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Bibliometric Analysis of Education 4.0 Trends in K-12 Across Asia Using VOSviewer and R

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ABSTRACT

The establishment of Education 4.0 signifies an increasing demand for essential 21st-century skills, including critical thinking, creativity, collaboration, and digital literacy. In the K–12 context, technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and adaptive learning tools have changed educational practices. Implementation across Asia is inconsistent, influenced by differing infrastructure, curriculum, and policy conditions. This study systematically maps and visualizes the evolution of Education 4.0 research in K–12 education across Asia from 2015 to 2025 using a bibliometric approach. A total of 396 articles indexed in Scopus were analyzed using the PRISMA screening method. Data visualization was performed using VOSviewer, while statistical analysis was conducted through the bibliometrix package in R. The research analyzed contributions at the country level, co-authorship systems, thematic trends, and the co-occurrence of keywords. The findings suggest that India, Indonesia, and Malaysia are at the forefront in terms of publication volume, exhibiting a consistent increase in results over the past decade. Analysis of keywords indicates a transition from broad themes, such as “Education 4.0,” to more focused subjects, including “artificial intelligence,” “blockchain,” and “machine learning.” Although the majority of collaborations are domestic, certain countries are establishing international partnerships. Thematic clusters highlight significant connections between educational reform and digital transformation, indicating a shift toward adaptive, data-driven instruction. Prominent papers frequently emphasize the importance of interdisciplinary methodologies and the integration of technology. The research conducted concludes that Asia significantly influences the discourse surrounding Education 4.0 in the K–12 sector. Expanded global cooperation and empirical inquiry are crucial for addressing issues related to implementation, policy, and equity. Future research must examine long-term effects and promote cross-national comparisons to inform sustainable educational innovation.

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1. Introduction

Education 4.0 has emerged to address the growing need for 21st-century skills, including creativity, critical thinking, cooperation, and digital literacy [1–7]. In this novel approach, education transcends the mere transmission of knowledge, focusing on cultivating competencies pertinent to the dynamic and rapidly evolving landscape of work and life. Technologies, including Artificial Intelligence (AI), the Internet of Things (IoT), big data, and adaptive learning systems, have progressively integrated into educational practices. These technologies enable customized, adaptable, and data-driven educational experiences, allowing students to progress at their preferred pace and according to their individual needs. Thus, the function of educators is evolving from mere sources of data to facilitators who purposefully incorporate digital tools to improve student learning outcomes.

The adoption of Education 4.0 in K–12 environments presents both possibilities and obstacles [8–9]. Digital innovations present opportunities for enhanced access, effectiveness, and quality; however, they frequently encounter limitations due to infrastructural challenges, disparities in teacher digital skills, and unequal levels of preparedness among schools and students. The necessity for adaptive, competency-based curriculum is critical, particularly in areas where educational reforms are not keeping pace with technological progress. Ensuring the equitable utilization of technology in both urban and rural areas remains a significant challenge, particularly in developing Asian countries. To address these challenges, it is essential to implement inclusive policy frameworks and make substantial investments in digital school ecological systems.

K–12 students generally exhibit a lower level of technological maturity and independence in learning compared to those in higher education, necessitating increased pedagogical support [8,10]. The implementation of technology in both primary and secondary schools should be context-aware and developmentally appropriate. It should serve not merely as a supplement, but as an essential component of engaging, student-centered learning processes. To achieve this goal, it is crucial to implement innovative curricula and pedagogies, alongside ensuring adequate infrastructure and ongoing professional development for educators [11–13].

Asia offers a distinctive and strategic framework for examining Education 4.0, due to its varied socioeconomic and technological environments [14–18]. Countries in the region demonstrate differing degrees of digital willingness and regulatory support. Japan and South Korea have made notable advancements in integrating AI with other technologies in educational settings, whereas Indonesia and Vietnam face ongoing challenges related to access and infrastructure. Although the region holds significant importance, current studies on Education 4.0 are fragmented, primarily descriptive, and frequently centered on isolated local cases [23].

This indicates a notable research gap, specifically the absence of thorough, data-driven analyses that chart the evolution of Education 4.0 within K–12 education in Asia. Previous research has seldom investigated macro-level publication patterns, cooperation trends, or thematic trajectories using systematic bibliometric methods. A comprehensive bibliometric analysis can elucidate the framework of scientific knowledge, highlight prevailing research themes, identify key writers and institutions, and reveal underexplored domains. This analysis can facilitate policy making and educational preparation throughout the region. This study is guided by the following research questions to address the identified gap:

1. How has the research landscape of Education 4.0 in K–12 education evolved across Asian countries from 2015 to 2025?
2. What are the major thematic trends, keyword co-occurrences, and collaboration networks in Education 4.0 research within the K–12 context in Asia?

