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Evolving Science Teacher Professional Development in Asia: A Comparative Mapping of Southeast and East Asian Research

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ABSTRACT

Purpose of the study: This study aims to explore and compare the development trajectories, collaboration structures, and thematic emphases of professional development research for in-service science teachers in Southeast Asia and East Asia, providing insights into how Professional Development (PD) scholarship has evolved across the two regions from 2015 to 2025.

Methodology: A comparative bibliometric analysis was conducted using 87 Scopus-indexed publications (2015–2025). Biblioshiny (RStudio) and VOSviewer were used to examine publication trends, authorship networks, institutional and international collaborations, and thematic evolution of professional development research for in-service science teachers in Southeast Asia and East Asia.

Main Findings: Results reveal distinct yet complementary orientations. Southeast Asia's research is largely practice-oriented, reform-driven, and community-based, emphasizing teacher agency, STEM education, and action research. East Asia's studies are more conceptually grounded, technologically integrated, and methodologically cohesive, reflecting strong engagement with frameworks such as TPACK, argumentation, AI in teaching, and sustained quality assurance in professional development research.

Novelty/Originality of this study: This study offers a region-to-region comparative bibliometric mapping of science teacher professional development research in Southeast Asia and East Asia. Through integration of collaboration patterns, thematic evolution, and policy-linked orientations, it advances understanding of regional strengths and proposes a trans-Asian professional development framework that bridges participatory reform with analytical rigor.

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1. INTRODUCTION

Science education equips new generations with 21st century skills such as creativity, critical thinking, and problem-solving while fostering active engagement with real-world issues. These skills are needed to understand and address global challenges across social, economic, environmental, and other domains [1], [2]. For example, it encourages students to critically examine socio-scientific issues such as climate change [3]-[5]. As part of the broader STEM education framework, science education also develops competencies such as scientific literacy, which are important for international competitiveness and for adapting to rapid technological change [6].

Scientific literacy refers to an individual's ability to learn scientific concepts and content and to apply them in daily life, such as by identifying questions, drawing evidence-based conclusions, and making informed decisions about the natural world and the changes brought about by human activity [7], [8]. At the core of achieving these skills are teachers who influence students' scientific literacy, interest, and aspirations while also implementing curriculum and advancing science education reforms [9]-[11]. Accordingly, their crucial influence has led to a prioritization of educational research and sustained global investment in teacher professional development (PD) programs aimed at empowering and informing them with teaching strategies, knowledge, and skills in line with current trends of science teaching [12]. In other words, it is a continuous professional endeavor aimed at enhancing teachers' knowledge and skills by engaging them in relevant courses that serve as initiatives to upgrade their expertise and eventually produce high-quality educators [13]-[15].

Teachers' PD is viewed as the foundation of all effective educational innovations [16]. The examples of such PD initiatives include introducing them about inquiry approach [17], participatory action research [1], information, communication, and technology (ICT) tools [18], argumentation in science classroom [19], and language-support skills in elementary school science instruction [20], [21]. Despite these PD initiatives, not all always translate into meaningful changes in practice and student outcomes because of several constraints as reported by the literature. For example, Revina et al. [22], in their critical examination of the historical trajectory, current outcomes, and underlying causes of stagnation in Indonesia's teacher PD system, identified key reasons for ineffective teacher PD initiatives. These include unclear teaching standards, limited oversight, chronic underfunding, reliance on low-cost and short-term workshops, incoherent policies, lack of accountability for teacher performance, and repetitive basic content that reduces teachers' motivation and perceived relevance. Similarly, Ramli et al. [13] stressed the lack of congruence between PD programs and teachers' anticipated outcomes on top of undue burdens on their workload. This emphasizes the need for personalized PD initiatives tailored to teachers' unique needs and highlights the importance of conducting needs assessments to pinpoint specific domains requiring enhancement. While Revina et al. [22] emphasizes systemic and structural shortcomings (e.g., standards, funding, policy, oversight), Ramli et al. [13] presents issues on program design and implementation issues (e.g., needs assessment and workload burdens).

In Southeast Asia (SEA), these challenges are often magnified by resource disparities, centralized policy frameworks, and varied levels of teacher preparation [23]. On the contrary, East Asian (EA) systems, such as those in Japan, South Korea, and China, are often characterized by strong state-led reforms, well-established teacher evaluation mechanisms, and a culture of continuous improvement [24]. These two regions represent contrasting yet interconnected educational ecosystems shaped by different historical, political, and socio-economic educational reforms. SEA countries are generally characterized by rapidly expanding education systems undergoing reform and capacity building, whereas EA countries are often positioned as global leaders in structured teacher professional learning systems and educational performance.

Therefore, comparing SEA and EA provides a scientifically meaningful analytical lens because it allows the examination of how diverse governance structures, technological infrastructures, and policy environments shape the evolution of science teacher PD. Furthermore, such comparison enables identification of complementary strengths, transferable practices, and regional policy learning opportunities that cannot be captured through single-region or country-specific analyses. However, both regions are facing the common challenge of aligning PD with the rapidly evolving demands of science and technology education, particularly in areas such as inquiry-based teaching, digital integration, and interdisciplinary learning. While it may not be possible to address all these systemic challenges at once, an initial step is to synthesize existing literature through bibliometric analysis, an approach also undertaken in other studies with the same aim of helping policymakers identify which PD contents should be prioritized (e.g., [25], [26]). This is to align science teachers' evolving topical needs and teachers' practice with recent reform goals and evolving pedagogical standard. In other words, bibliometric analysis can systematically map the topic evolution, trends, and research gaps [27]. Consequently, performing bibliometic analysis regarding PD trends and research foci for science educators could eventually provide an evidence-based foundation for future PD program foci, trends, contributions, designs, and policy decisions [28].

Despite these contributions, several research gaps remain evident in the literature. First, from a conceptual perspective, existing studies often treat professional development as a generalized construct without sufficiently distinguishing how pedagogical innovation, teacher agency, technological integration, and institutional reform interact within specific regional contexts. Second, from a methodological standpoint, many PD syntheses rely on systematic reviews or narrative reviews that provide thematic insights but lack quantitative mapping of intellectual structures, collaboration networks, and thematic evolution over time. Third, from a regional perspective, existing bibliometric and review studies predominantly focus on Western educational systems or examine Asian countries individually, resulting in limited comparative understanding of how PD scholarship evolves across subregions of Asia. Moreover, a comparative bibliometric approach can highlight convergences and divergences between SEA and EA contexts. This may eventually offer region-specific insights for reform implementation. It is crucial because science education research in Asia has grown unevenly across subregions. Focusing also on the period 2015–2025 allows the study to capture both pre- and post-COVID-19 dynamics which introduced new pressures

and opportunities for digital PD, remote collaboration, and rethinking classroom practices. This time-sensitive and region-specific bibliometric synthesis may illuminate how PD for science educators evolves in relation to broader educational reforms, regional challenges, as well as global shifts. Existing reviews and syntheses on teacher PD tend to be broad in scope across all disciplines, with limited focus on science-specific PD (e.g., [29], [30]. Some often lack a longitudinal view on how PD research foci have evolved over time or conclude at a temporal boundary set several years ago, leaving a gap for the years not covered up to the present [28]. Consequently, these could result to lack of information regarding emerging topics in the field, emphasizing the need for a bibliometric analysis that is both discipline-specific and time-sensitive.

The novelty of the present study lies in its region-to-region comparative bibliometric mapping of science teacher professional development research across Southeast Asia and East Asia, integrating collaboration structures, thematic evolution, and policy-oriented research directions. Unlike previous studies that focus on single-country PD trends or global generalizations, this study provides a cross-regional analytical framework that captures both divergence and convergence of PD scholarship across two major Asian educational regions. The urgency of this research is underscored by rapid technological advancement, the growing integration of artificial intelligence in education, and the continuing transformation of science teaching practices following the COVID-19 pandemic, which collectively demand responsive, evidence-based, and regionally contextualized PD systems. Without systematic mapping of evolving PD research trends, policymakers and educational institutions may face challenges in designing adaptive and sustainable teacher training programs aligned with contemporary science education demands. Therefore, this study aims to map evolving research trends in professional development for science educators in SEA and EA from 2015 to 2025 to provide both a comprehensive overview and a comparative lens. Eventually, it aims to provide policy, programmatic, theoretical, and global developmental implications for strengthening, sustaining, and harmonizing professional development systems for in-service science teachers across SEA and EA.

