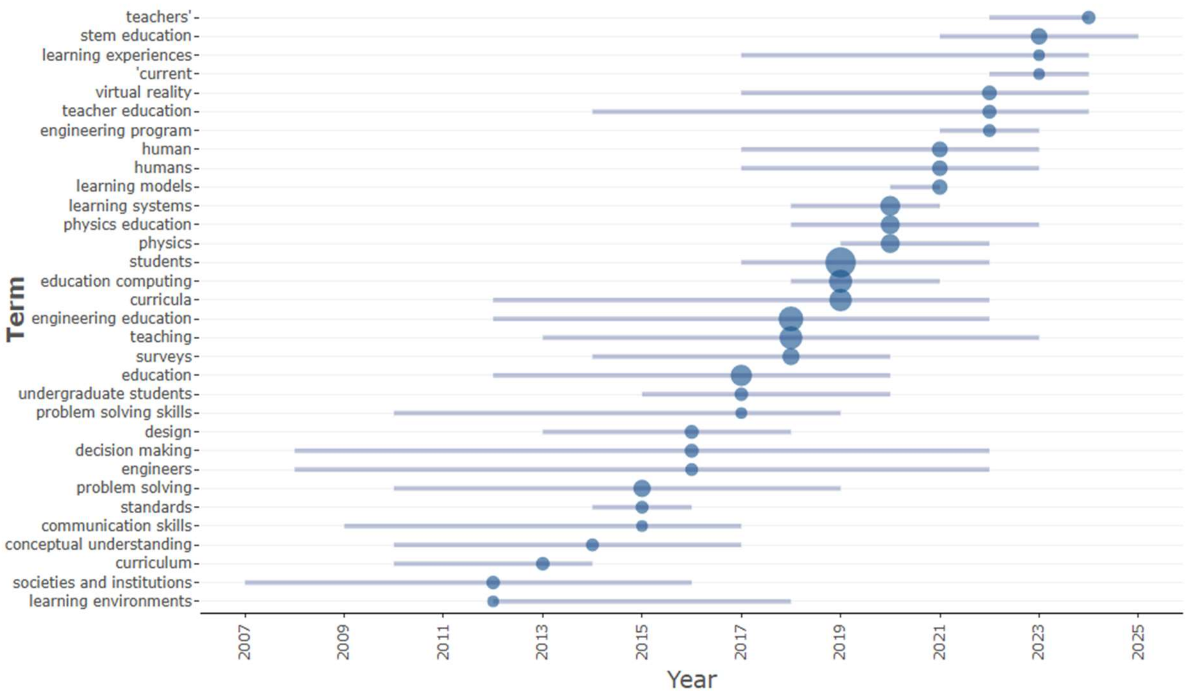

Figure 4. Research Topics Based on Terms/Keywords and Their Distribution Over Time (2007–2025)

Based on these results, it is clear that in the initial period (2007–2012), the dominant terms included "curriculum," "standards," "problem solving," and "communication skills," reflecting the initial research orientation on curriculum aspects and basic 21st-century skills. Entering the 2013–2017 period, research terms began to shift towards more applicable ones, such as "engineering education," "design," "decision making," "problem-solving skills," and "teacher education." This theme shows the strengthening of the role of engineering education and teacher training in equipping students with 21st-century competencies. In the most recent period (2018–2025), terms related to technology and innovative learning experiences have emerged, including "virtual reality," "STEM education," "learning experiences," "learning systems," and "learning models." In addition, terms related to students such as "students," "undergraduate students," and "humans" are also becoming more prominent.

These findings are supported by research by Tawil (2024), which shows that both teachers and students consider science process skills (SPS) to be an important component in developing observation, data analysis, and problem-solving abilities. Consequently, much research now focuses on improving SPS through the use of more realistic experimental methods. Technology integration plays a crucial role in education. The use of virtual laboratories, digital worksheets, and learning methods incorporating digital sensors have been shown to effectively enhance students' experimental skills (Kurniawan et al., 2023). Furthermore, Maimunah et al. (2025) developed curriculum-aligned student worksheets that successfully enhanced student creativity and collaboration on the topic of renewable energy.