This research presents multiple significant contributions. The study presents a comprehensive bibliometric analysis of K–12 Education 4.0 research in Asia, utilizing VOSviewer and R. Furthermore, it outlines the evolution of research, patterns of co-authorship, and conceptual trends observed over the past decade. The findings provide practical insights for policymakers, curriculum

developers, and educational researchers aiming to facilitate digital transformation in schools. The visualizations and data-driven analysis establish a basis for regional comparisons and the design of future research.

This paper is organized as follows: Section 2 outlines the methodology, data sources, and bibliometric tools utilized. Section 3 presents the findings, which encompass publication trends, thematic clusters, and collaboration patterns. Section 4 examines the implications for research and policy. Section 5 concludes the study and delineates avenues for future research.

2. Method

This study employs a bibliometric approach to systematically explore the evolution of Education 4.0 research within the context of K–12 education in Asia. Bibliometric analysis provides a robust quantitative method for examining scientific output, research trends, author collaborations, and thematic developments across time and geography. This approach is particularly suitable for capturing the dynamic growth of the literature in technology-driven education.

2.1. Data Collection and Screening Process

All bibliometric data were retrieved from the Scopus database, a widely recognized indexing platform for international, peer-reviewed literature. To ensure high-quality sources, the search query used was: TITLE-ABS-KEY (“education 4.0”) AND PUBYEAR > 2015 AND PUBYEAR < 2025, which retrieved documents published from 2016 through 2024. This initial search yielded 942 publications that mentioned Education 4.0, either in the title, abstract, or keywords. The data selection process adhered to the PRISMA 2020 guidelines to ensure transparency and reproducibility. In the screening phase, all 942 documents were reviewed based on titles and abstracts to determine their relevance to K–12 education specifically. Documents that focused exclusively on higher education, tertiary systems, or general theory unrelated to primary and secondary education were excluded. This step yielded 526 documents for further assessment.

In the eligibility phase, a more detailed evaluation of the complete texts was conducted to ensure alignment with the research scope. Documents were excluded if they lacked focus on the K–12 sector or if Education 4.0 was only tangentially mentioned. Contrary to an earlier draft of this study, no documents were excluded based on country affiliation. Countries such as India, Malaysia, Indonesia, China, Japan, South Korea, Vietnam, and the Philippines were not excluded but rather included as they represent key contributors to Education 4.0 research in Asia. The prior mention of country-based exclusion has been revised for accuracy and consistency with the final results.

Following this process, a total of 408 documents were retained for inclusion in the bibliometric analysis. The whole selection pathway is illustrated in the updated PRISMA flow diagram (Fig. 1), which outlines each stage of filtering from identification to inclusion.

2.2. Inclusion and Exclusion Criteria

From the 408 documents initially deemed eligible, 396 records were ultimately included in the final bibliometric analysis. These met all inclusion criteria, which required: (1) direct thematic relevance to Education 4.0 in the K–12 education context within Asia, (2) publication in peer-reviewed sources indexed by Scopus (including journal articles and conference proceedings), and (3) the presence of complete bibliographic metadata—such as title, abstract, author keywords, and affiliations—necessary for bibliometric processing. Meanwhile, 12 documents were excluded during the final validation stage. The reasons for exclusion included record duplication, incomplete metadata (e.g., missing abstracts or keywords), and misalignment with the study’s focus, particularly for papers that, despite mentioning Education 4.0, were primarily centered on vocational training or higher education contexts rather than K–12 education.

2.3. Data Analysis Tools

Two analytical tools were utilized to process and visualize the bibliometric data. VOSviewer was employed to generate network visualizations of author collaboration, institutional affiliations, and keyword co-occurrence. These maps provided visual insights into the intellectual structure and thematic evolution of the field. Additionally, the R programming language, using the Bibliometrix package, supported statistical bibliometric analysis, including annual publication trends, source impact, and co-citation metrics. The combined use of VOSviewer and R ensures methodological rigor, analytical depth, and alignment with best practices in scientometric research.