2. RESEARCH METHOD

Bibliometric analysis systematically examines scientific literature to identify patterns, trends, and impacts within a specific research field [31]. Eck and Waltman [32] laid out the major steps which involded identifying the appropriate bibliographic database, developing search criteria, selecting suitable data analysis software tools, and conducting a comprehensive analysis of the retrieved data. *Identifying the Bibliographic Database and Developing Search Criteria.* The analysis initiated with data extraction from documents listed in Scopus database. The database was selected because of its extensive collection of literature and rigorous evaluation by experts in the relevant field prior to contribution's inclusion in the database. Moreover, its robust indexing of author affiliations, citations, and keywords, along with easy export of metadata for bibliometric tools, made it the ideal source of data [33]-[35]. The subsequent steps followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (see Figure 1).

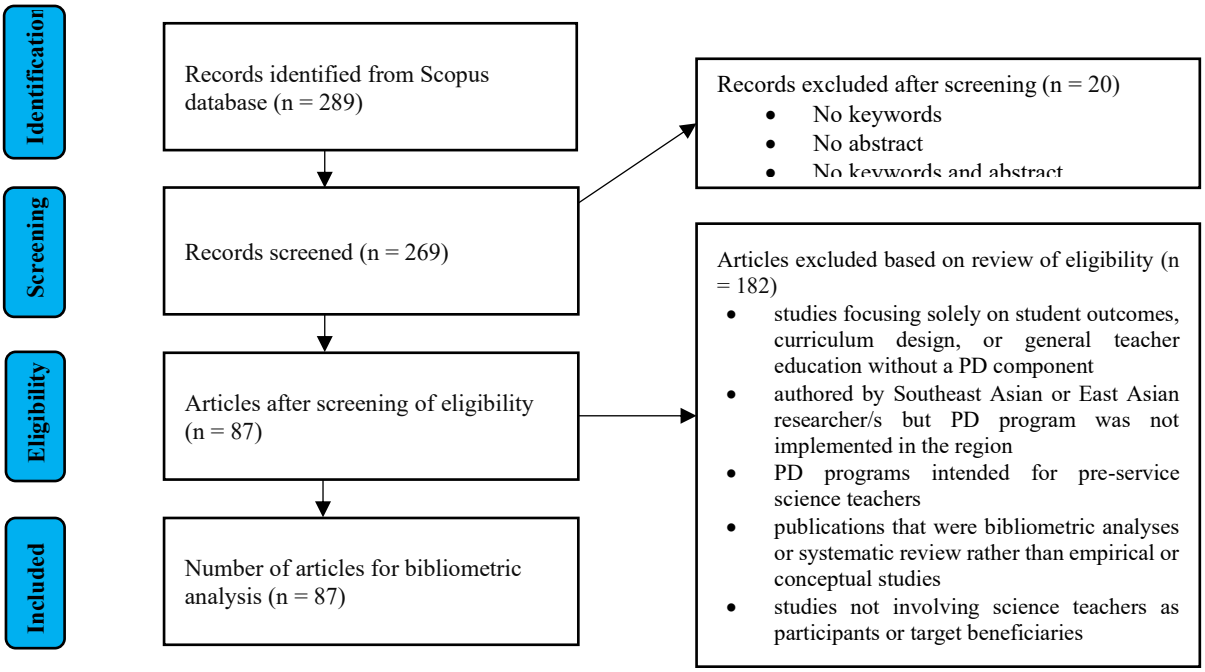


Figure 1. PRISMA method procedure for identifying and selecting the documents

The search strategy was carefully designed to capture literature relevant to the research objectives while minimizing irrelevant results (see Table 1). The query was performed in Scopus using the TITLE-ABS-KEY field which limits the results to documents containing the search terms in the title, abstract, or keywords to enhance conceptual relevance. The search combined two thematic groups which are (1) professional development OR teacher training and (2) science educators OR science teachers. These are linked with the Boolean operator AND to identify studies addressing both teacher development and science education. Only publications from 2015 to 2025 were included (PUBYEAR > 2014 AND PUBYEAR < 2026).

Eventually, the strategy applied a series of exclusion and inclusion criteria during the initial screening stage to refine the dataset. These are shown in Table 1. Subject area filters were used to eliminate publications outside the scope of the study. Only documents categorized under social sciences, computer science, engineering, mathematics, psychology, physics and astronomy, environmental science, chemistry, and agricultural and biological sciences were retained to focus the analysis on educational and scientific domains and enhance thematic coherence. Furthermore, only specific document types (*i.e.*, articles, conference papers, book chapters, and reviews) were included because these represent peer-reviewed and substantive scholarly outputs that best reflect research progress in teacher professional development within science education. The publication stage and language were restricted to "final" and "English," meaning in-press and non-English documents were excluded. The source type was also limited to journals and conference proceedings. Lastly, only publications affiliated with Southeast Asian and East Asian countries were included. All other parameters, such as source title, keyword, affiliation, funding sponsor, and open access, were set to "all." These search criteria yielded a total of 289 documents.

Table 1. Search Strategy

Parameters	Criteria
Database	Scopus
Search String	TITLE-ABS-KEY (("professional development" OR "teacher training") AND ("science educators" OR "science teachers" OR "STEM educators" OR "STEM teachers"))
Time Span	2015 – 2025
Subject Area	Limit to: Social Sciences, Computer Science, Engineering, Mathematics, Psychology, Physics and Astronomy, Environmental Science, Chemistry, Agricultural and Biological Sciences
Document Type	Limit to: Article, Conference Paper, Book Chapter, and Review
Source Title	All
Publication Stage	Limit to: Final
Keyword	All
Affiliation	All
Funding Sponsor	All
Country/Territory	Southeast and East Asian Countries
Source Type	Limit to: Journal and Conference Proceeding
Language	English
Open Access	All

Subsequently, in the eligibility phase, retrieved documents were subjected to detailed screening to ensure alignment with the objectives of the study by three panel of evaluators with research profiles in bibliometric analysis, science education, and teacher training programs. They were assigned specific publications to review and collectively discuss in order to assess their eligibility for inclusion in the study based on the titles, abstracts, and keywords. Only publications directly addressing professional development (PD) programs for in-service science teachers within SEA and EA were retained. The following exclusion criteria were applied to refine the dataset and maintain conceptual focus: studies that focused solely on student outcomes, curriculum design, or general teacher education without a PD component; studies authored by Southeast Asian or East Asian researchers but with PD programs implemented outside their respective regions; PD programs intended for pre-service rather than in-service science teachers; publications that were bibliometric analyses or systematic reviews rather than empirical or conceptual studies; and studies not involving science teachers as participants or target beneficiaries. These criteria ensured that the final dataset represented research with direct relevance to the design, implementation, or evaluation of PD programs for in-service science teachers across the selected regions. Toward the end of this phase, 178 documents were excluded.

Finally, in the inclusion phase, the final dataset was consolidated into a single Microsoft Excel file comprising 91 publications deemed eligible for analysis of which 64 were from SEA and 23 from EA. Each entry

included detailed information such as the following but not limited to author name(s), profile link(s), document title, source type, summary, keywords, citation count, year of publication, and references.