These findings suggest that technology integration supports a student-centered and active learning environment, where students engage in problem-solving, collaboration, and conceptual exploration. This trend helps explain the increasing attention to technology- and computation-based learning in physics education research. In physics labs, research by Rinjani and Romadona (2023) revealed that experimental activities, such as changes in the state of matter, can significantly improve observation and scientific communication skills. Furthermore, Adam et al. (2022) found that university physics students often lack proficiency in experimental and observation skills. These findings have prompted numerous studies aimed at developing scientific process skills (SPS) through laboratory-based learning.

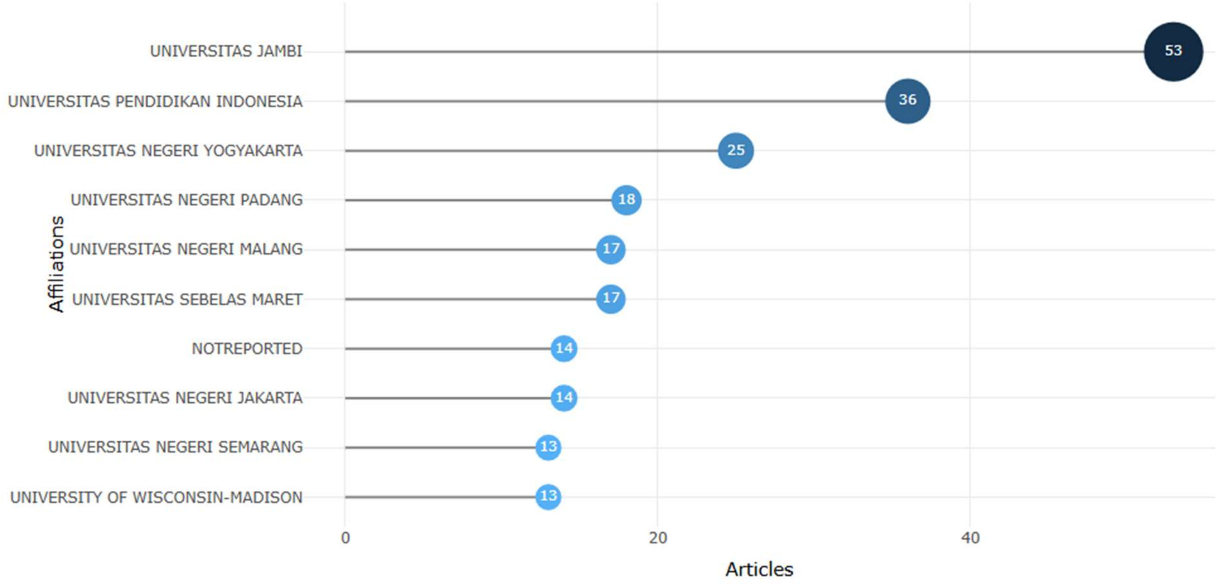

Figure 5. Distribution of Publications Based on Institutional Affiliation

Figure 5 shows that of the top 10 affiliates, eight are from Indonesia, indicating a high geographic concentration of research in that country. Furthermore, only one non-Indonesian institution is among the top-ranked institutions, the University of Wisconsin-Madison, from the United States. This finding indicates that, despite the global nature of the research topic, publication contributions are still dominated by specific national contexts, particularly Indonesia. The analysis also reveals the presence of a "Not Reported" category, indicating that some publications lack institutional affiliation information identified in the database metadata. In this dataset, this category includes 14 publications.