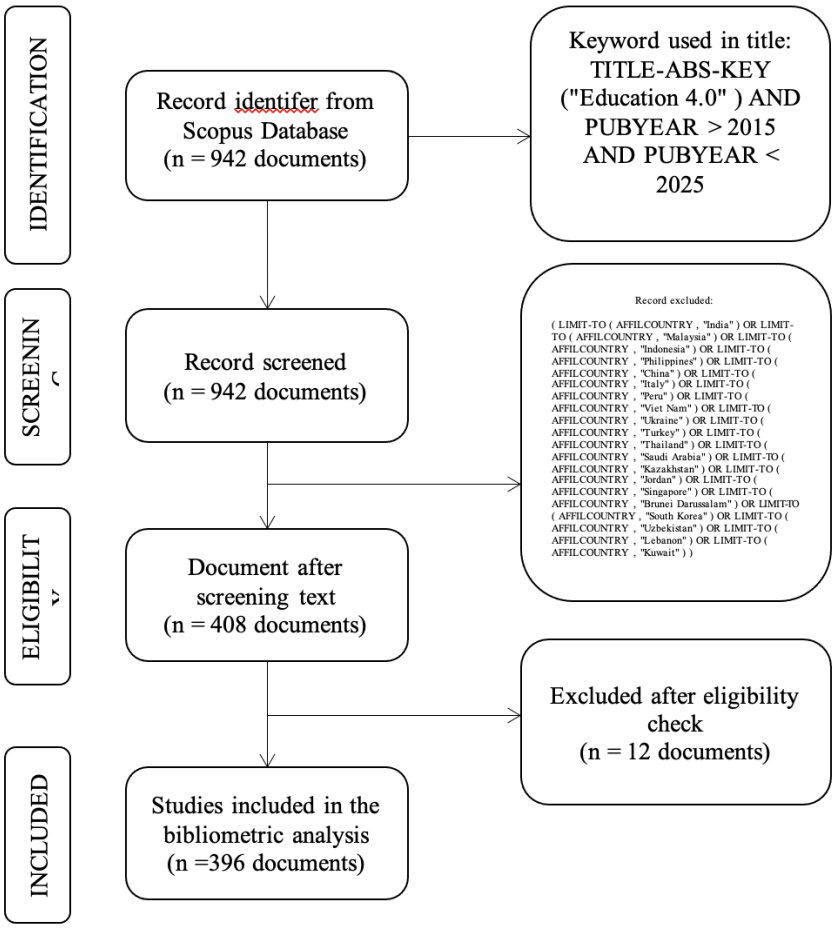

Fig. 1. PRISMA of the document selection process for this bibliometric study.

3. Results and Discussion

This section details the bibliometric analysis of Education 4.0 research in K–12 education across Asia from 2015 to 2025. It is organized into five main themes: (1) national scientific output, (2) publication trends over the years, (3) citation impact, (4) collaboration networks, and (5) thematic development and emerging keywords. Each subsection concludes with a summary that highlights key insights and aids reader comprehension.

3.1. Country-Level Scientific Production

The distribution of Education 4.0 publications in the K–12 sector across Asia reveals a notable geographical focus, with South and Southeast Asian nations as the primary contributors. As shown in Fig. 2, India, Indonesia, Malaysia, the Philippines, and Thailand exhibit the highest publication volumes, marked by darker blue areas on the map indicating elevated scientific activity. In contrast, East Asian countries such as China, Japan, and South Korea exhibit moderate levels of engagement.

Overall, contributions from other regions, including Africa, South America, and Eastern Europe, are comparatively limited.

Multiple interconnected factors influence the variation in research output across different regions. Many countries in South and Southeast Asia have integrated ambitious digital transformation efforts into their national education policies. For instance, India's National Education Policy 2020 highlights digital learning, AI, and computational thinking in schools. Similarly, Malaysia's Education Blueprint (2013–2025) and Indonesia's Smart School Program have spurred increased research on the implementation of EdTech. These countries also face pressing issues related to educational equity and infrastructure, which often drive the development of research-based solutions. The goal of bridging digital divides and improving learning outcomes in underserved areas motivates educators and researchers to develop localized Education 4.0 applications. Consequently, necessity-driven innovation functions as a catalyst, fueling research activity even in developing economies.

The limited contributions from other parts of Asia and the Global South prompt questions about access, representation, and capacity-building. Regions such as Sub-Saharan Africa and Latin America, which face similar educational challenges, are underrepresented in this context. This could reflect systemic barriers, such as research funding, access to publications, or digital infrastructure, consistent with findings from global bibliometric studies, including those by Nguyen et al. (2022).