Data Analysis. The data extracted from Scopus database were processed using Microsoft Excel and OpenRefine to prepare the raw data for analysis. OpenRefine is an open-source tool which cleans, transforms, and organize data ready for use in bibliometric software. Subsequently, the bibliometric data were analyzed in RStudio using Biblioshiny, a web-based graphical user interface for the Bibliometrix R package. It performs bibliometric analyses through an interactive dashboard in the web browser. Outputs in form of tables from the analyses were downloaded in Microsoft Excel format. These serve as inputs for generating enhanced data presentation in Microsoft Excel. Other graphical outputs generated by Biblioshiny were retained and presented in their original form. Finally, the co-occurrence analysis was performed in VOSviewer. This software visualizes the relationships among keywords within the dataset. A minimum frequency threshold was set to identify which keywords were retained for the final analysis.

The data extracted from the Scopus database were processed using Microsoft Excel and OpenRefine to prepare the raw dataset for analysis. OpenRefine, an open-source application, was used to clean, transform, and organize the data for compatibility with bibliometric software. The processed data were then analyzed in RStudio using Biblioshiny. Outputs generated by Biblioshiny in tabular forms were downloaded. These serve as inputs for generating enhanced data presentation in Microsoft Excel. The other graphical outputs generated by the software were retained and presented in their original form. Finally, a co-occurrence analysis was conducted in VOSviewer to visualize the relationships among keywords within the dataset. For the VOSviewer keyword co-occurrence mapping, a minimum occurrence threshold of one was applied for documents of both regions (*i.e.*, SEA and EA) due to the limited number of studies which affected keyword frequency. The full counting method was employed, assigning equal weight to each co-occurrence link regardless of the number of publications. Clustering of terms was performed using the default VOSviewer clustering technique.

3. RESULTS AND DISCUSSION

3.1. Overview of the Data

Table 2 presents general information on documents retrieved from the Scopus database regarding PD programs for science teachers over the past ten years, including the present year. A total of 87 eligible documents were included for bibliometric analysis out of the 289 initially retrieved. These consist of 66 primary research articles, 20 conference proceedings, and one book chapter. An annual publication growth rate of 14.87% has been observed over the last ten years in this domain with each document cited an average of 10.99 times. The average publication date of the documents is relatively recent, with an average age of 4.22 years. These figures collectively indicate substantial growth in this field with the steady rise in publications and citations reflecting its increasing academic significance. The analysis also shows that the documents contained 133 index keywords and 352 author keywords. The higher number of author keywords suggests that researchers emphasize more specific and diverse themes in their studies, while database indexing captures fewer but more standardized terms. In other words, the greater use of author keywords highlights the field's breadth and evolving themes. Furthermore, a total of 273 authors contributed to the corpus with only eight single-authored works. It indicates a strongly collaborative research environment. The mean of 3.59 co-authors per document and 21.84% international collaboration rate further suggest increasing regional and cross-border academic engagement particularly within SEA-EA networks.

Table 2. General information on professional development programs in SEA and EA for in-service science teachers

Variables	Results
Data Set Properties	
• Timespan	2015:2025
• Sources (journals, books, etc.)	49
• Documents	87
• Annual growth rate (%)	14.87
• Document average year of publication (years)	4.22
• Average citations per document	10.99
Document Contents	
• Index keywords of all documents	133
• Author's keywords of all documents	352
Authors	
• Total authors (unique individuals)	273
• Authors of single-authored documents	8

Variables	Results
Authors Collaboration	
• Single-authored documents	8
• Co-Authors per document	3.59
• International co-authorships (%)	21.84
Document Types	
• Primary research article	66
• Conference paper/proceedings	20
• Book Chapter	1

3.2. Publication and Citation Trends

Figure 2 presents the annual publication and citation trends of PD research for in-service science teachers from 2015 to 2025. The data show a gradual increase in research output, rising from four publications in 2015 to sixteen in 2025. The increase may be slower but it reflects a steady expansion of scholarly interest in this domain. With regard to the citation performance, it fluctuates across the decade. The earlier publications (*i.e.*, 2015, 2016, and 2019) exhibits the highest mean citations per document suggesting their continued academic influence. In contrast, the lower citation means in 2024 and 2025 result from the expected citation time-lag effect where recent works having limited exposure for scholarly referencing usually receives lower citation performance. The notable citation peak in 2023 (mean = 7.11) may suggest renewed attention to PD research following the COVID-19 disruptions. It was the period when digital and hybrid training models became more prevalent. These patterns generally suggest a maturing and increasingly productive PD research landscape for in-service science teachers that balances long-term scholarly influence with emerging innovations in PD for science educators.

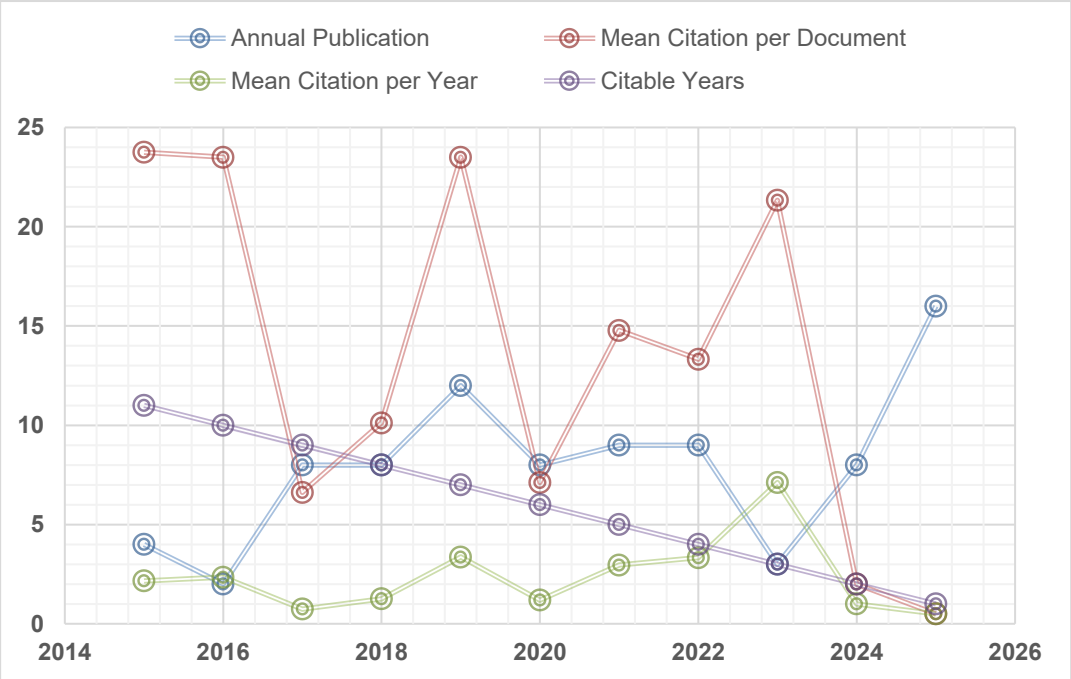


Figure 2. Annual publication trends and citation performance of documents on professional development research for in-service science teachers in SEA and EA (2015–2025)

3.3. Document Analysis by Source

Table 3 presents the results of the source analysis which identify leading journals and publication outlets contributing to the research on PD programs for in-service science teachers between 2015 and 2025. The *Journal of Physics: Conference Series* emerged as the most prolific outlet with twelve publications highlighting its role as a key venue for disseminating conference-based studies on science teacher PD. In contrast, *Asia-Pacific Science Education* demonstrated the highest scholarly influence with 214 total citations and an *h*-index of six. It reflects its prominence as a specialized regional journal advancing science education discourse. Similarly, *Research in Science Education* and the *Eurasia Journal of Mathematics, Science, and Technology Education* displayed strong academic visibility. These are, respectively, supported by reputable international publishers, Springer and Modestum Ltd. The presence of *Science Education International* and *Education and Information Technologies* both indexed in good quartiles further reflects the field's integration with broader global trends in educational research and technology-enhanced learning. Meanwhile, regionally anchored journals such as *Jurnal Pendidikan*

IPA Indonesia and the *Journal of Education and Learning* represent growing Southeast Asian contributions to this research area. The inclusion of both high-impact international journals and emerging regional outlets suggests a balanced scholarly ecosystem where global standards intersect with local educational imperatives. The results essentially suggest that research on PD programs for in-service science teachers is gaining visibility through a combination of established and high-impact journals with dynamic regional platforms. This reflects both the maturity and expanding inclusivity of the field.