The publication distribution map in figure 6 bellow illustrating how research on Science Process Skills is spread across the globe, with a particular focus on certain countries. Darker shades of blue indicate higher publication productivity, while lighter shades of blue indicate lower publication output. Gray areas indicate countries that have no publications recorded in the dataset.

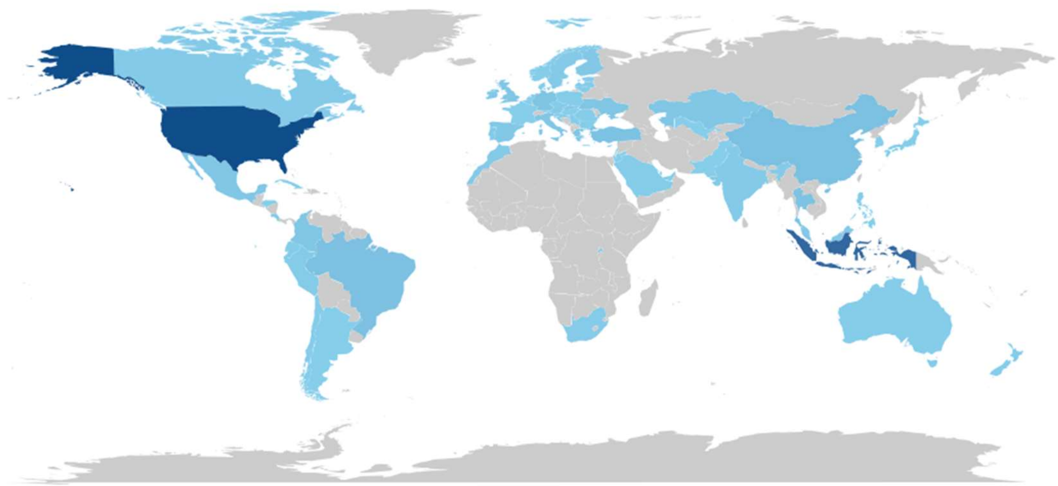

Figure 6. Map of Productive Countries

The publication distribution map shows that the highest contributions come from the United States and Indonesia. They are followed by other important countries including China, India, the United Kingdom, Canada, Australia, Malaysia, and Brazil. Several European countries such as Germany, the Netherlands, Spain, and Italy, along with Asian countries such as Japan, South Korea, and the Philippines, are also involved,

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although their participation is more limited. Meanwhile, most countries in Africa and the Middle East still have relatively low contributions. The color gradient reflects publication density, allowing for a visual comparison of research productivity across regions. This visualization highlights the geographical concentration of research output and identifies regions with growing research activity. The analysis of international collaboration reveals that publications in Science, Physics, and STEM (SPS) are predominantly authored by researchers from Asian and American countries, while participation from Africa and the Middle East remains limited. These findings highlight the necessity to expand cross-border research networks.