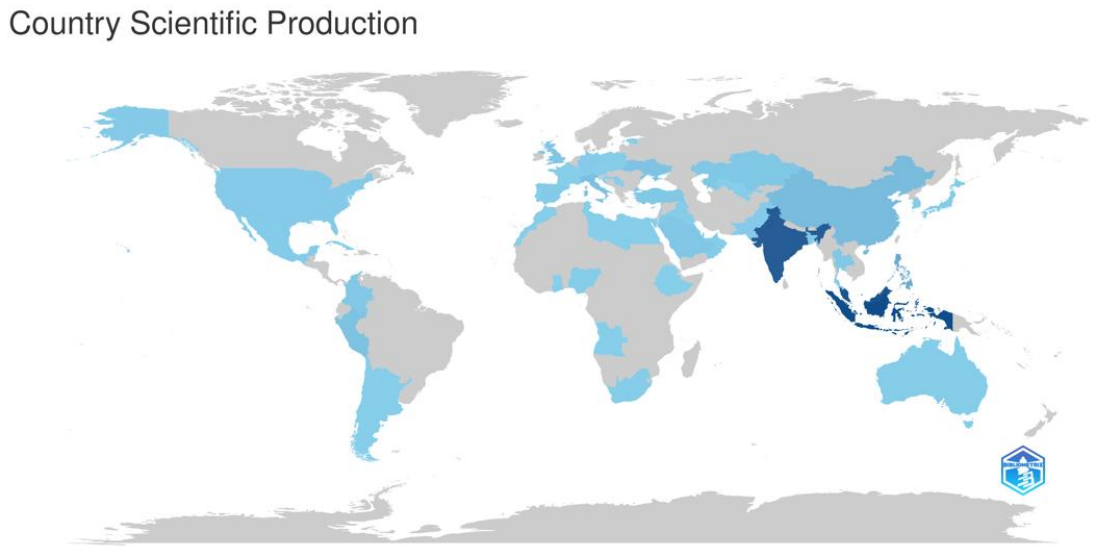

Fig. 2. Country Scientific Production

3.2. Publication Growth Trends by Country

A temporal analysis of publication output from 2017 to 2025 (see Fig. 3) reveals a consistent upward trend across five Central Asian countries: India, Malaysia, Indonesia, China, and the Philippines. India is expected to show the most significant increase, with projections exceeding 300 publications by 2025, while Malaysia is projected to have over 250. Indonesia's growth, though slower, remains steady and positive. Meanwhile, China and the Philippines exhibit more moderate, stable growth patterns. The data highlight that policy commitment and institutional investment are crucial factors driving research productivity. India's rapid growth is likely related to its large-scale national EdTech initiatives, increased research funding, and promotion of academic–industry collaborations. Malaysia's steady rise corresponds with initiatives like MyDigital and the Malaysian MOE's focus on blended and virtual learning, emphasizing research-driven digital curriculum development.

Indonesia's consistent growth indicates a long-term strategy to incorporate digital tools in schools, backed by the Ministry of Education and Culture's Merdeka Belajar initiative. In contrast,

China and the Philippines show relatively lower growth rates, suggesting that digital education advancement is more focused on higher education and workforce training rather than K–12 schools. Additionally, regional collaborations and language barriers may affect the visibility of their outputs in English-language databases, such as Scopus. For example, Chinese educational research published locally may not be fully captured, potentially underrepresenting the actual level of activity.