Table 3. Sources with at least two publications on PD programs for in-service science teachers in SEA and EA

Source	NP	TC	h-index	Q	Publisher	Country
Journal of Physics: Conference Series	12	62	5	NR	IOP Publishing Ltd.	United Kingdom
Asia-Pacific Science Education	6	214	6	3rd	Brill Academic Publishers	Netherlands
Eurasia Journal of Mathematics, Science, and Technology Education	6	20	3	2nd	Modestum LTD	Turkey
Research in Science Education	4	90	3	1st	Springer	Netherlands
Advanced Science Letters	3	8	1	4th	American Scientific Publishers	United States
Science Education International	3	14	2	3rd	International Council of Associations for Science Education (ICASE)	Ireland
Education and Information Technologies	2	66	2	1st	Kluwer Academic Publishers	United States
International Journal of Innovation, Creativity, and Change	2	15	1	NR	NR	Australia
International Journal of Learning, Teaching, and Educational Research	2	0	0	3rd	Society for Research and Knowledge Management	Mauritius
Journal of Education and Learning	2	9	1	4th	Intelektual Pustaka Media Utama	Indonesia
Journal of Science Education and Technology	2	28	2	1st	Springer	Netherlands
Jurnal Pendidikan IPA Indonesia	2	23	2	3rd	Universitas Negeri Semarang	Indonesia
Social Sciences and Humanities Open	2	0	0	1st	Elsevier Ltd	United Kingdom

Note. NP – Number of Published Documents, TC – Total Citations, Q – Quartile, NR – Not Reported

3.4. Production and Collaboration by Institutions, Authors, and Countries

Figure 3 presents the distribution of scientific production on PD programs for in-service science teachers across contributing countries. Indonesia leads with the highest research output (70 publications), followed by China (49), Thailand (47), Malaysia (47), the Philippines (39), Singapore (7), Japan (7), and South Korea (7). These figures indicate that SEA, collectively, dominates the research landscape in this field while contributions from EA remain significant although though smaller in number. Western nations such as the United States, Australia, the United Kingdom, Canada, and Ireland are contributing to the scientific production through research collaborations.

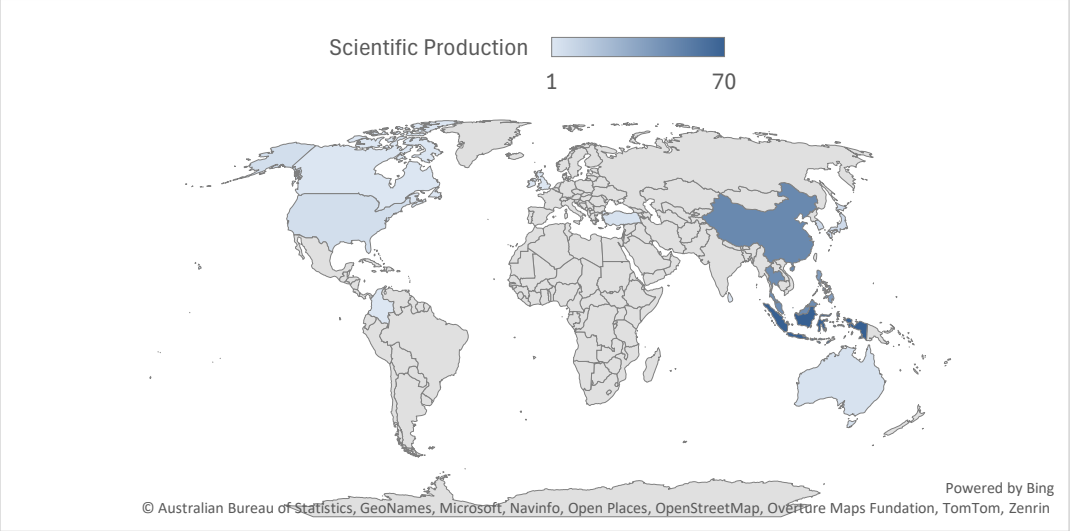


Figure 3. Scopus document distribution and country collaboration on PD programs for in-service science teachers in SEA and EA

Meanwhile, Figure 4 illustrates the production of authors with at least two publications on PD programs for in-service science teachers in SEA and EA from 2016 to 2025. It is notable that none from these authors were able to publish from 2015 – 2016 but there have been a progressive expansion of research on the field between 2017 to 2025. The initial outputs from 2016 to 2018 were limited and sporadic which suggests that systematic inquiry into PD initiatives was still emerging within the region. A marked increase in publication activity occurred between 2020 and 2022 to align with the broader global emphasis on teacher capacity-building and the integration of digital pedagogies during the COVID-19 pandemic. This period likely reflects both a response to shifting instructional demands and the growing recognition of PD as a critical mechanism for improving science education quality. From 2023 onward, multiple authors such as Cortes, Lorca, and Pineda demonstrated sustained productivity indicating long-term research programs and strengthened collaborative linkages. Rather than concentrated dominance by a few prolific scholars, the distributed authorship pattern points to a diversifying and maturing research community. At the institutional level (see Figure 5), universities such as *Universitas Pendidikan Indonesia*, *Universiti Kebangsaan Malaysia*, and *Universiti Teknologi Mara* emerged as consistent leaders, reflecting long-term institutional investment in PD-related research. The rapid growth of *Beijing Normal University* and *Cebu Technological University* in the later years further signals regional diversification and expanding engagement in PD scholarship. These trends reveal a transition from isolated studies to a cohesive and interconnected research community suggesting SEA and EA's growing commitment to advancing evidence-based approaches for science teacher professional learning.

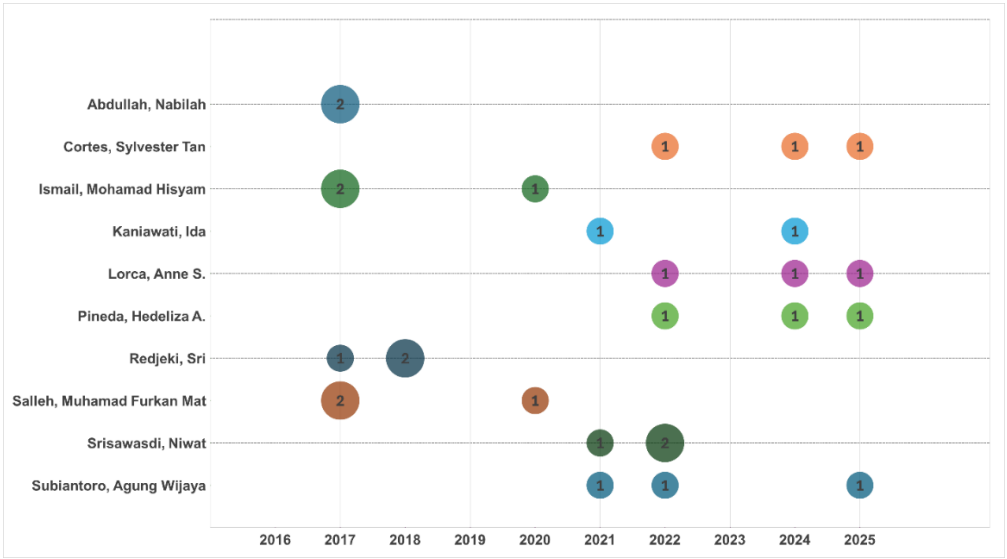


Figure 4. Production of authors with at least two publications on PD programs for in-service science teachers in SEA and EA