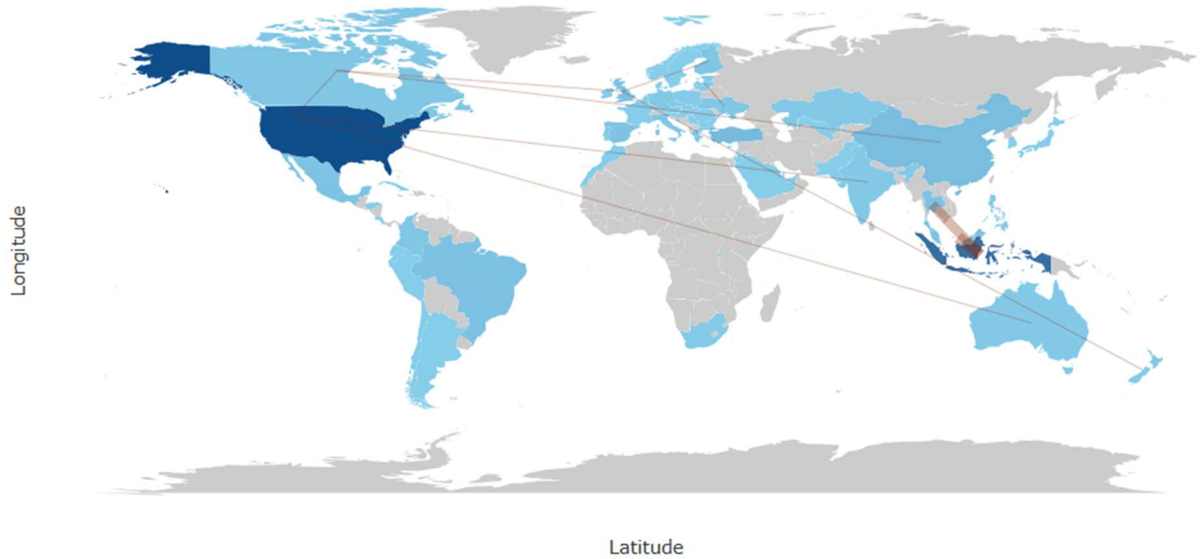

Figure 7. Plot of Inter-Country Collaboration Map

Figure 7 shows a map of international collaboration, illustrating that research related to Science Process Skills involves cross-national collaboration networks, but with a fairly strong regional pattern. The United States remains the center of global collaboration with connections to various countries in Europe, Asia, and Australia. Meanwhile, Indonesia displays a more dominant collaboration pattern regionally, particularly with countries in Southeast Asia. Based on the visualization, Indonesia appears to have clearer collaboration connections with countries like Thailand compared to direct connections to the United States. This indicates that Indonesia's research network in this field remains relatively strong regionally.

On the other hand, the United States appears to play a role as a global collaboration hub, with connections to various regions of the world. However, there is no strong direct connection between Indonesia and the United States in this visualization, suggesting that research collaboration between the two countries in this dataset may still be limited or not dominant. This finding indicates that strengthening international collaboration across regions (e.g., Southeast Asia-North America or Southeast Asia-Europe) remains a significant opportunity for future research development. Furthermore, the dominance of regional collaboration can also be a strength in itself, as it allows for the development of research that is more contextual and relevant to local educational needs.

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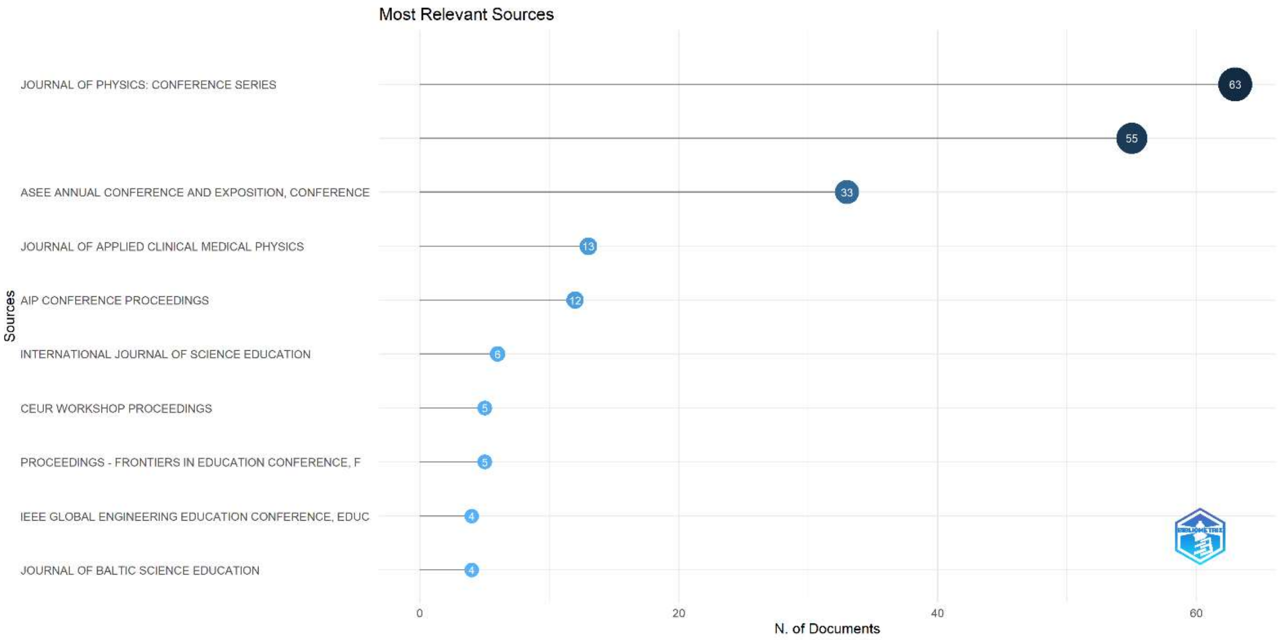