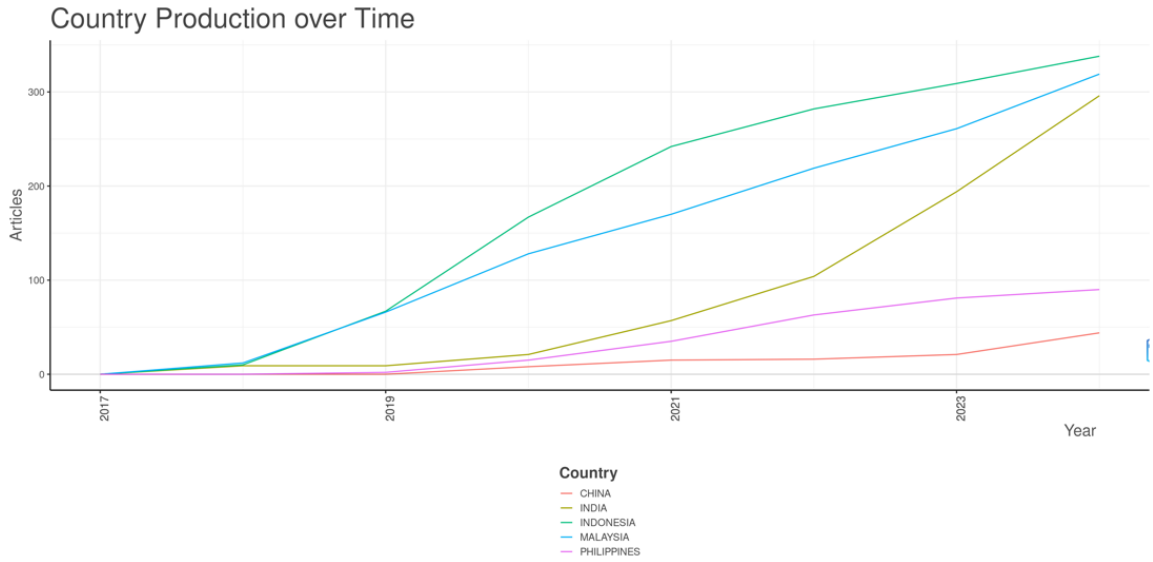

Fig. 3. Country Production Over Time

3.3. Citation Performance and Most Influential Works

Citation analysis (Fig. 4) highlights the most influential documents in the Education 4.0 and K–12 discourse in Asia. The leading paper by Hariharasudan A. (2019) has been cited 164 times, followed by works by Qureshi MI (2021) and Bizami NA (2023), which received 132 and 125 citations, respectively. These studies cover various subfields, including digital pedagogy, innovative learning environments, and the ethical and socio-economic impacts of EdTech. A notable trend is the recent increase in high-impact publications, with many of the top ten papers published after 2020. This suggests an accelerated scholarly response to digital transformation, likely driven by the global shift to remote learning during the COVID-19 pandemic.

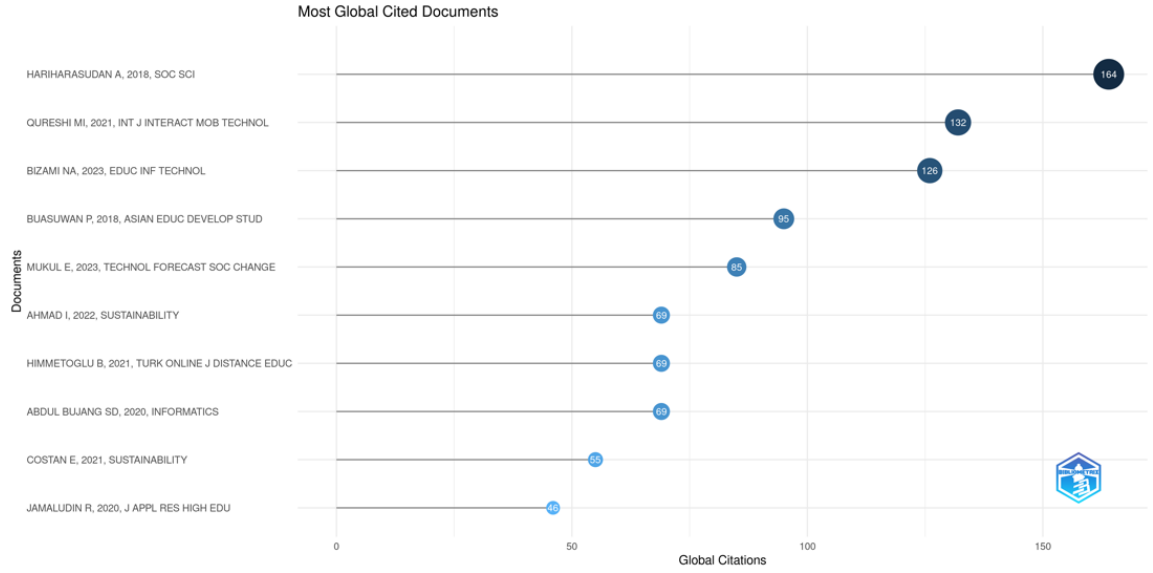

Fig. 4. Most Global Cited Documents

Moreover, the interdisciplinary nature of these documents drawing from education, computer science, sociology, and public health has boosted their citation impact across various fields. Notably, highly cited works frequently focus not only on technological integration but also on vital issues like equity, ethics, and practical implementation. This suggests that influential research in this area needs to strike a balance between innovation, practicality, and social responsibility, a trend observed in global studies, such as Dabbagh et al. (2023).