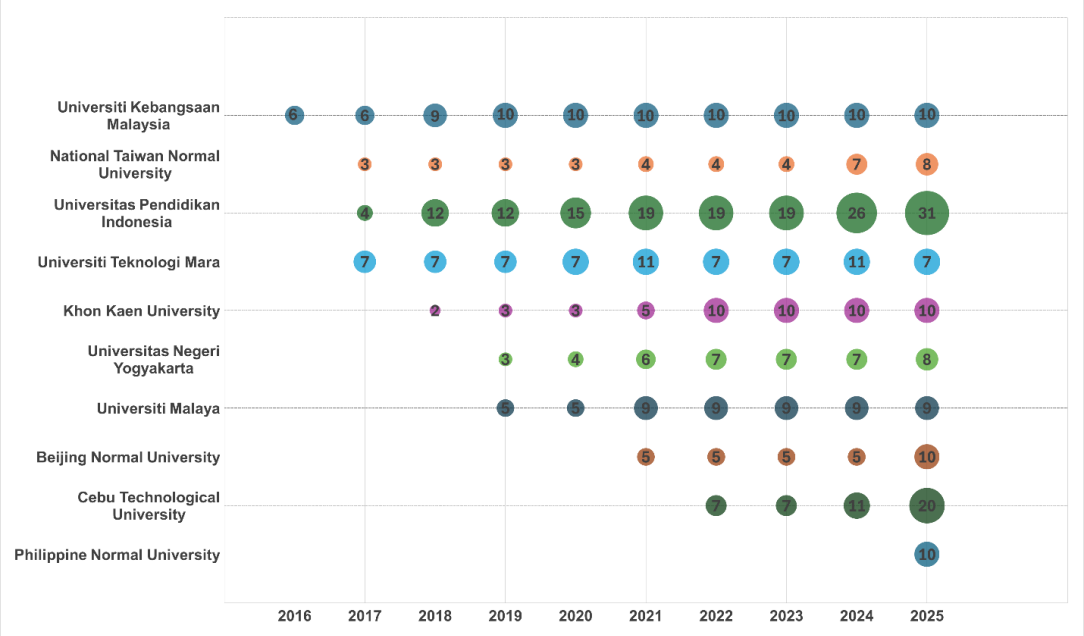
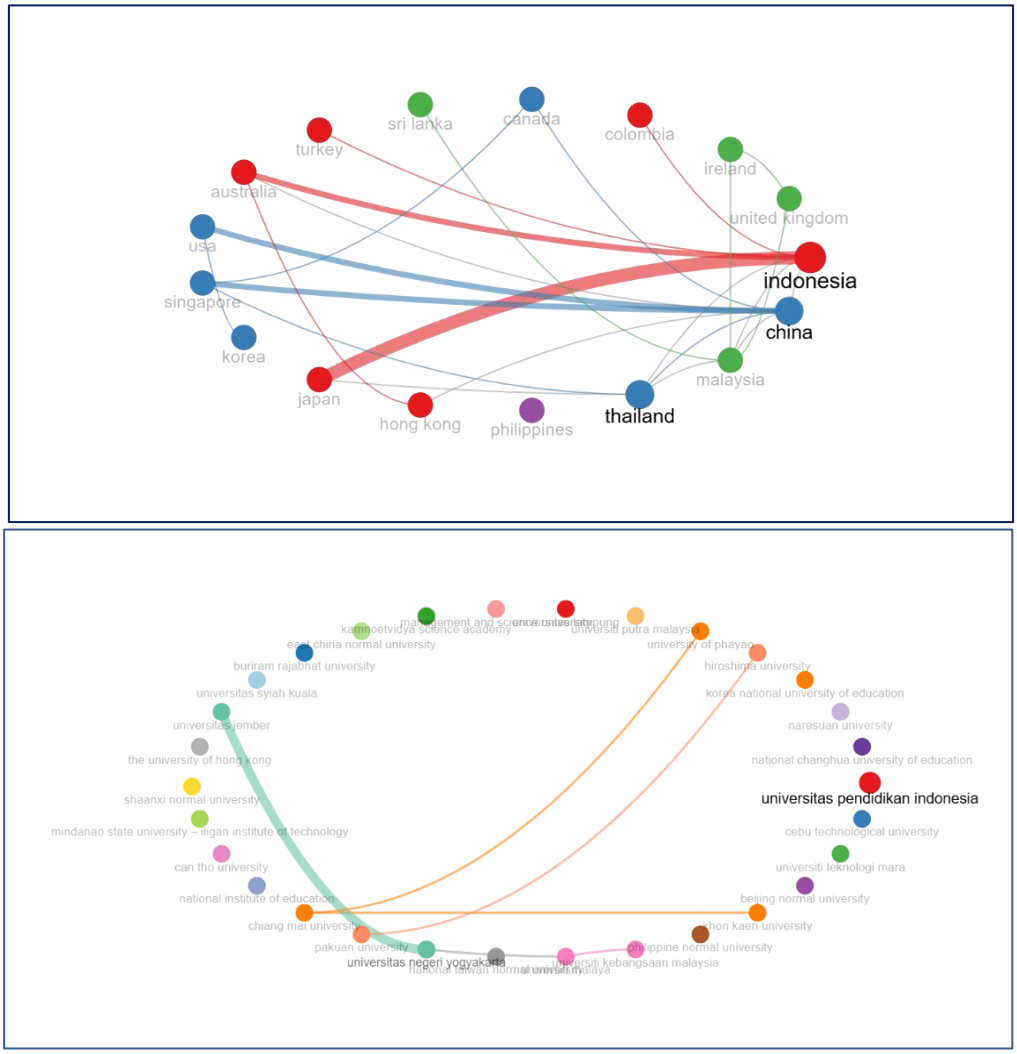


Figure 5. Annual document output of top ten institutions reporting publications on PD programs for in-service science teachers in SEA and EA



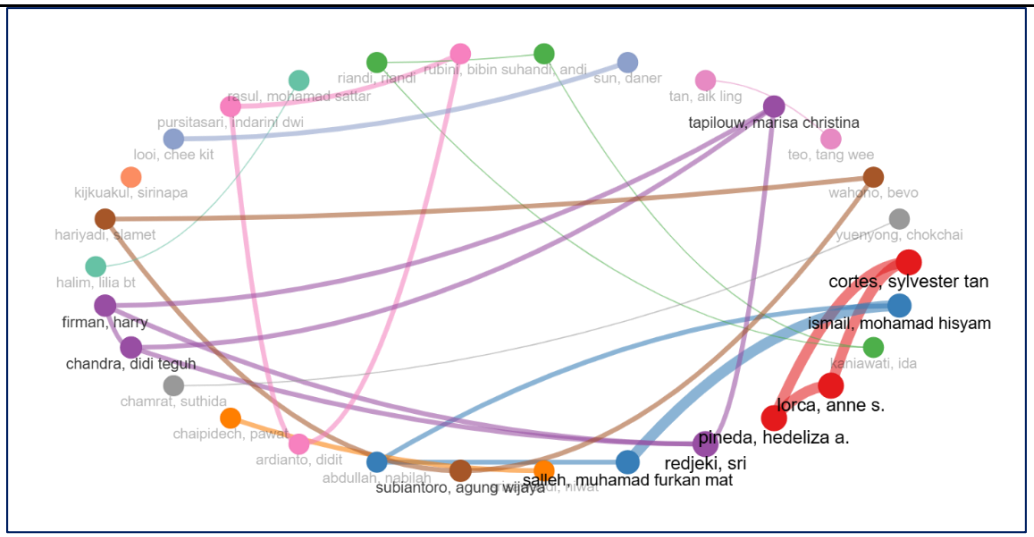


Figure 6. Collaboration network among (a) countries, (b) institutions, and (c) authors with studies on PD programs for in-service science teachers

Figures 6 visualize the collaboration networks among institutions, authors, and countries using multidimensional scaling and edge betweenness clustering. In these figures, node size corresponds to the total number of publications, edge thickness represents the strength of co-authorship or institutional linkages, and node colors indicate clusters of closely collaborating entities. These visual encodings clarify how productivity, influence, and partnership density vary across research structures at multiple levels. The country collaboration network (see Figure 6a) demonstrates stronger connectivity than the institutional or author networks. Regional clusters, especially those linking Indonesia, Malaysia, Thailand, Singapore, China, Japan, and Hongkong are highly prominent which indicates active co-authorship and shared thematic interests in in-service science teacher training and education reform. Meanwhile, collaborative ties between Asian countries and Western partners such as the United States, the United Kingdom, and Ireland are relatively limited. This means that the research ecosystem remains regionally anchored, driven by these Asian countries educational initiatives but with emerging potential for transnational partnerships. In terms of institutional collaboration, the network (see Figure 6b) exhibits an emerging but fragmented structure, with a few universities serving as central nodes that connect smaller institutional groups. The collaboration is predominantly intra-national (*e.g.*, Universitas Jimber and Universitas Negeri Yogyakarta in Indonesia, and Chiang Mai University with University of Phayao and Khon Kaen University in Thailand) implying that partnerships are more often driven by shared national research priorities and educational policies than by international cooperation. Nevertheless, the increasing number of inter-institutional linkages hints at the gradual development of broader academic networks within the region (*e.g.*, Universiti Kebangsaan Malaysia with Philippine Normal University and National Taiwan University).