Figure 8. Publication Sources with the Highest Number of Documents

The graph in Figure 8 shows that research on Science Process Skills was most frequently published in the Journal of Physics: Conference Series, with a total of 63 documents. The ASEE Annual Conference and Exposition followed, also showing a significant contribution to publications. Below these two main sources, there are other sources with medium contributions, such as the Journal of Applied Clinical Medical Physics and the AIP Conference Proceedings, demonstrating the research's relevance to applied physics and the multidisciplinary STEM fields. Meanwhile, science education journals such as the International Journal of Science Education appeared, but at a smaller proportion than conference proceedings. Overall, this pattern indicates that research dissemination in this field still relies heavily on international conference forums. The dominance of conference proceedings over journal publications indicates that research on science process skills is still developing rapidly. Conference papers typically allow for faster dissemination of new findings, while journal articles undergo a more rigorous peer-review process and often present more comprehensive theoretical and methodological contributions. Therefore, while conferences play a crucial role in accelerating innovation, increased publication in high-impact journals will strengthen the theoretical consolidation and long-term academic influence of this research field.

The graph in Figure 9 below shows the shift in research focus from 2001–2020 to 2021–2025. The thickness of the lines in the graph indicates the strength of the relationship and the intensity of theme occurrence, with thick lines indicating dominant and consistent themes across the period, while thin lines indicate themes with more limited occurrence.

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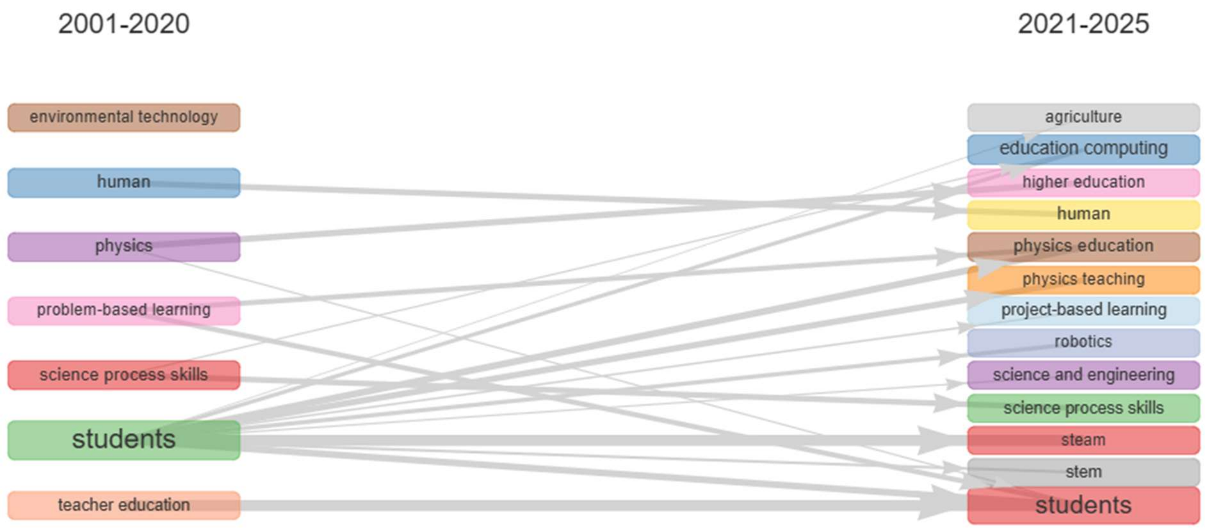