3.4. Collaboration Patterns of Corresponding Authors

Analysis of the authors30b4 country affiliations and collaboration types (Fig. 5) reveals that single-country publications (SCPs) are the most common, particularly in Malaysia, India, and Indonesia. Although these countries lead in publication volume, most of their research is conducted domestically with limited cross-national collaboration. Conversely, China and the Philippines show a more balanced mix between SCP and MCP (multiple-country publications), indicating a greater degree of international cooperation.

These trends indicate that, although some countries have robust domestic research systems, there remains an untapped opportunity for international collaboration. The emphasis on domestic publications may stem from national research funding priorities, such as a preference for domestic grants, or language and logistical barriers to international collaboration. On the other hand, international collaboration offers notable benefits, including access to diverse viewpoints, shared resources, and enhanced methodological rigor.

Moreover, the absence of collaboration is more than a logistical problem; it also has epistemic implications. Research conducted in isolation tends to be limited to specific contexts or inward-looking, while international networks foster broader applicability, comparison, and global significance. This aligns with Silva et al. (2021), who warned about the fragmentation of educational technology research across Asia.

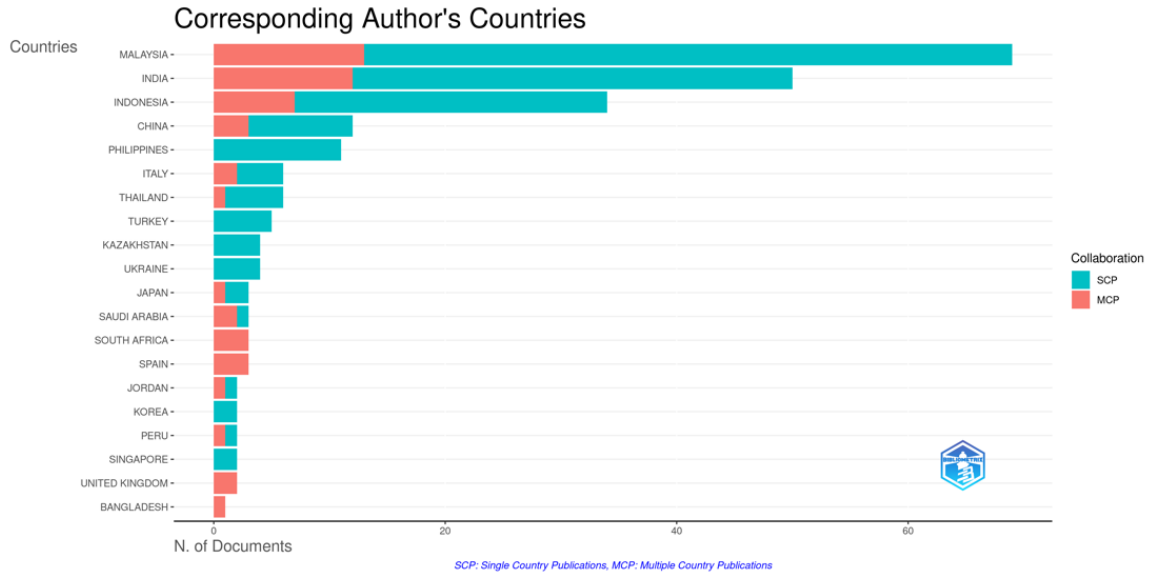

Fig. 5. Corresponding Author's Countries

3.5. Thematic Clusters and Keyword Co-Occurrence

The keyword co-occurrence analysis, shown in Fig. 6, offers insights into the intellectual structure and key themes of Education 4.0 research in K–12 education across Asia. Using VOSviewer, a network map was generated based on author keywords, with the central node "education 4.0" standing out as the most significant term, underscoring its importance in this field. The analysis revealed three primary thematic clusters:

1. The green cluster emphasizes pedagogical reform, featuring keywords such as “students,” “teaching,” “curricula,” and “cloud computing.” This cluster covers research aimed at redesigning teaching methods and implementing student-centered learning approaches, frequently utilizing cloud platforms to access content and deliver curricula.
2. The red cluster connects terms such as “e-learning,” “virtual reality,” “gamification,” and “Industry 4.0.” This group emphasizes immersive learning environments and engaging strategies. The inclusion of “Industry 4.0” indicates a link between technological and economic concepts and educational reform, illustrating how education systems are evolving to meet the needs of the future workforce.
3. The purple cluster encompasses “higher education,” “digital technologies,” and “learning analytics.” While this group combines terms from both general and tertiary education, it highlights the connection between higher education and the K–12 sectors, particularly in terms of technology adoption and data utilization.