At the author level (Figure 6c), the network reveals several localized clusters of scholars engaged in repeated co-authorship. An example is the recurring collaboration among Cortes, Lorca, and Pineda, who are affiliated with the same university and conduct research on teacher training in action research. While a few prolific researchers act as key connectors, much of the network remains sparse. This is characterized by multiple small groups with limited cross-linkages. This network pattern suggests that research on PD programs for in-service science teachers is expanding through independent teams or institutional hubs but has yet to form a tightly integrated international community. In this regard, strengthening inter-group collaborations could help unify fragmented research efforts and enhance knowledge sharing across regions. In general, the results indicate that PD research for in-service science teachers in SEA and EA is both growing and consolidating with regional cooperation at its core. The expansion of inter-regional linkages and fostering of sustained global collaborations remain critical to enhancing visibility, citation impact, and the transference of best practices in science teacher professional development.

3.4. PD Programs Research Foci and Evolving Trends for Science Educators through Keywords Analysis

The network visualization of keywords for SEA shown in Figure 7a shows a dense and multifaceted structure dominated by nodes such as “professional development,” “science teachers,” and “teacher professional development.” The prominence of these interconnected keywords signifies a strong emphasis on teacher empowerment through continuous learning. Meanwhile, the frequent co-occurrence of “STEM education,” “teacher training programs,” “action research,” “professional learning community,” and “professional development program” reflects the applied and practice-oriented nature of PD research in SEA. This aligns with

policy-driven efforts in ASEAN nations to improve teacher competency through localized training initiatives often supported by international collaborations. In this regard, PD in the region is therefore viewed not merely as skills enhancement but as a mechanism for educational reform, encouraging inquiry-based teaching, reflective practice, and pedagogical adaptation to changing curriculum standards. Moreover, the integration of "education computing," "science literacy," and "integrated science" reveals a growing scholarly interest in digital literacy and interdisciplinary instruction particularly in the post-pandemic era when hybrid learning modalities became a necessity. The inclusion also of terms such as "secondary schools," "students," and "curricula" may suggest that PD research in the region often targets K–12 contexts that aims to strengthen teacher competencies at foundational levels of science education. It is notable that the color gradient of the visualization indicates that recent studies (*i.e.*, from 2021–2025) have shifted toward "teacher agency," "action research," "decode model," "arduino-based learning," "confidence," and "STEM education." The emergence these keywords signals a notable evolution in Southeast Asian research on PD program for in-service science teachers. The prominence of "teacher agency" and "action research" reflects a shift

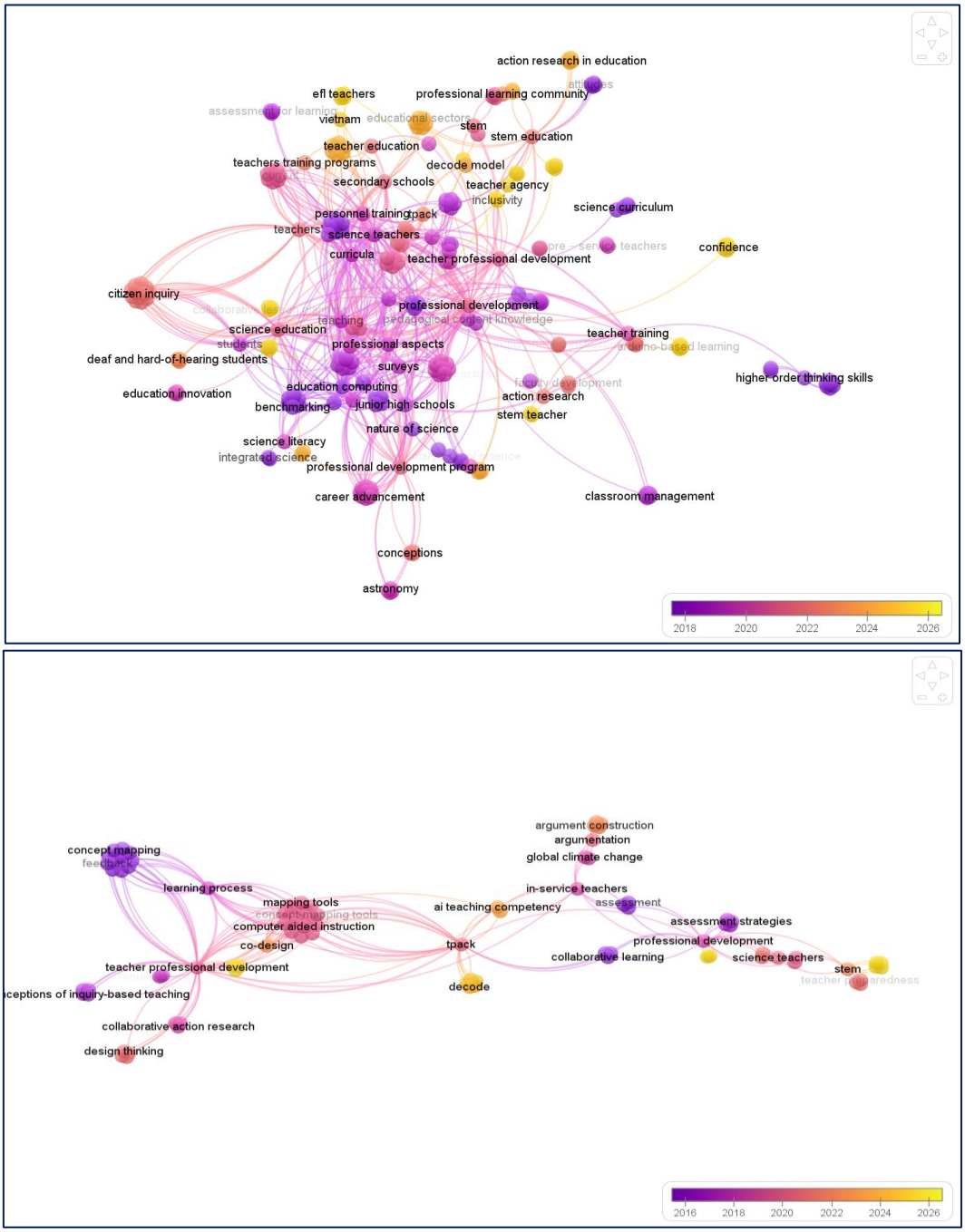


Figure 7. Visualization of keyword occurrence over time for professional development programs of in-service science teachers in (a) SEA and (b) EA

toward teacher-led inquiry and empowerment which positions teachers as reflective practitioners actively shaping their professional growth. This evolution suggests a transition from top-down PD approaches toward teacher-driven models emphasizing self-efficacy, collaboration, and contextual adaptation. Such transformation resonates with calls to move beyond short-term workshops toward sustainable professional learning communities. The appearance of "decode model" and "arduino-based learning" indicates a growing integration of technological and inquiry-based pedagogies in PD programs which emphasize the relevance of digital literacy and hands-on experimentation in science instruction. Meanwhile, the keyword "confidence" suggests an emerging concern for the psychological and affective dimensions of professional learning, particularly teacher self-efficacy and motivation. The continued centrality of "STEM education" stresses its role as a unifying framework that connects these innovations. These keywords collectively suggest that PD research in SEA is transitioning from externally driven training models to contextually grounded, participatory, and technology-enhanced frameworks. This evolution illustrates the region's growing alignment with global movements promoting teacher autonomy, digital competence, and inquiry-oriented professional learning.