Figure 9. Evolution of Research Themes

Figure 9 shows that during the 2001–2020 period, research was dominated by the themes of science process skills, teacher education, students, and problem-based learning, indicating a focus on strengthening pedagogy and the role of teachers in developing science process skills. This indicates that the research orientation still tends to be teacher-centered. Entering the 2021–2025 period, a shift toward more student-centered learning is evident, caused by the strengthening of the student theme and the decreasing dominance of teacher education. In addition, technology-based and multidisciplinary themes such as STEM, STEAM, educational computing, and robotics have emerged. Despite the diversity of approaches, the core theme of science process skills and students remains a consistent focus of research, demonstrating continuity in the direction of study as well as adaptation to the demands of 21st-century education.

Furthermore, an analysis of the evolution of themes indicates increasing attention to technology-based learning environments, particularly virtual laboratories, digital simulations, and computational education. The bibliometric shifts identified in this study indicate that SPS research is increasingly directed at optimizing learning experiences through virtual and digital technologies. Recent research no longer focuses solely on curriculum structure but rather emphasizes how technology can facilitate scientific investigation, concept exploration, and active student participation. Similarly, Sakdiah et al. (2022) have emphasized that integrating art and technology into physics education not only strengthens SPS frameworks but also enhances scientific attitudes and creativity, which are essential components of global competency requirements. This alignment suggests that the increasing use of virtual technologies reflects the need to provide more flexible, authentic, and accessible science learning experiences to support the development of science process skills.

Overall, the findings indicate a significant increase in publications since 2010, peaking in 2019, coinciding with a shift in research focus from curriculum issues to digital technology integration, STEM/STEAM approaches, and virtual laboratories. However, the uneven geographic distribution and the concentration of research themes on specific approaches indicate that structural gaps persist within the SPS research field. This pattern indicates that while SPS has received global attention, research development remains focused on specific areas and pedagogical approaches, opening up opportunities for cross-contextual and cross-disciplinary exploration in future research.

This study presents three key implications. First, research on Science Process Skills (SPS) should continue to emphasize the integration of digital technology, virtual laboratories, and computational education to address the demands of 21st-century competencies. Second, it is essential to expand research into higher education and vocational education, as existing studies in these areas are limited. Third, international collaboration must be strengthened to enhance the global impact and advancement of SPS research. Additionally, this study significantly contributes to the field of physics education. First, it demonstrates that SPS serves as a vital foundation for improving scientific capabilities and 21st-century skills. Second, the findings underscore the necessity of systematically incorporating digital technology, virtual laboratories, and

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STEM/STEAM approaches into physics instruction. Lastly, there is an urgent call to broaden SPS research in higher education and vocational settings, as well as to enhance international research partnerships. Consequently, this study offers new insights for the development of SPS-based learning theory and practice.

The results of this study indicate that the development of SPS research not only reflects increased scientific productivity but also demonstrates a conceptual transformation in modern science education. The trend of increasing publications and shifting research themes answers RQ1 by indicating that SPS is increasingly positioned as a core competency in science learning. Meanwhile, the identification of research gaps answers RQ2 by showing that although SPS research is growing globally, the distribution of research, the variety of educational contexts, and the diversification of pedagogical approaches still require strengthening in future research.

Although this study offers a comprehensive overview of trends in Science Process Skills (SPS) research in the field of physics education, it still has several limitations. First, the analysis relies solely on the Scopus database, which may not fully reflect publications recorded in other major databases, such as Web of Science, Dimensions, or national indexing systems. Second, the results of bibliometric analysis are highly dependent on the accuracy and completeness of metadata, such as author affiliations, keywords, and citation data, which can vary between publications due to publisher-managed metadata input processes, indexing methods, and standardization, and are therefore not always consistent across journals and time periods. Third, this study emphasizes quantitative mapping of publication patterns and collaboration networks, without involving in-depth analysis of the content of each study. Thus, further research is recommended to integrate various databases and combine bibliometric methods with qualitative or content-based analysis approaches to gain deeper insights into the progress of SPS research.

This study contributes to the achievement of Sustainable Development Goal (SDGs) 4 and SDGs 17 through several important implications. The impact on SDGs 4 (Quality Education) lies in providing a comprehensive mapping of research trends on science process skills in physics education, which can guide educators, researchers, and policymakers in designing learning approaches that strengthen scientific literacy and 21st-century competencies through technology integration and innovative instructional strategies. Meanwhile, the impact on SDGs 17 (Partnerships for the Goals) is reflected in the identification of global collaboration networks among authors and countries, which highlights the importance of strengthening international research partnerships, promoting knowledge exchange, and expanding collaborative opportunities to advance science education research across different regions.

CONCLUSION

The findings reveal that research on scientific process skills (SPS) in physics education has experienced significant growth over the past two decades, both in the number of publications and the diversity of research themes. The mapping results indicate that the development of SPS research aligns with Sustainable Development Goal (SDGs) 4, which aims to improve the quality of science learning and foster 21st-century competencies through innovations such as digital learning, STEM/STEAM education, and virtual laboratories. Furthermore, increased collaboration among authors and countries contributes to SDGs 17 by strengthening global partnerships in publishing, knowledge exchange, and international research networks. However, because this study relies solely on a single database, Scopus, and its reliance on metadata completeness and keyword consistency, future research should utilize additional databases such as Web of Science, Sinta, or Dimensions, along with advanced bibliometric analysis techniques such as structural variation analysis, complex network analysis, and machine learning-based topic modeling. In addition, future studies are expected to focus on mapping SPS in the context of bold learning, artificial intelligence, and higher education, areas that are currently underrepresented in research trends, thus providing a more comprehensive view of global SPS developments.

AUTHOR CONTRIBUTIONS

Khofifatur Risma Faradillah: Conceptualization, Visualization, Formal Analysis, Writing - Original Draft; **Indri Maya Ariana:** Formal Analysis, Writing - Review & Editing; **Muhammad Ghiyats Naufal:** Methodology and Software; **Adrian Bagas Damarsha:** Software, Resources, and Investigation; **Titin Sunarti:** Validation and Supervision; **Hanandita Veda Saphira:** Writing - Original Draft, Writing - Review & Editing. All authors have read and approved the final version of this manuscript.

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DECLARATION OF COMPETING INTEREST

The authors declare no known financial conflicts of interest or personal relationships that could have influenced the work reported in this manuscript.

DECLARATION OF ETHICS

The authors declare that the research and writing of this manuscript adhere to ethical standards of research and publication, in accordance with scientific principles, and are free from plagiarism.

DECLARATION OF ASSISTIVE TECHNOLOGIES IN THE WRITING PROCESS

The authors declare that generative artificial intelligence (Gen AI) and other AI-assisted tools were used prudently, not excessively, during the research and preparation of this manuscript. Specifically, Blackbox AI for improving readability; ChatGPT was used for Brainstorming ideas; DeepL was used for translation; Grammarly for grammar and style correction. All AI-generated material was reviewed and edited for accuracy, completeness, and compliance with ethical and scholarly standards. The authors accept full responsibility for the final content of the manuscript.

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