On the contrary, the East Asian network (see Figure 7b) exhibits a less dense but more conceptually consolidated structure, dominated by the nodes "teacher professional development," "TPACK," "in-service teachers," and "argumentation." This configuration reflects a theory-oriented research tradition emphasizing technological, pedagogical, and cognitive sophistication in professional learning. The central role of "TPACK" (Technological Pedagogical Content Knowledge) indicates that East Asian PD research often integrates digital competence frameworks and seeks to optimize the relationship between technology, pedagogy, and disciplinary knowledge. Meanwhile, the emergence of nodes such as "AI teaching competency," "collaborative action research," "argumentation," and "assessment strategies" suggests a shift toward high-level cognitive and evaluative dimensions of PD. Unlike the pragmatic focus of PD programs research in SEA, EA's PD scholarship often investigates how teachers develop complex reasoning, reflective thinking, and adaptive assessment practices through structured learning cycles. The recent yellow-coded nodes which include "global climate change," "decode," and "AI teaching competency" highlight an emerging interest in sustainability education and artificial intelligence integration from 2022 to 2025. These trends reflect an expansion of PD research toward interdisciplinary global challenges and digital transformation. These mark EAs strong responsiveness to global education innovation discourses. The EAs bibliometric pattern points to a more compact yet conceptually deep PD research network. It is characterized by precision in theoretical framing and integration of technological competencies.

Table 4 compares the developmental trajectories of PD research for in-service science teachers in SEA and EA from 2015 to 2025. Despite differences in publication volume, both regions show distinct yet complementary pathways shaped by their educational contexts. In SEA, PD research is predominantly practice-oriented, collaborative, and reform-driven which emphasizes grounded initiatives such as teacher training, in-service learning, and action research. The core keywords such as "professional development," "science teachers," "STEM education," and "teacher agency" reflect a focus on classroom practice and reform alignment. Emerging topics like STEM integration, digital pedagogy, and confidence building (2021–2025) further highlight a shift toward teacher empowerment and technology-enhanced learning. These mark a pragmatic evolution responsive to post-pandemic educational demands. Meanwhile, EA's PD research is conceptually grounded, technology-integrated, and research-driven, with dominant themes such as TPACK, argumentation, assessment strategies, and AI teaching competency. These keywords suggest a theoretically mature approach supported by policy and data-informed decision-making. Emerging areas like artificial intelligence, multimodal learning, sustainability, and collaborative design indicate a forward-looking integration of educational technology and inquiry-based pedagogies. SEA's scholarship collectively appears as expanding and practice-based which focuses on contextual adaptation and reform implementation. In the case of EA, it is concentrated and conceptually advanced, grounded in robust theoretical and methodological frameworks such as TPACK. Both of these trajectories illustrate a convergence between contextual relevance and conceptual sophistication. Both of which reinforce the global advancement of science teacher professional development as both a reform practice and a research discipline.

Table 4. SEA and EA's developmental trajectories in the scholarly evolution of PD program for in-service science teachers

Dimension	Southeast Asia (n = 66)	East Asia (n = 25)
Core Emphasis	Practice-oriented, collaborative, and reform-based PD [*professional development, science teachers, STEM education, action research, teacher agency*]	Conceptually grounded, technology-integrated, and research-driven PD [*teacher professional development, TPACK, argumentation, assessment strategies*]

Dimension	Southeast Asia (n = 66)	East Asia (n = 25)
Dominant Keywords	Professional development, science teachers, STEM education, action research, teacher agency	Teacher professional development, TPACK, argumentation, assessment strategies, AI teaching competency
Emerging Themes (2021–2025)	Teacher agency, STEM integration, digital pedagogy, confidence building [*teacher agency, digital pedagogy, confidence, STEM integration*]	Artificial intelligence, multimodal learning, sustainability, collaborative design [*AI teaching competency, multimodal learning, sustainability, collaborative design*]
Nature of PD Models	Externally supported, context-driven, often reform-aligned [*teacher training, in-service training, action research, school-based programs*]	Policy-supported, data-informed, and theoretically modeled [*TPACK, assessment strategies, digital learning environments*]
Research Maturity	Expanding and practice-based [*science teachers, curricula, secondary schools, personnel training*]	Concentrated and conceptually advanced [*learning process, computer-aided instruction, argumentation, assessment strategies*]

Note. Enclosed in [] are keywords supporting the comparison dimensions

The bibliometric analysis reveals a dynamic and rapidly evolving field of research on PD programs for in-service science teachers. It is characterized by increasing scholarly productivity and diversification over the past decade. The steady growth in publication output signifies a maturing domain that has shifted from isolated studies to an interconnected research community. This trend, in turn, reflects the growing recognition of PD as a critical mechanism for improving teacher competence and enhancing the quality of science education. The observed gradual increase in research productivity also mirrors global education reform movements emphasizing evidence-based teaching, continuous professional learning, and teacher empowerment as tools for educational transformation. These findings are consistent with earlier global reviews of teacher professional development which reported a steady expansion of PD scholarship alongside increased policy attention to teacher quality improvement [36], [37]. However, unlike these broader syntheses that predominantly examined Western educational contexts, the present study highlights how PD research growth in Asian regions reflects localized reform agendas shaped by socio-cultural and policy-specific educational priorities. This suggests that while global PD discourse promotes common quality indicators, regional trajectories demonstrate contextual adaptation and diversification. A closer examination of publication and citation trends reveals that while the field has experienced sustained growth, its impact follows the typical citation time-lag effect. Foundational studies from earlier years continue to accumulate citations and influence ongoing discourse, whereas more recent publications are still consolidating visibility. Morris *et al*. [38] attribute this phenomenon to the inherent delay between publication and scholarly uptake, during which newer works have limited opportunities for citation. Nonetheless, the continuous entry of new authors and institutions signals the field's expanding appeal and intellectual diversification. These shifts suggest not only an intensification of research activity but also the emergence of new paradigms that bridge theory, practice, and technology in science teacher development.

The dissemination of PD scholarship remains shaped by a small number of leading journals that function as primary venues for intellectual consolidation and visibility. High-impact journals such as *Asia-Pacific Science Education*, *Research in Science Education*, and *Education and Information Technologies* continue to serve as focal points of theoretical advancement and often determine the direction of global discourse. As Herut [39] notes, publication in high-impact outlets amplifies scholarly reach but can also reinforce epistemic concentration. Consequently, the dominance of these Western-based journals may perpetuate geographic imbalances by limiting the visibility of research from emerging regions. This observation aligns with prior bibliometric investigations in science education research which reported that global scholarly communication remains disproportionately influenced by Western academic publishing ecosystems (*e.g.*, [40]). Nevertheless, the growing participation of scholars in the region and the inclusion of regionally anchored journals (*e.g.*, *Journal of Education and Learning* and *Jurnal Pendidikan IPA Indonesia*) indicate a gradual diversification of publication platforms. This trend signals the globalization of PD research and a more inclusive representation of pedagogical contexts beyond traditional Western frameworks.

In regard to collaboration patterns among authors, institutions, and countries, co-authorship networks indicate that much of the field's productivity arises from small, localized research clusters built on long-term institutional collaborations. For example, repeated partnerships among Cortes, Lorca, and Pineda demonstrate sustained institutional engagement in teacher training and action research [1], [9], [41]. These collaborations often anchor research within national and institutional priorities. At the institutional level, universities in Indonesia, Malaysia, and Thailand have emerged as central nodes. This reflects both national investment and regional

leadership in PD research. Figures depicting collaboration networks show that node size corresponds to publication output, edge thickness to co-authorship strength, and node color to cluster membership. These visual encodings reveal that while collaboration is dense within national boundaries, international linkages remain uneven. At the country level, Southeast Asian nations dominate the research landscape, but collaboration with Western countries such as the United States, the United Kingdom, and Australia remains limited. This pattern aligns with the Network Theory of Internationalization [42] which posits that relational expansion occurs gradually through trust-building and mutual dependency. Similarly, Social Capital Theory [42], [43] explains how relational resources such as shared norms, cooperation, and credibility enhance research productivity and influence. International research collaboration enhances innovation capacity and citation impact but often remains constrained by institutional funding structures and geopolitical academic hierarchies. The present findings extend this understanding by demonstrating how regional PD collaboration networks in Asia remain predominantly intra-national, suggesting the need for stronger cross-border research integration.

The analysis of author keywords and co-occurrence networks highlights the intellectual evolution of PD research. Earlier studies focused primarily on structural and policy-oriented dimensions (*e.g.*, teacher training, curriculum alignment, and assessment) which reflect top-down reform initiatives. Over time, the field diversified toward themes emphasizing teacher cognition, professional learning communities, and inquiry-based instruction. This indicates a paradigm shift toward collaborative and practice-centered learning. The most recent period reveals the rise of innovative and participatory constructs such as *teacher agency*, *action research*, *decode model*, *Arduino-based learning*, *confidence*, and *STEM education*, particularly between 2021 and 2025. These emerging terms signify a shift from externally imposed training to teacher-driven professional learning frameworks. The prominence of *teacher agency* and *confidence* emphasizes the affective and motivational aspects of PD, acknowledging that teacher growth extends beyond technical skill to encompass self-efficacy and reflective autonomy. In other words, teacher growth should go beyond improving behaviors. It should also involve developing attitude, intellect, and reflective autonomy where teachers critically analyze and take ownership of their professional practice. The authentic teacher development occurs when he/she becomes reflective and self-directed professionals who continuously shape his/her own learning and identity. Meanwhile, the integration of *Arduino-based learning* (*e.g.*, [38]) and *decode model* (*e.g.*, [45], [46]) represents the increasing infusion of technological innovation and computational pedagogy into science teacher training. This technological integration is further supported by contemporary PD literature emphasizing digital transformation and technology-enhanced teacher learning ecosystems [47]-[49]. However, the present study reveals that such integration manifests differently across Asian regions, reflecting variations in policy direction and technological readiness. These developments generally mark a move toward a more holistic PD paradigm that integrates digital fluency, inquiry orientation, and contextual adaptability.

A comparative reading of SEA and EA reveals distinct developmental trajectories but are complementary. SEA's research landscape is predominantly practice-oriented and reform-driven, emphasizing teacher empowerment through community-based and context-responsive models. Its dominant themes (*e.g.*, *STEM integration*, *action research*, and *teacher confidence*) reflect grassroots reform initiatives often supported by external programs. While this model promotes inclusivity and adaptability, it also faces challenges of sustainability and theoretical cohesion. In contrast, EA's research profile is conceptually grounded and technologically sophisticated. Central constructs such as *TPACK*, *AI teaching competency*, and *argumentation* demonstrate the region's emphasis on integrating technology, theory, and assessment literacy into PD frameworks. Despite producing fewer publications, EA's corpus exhibits greater methodological rigor and theoretical precision which aligns with policy-driven and data-informed professional learning systems. As an example, the China-UK Southwest Basic Education Project (SBEP), a joint initiative between the Chinese and UK governments aimed at strengthening China's basic education system. It provided sustained support for teachers in remote rural schools. SBEP established a county-level support system for continuous professional development (CPD) built on existing local infrastructure [50]. One major contribution of the present study, therefore, is its ability to synthesize these regional trajectories into a comparative analytical framework rather than treating PD development within isolated national or regional silos. By integrating bibliometric mapping with thematic interpretation, the study provides a holistic view of how professional learning models evolve in response to policy, technology, and institutional factors across Asia. The novelty of this research lies in its region-to-region comparative bibliometric mapping of science teacher PD scholarship across Southeast and East Asia. Unlike previous bibliometric studies that focus on single-country or global trend analyses, this study systematically juxtaposes collaboration structures, thematic evolution, and policy-driven orientations across two distinct yet interconnected Asian educational regions.

Nonetheless, these regional distinctions reveal a promising opportunity for intellectual and institutional synergy. SEA's participatory and reform-oriented ethos complements EA's analytical rigor and technological innovation which could potentially lead toward a unified Trans-Asian PD framework. Strengthening collaborative platforms between ASEAN and East Asian consortia could harmonize PD standards, foster knowledge exchange, and promote teacher mobility across borders. As both regions increasingly emphasize *digital pedagogy*, *AI integration*, and *multimodal learning*, a shared agenda that integrates adaptive learning technologies and data-

informed design could advance the regional quality of science education. This potential collaboration would not only enhance the visibility of Asian PD research globally but also reinforce its contribution to UNESCO's Sustainable Development Goal 4 on Quality Education.

These findings point to clear policy and program implications. In SEA, PD systems tend to focus on inclusivity and capacity-building but often struggle with long-term sustainability and quality assurance. In contrast, EA has more structured and data-driven systems that effectively integrate digital skills and evaluation, though they can be less open to external collaboration. Strengthening partnerships between ASEAN and East Asian institutions could help align standards, expand knowledge sharing, and support teacher mobility. Both regions would also benefit from integrating AI and adaptive learning into PD to keep pace with changing educational demands.At the program level, both regions are moving toward more collaborative and sustained learning models. SEA could strengthen its professional learning communities by adopting more systematic feedback and evaluation practices from EA, while EA could benefit from SEA's flexible and context-sensitive approaches. Bringing these strengths together may support the development of a more balanced and regionally relevant PD framework aligned with broader goals such as quality and equitable education.

This study has several limitations. It relies only on Scopus-indexed publications, which may exclude relevant regional studies. Bibliometric analysis also focuses on publication trends and may not fully capture classroom impact. In addition, grouping countries into SEA and EA may overlook important local differences. Future research could address these gaps by using multiple databases, applying mixed-method or qualitative approaches, and conducting longitudinal and comparative studies. Further work on cross-regional collaboration and emerging areas such as AI in PD would also provide deeper insights into how professional learning can be improved across different contexts.

4. CONCLUSION

The comparative bibliometric analysis reveals that professional development (PD) programs for in-service science teachers in Southeast Asia (SEA) and East Asia (EA) have followed distinct yet complementary trajectories from 2015 to 2025. SEA's research landscape is largely practice-oriented, emphasizing participatory, reform-driven, and context-responsive PD initiatives that promote teacher agency, STEM education, and action research. In contrast, EA demonstrates a more conceptually grounded and technologically integrated approach, with strong emphasis on TPACK, argumentation, and artificial intelligence (AI) teaching competencies, reflecting greater theoretical cohesion and methodological rigor. These findings contribute to the growing body of literature on science teacher professional development by providing a regional comparative perspective that highlights how differing educational priorities shape PD research and practice. The study underscores the complementary strengths of both regions, positioning SEA's contextualized and participatory approaches alongside EA's theory-driven and technology-enhanced frameworks. Based on these conclusions, future research is recommended to expand bibliometric coverage by incorporating multiple databases and to employ mixed-method or longitudinal designs to better capture the effectiveness and sustainability of PD programs. Further comparative and cross-regional studies are also encouraged to explore collaborative frameworks that can integrate the strengths of both regions and support the development of more inclusive, adaptive, and sustainable professional learning systems.

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INFORMED CONSENT STATEMENT

Not applicable.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that artificial intelligence (AI) tools were used solely for grammar checking and language clarity improvement. All aspects of the research, including study design, data collection, analysis, interpretation, and manuscript writing, were conducted entirely by the authors without substantive AI-generated content or analytical assistance.

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