This multidimensional framework highlights a converging trend in Education 4.0 research, where pedagogical change closely aligns with technological advancements. For example, terms like “teaching” are now frequently linked with “cloud computing” and “learning analytics,” indicating that data, automation, and real-time feedback systems are playing an increasingly significant role in teaching methods. Nonetheless, advanced technologies such as augmented reality (AR), blockchain, and AI remain only as peripheral or weakly connected elements in the network. This suggests that, although these technologies are beginning to appear in discussions, they have not yet achieved the necessary critical mass or empirical backing within the K–12 education literature in Asia.

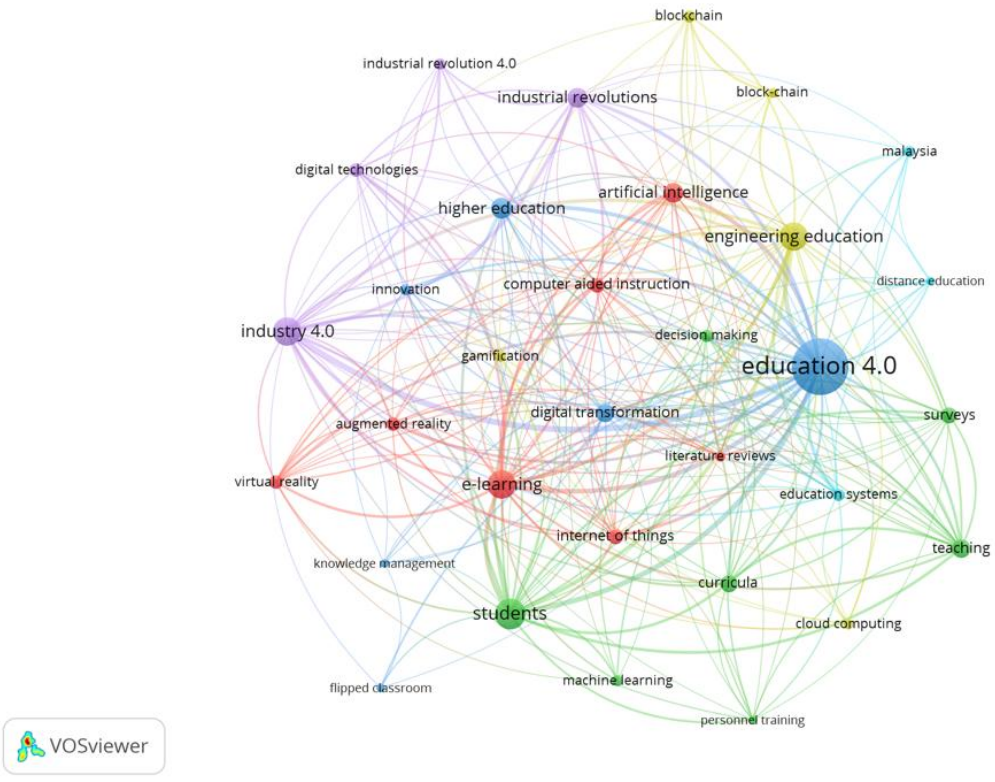

Fig. 6. Research Focus Analysis

3.6. Keyword Novelty and Future Research Trajectories

The overlay visualization of keywords in Fig. 7 illustrates the evolution of thematic focus over time. In this map, older keywords, such as “students,” “e-learning,” and “curricula,” are represented in cooler colors, like blue and green. Conversely, more recent terms, such as “artificial intelligence,”

"blockchain," "digital transformation," and "knowledge management," are depicted in warmer colors, like yellow and orange, highlighting their rising prominence from 2022 to 2023.

This shift signifies a grown maturity in the research area (Table 1), moving from a primary focus on digital access and virtual learning towards more sophisticated, intelligent, and systemic innovations. Specifically:

1. Artificial Intelligence (AI) and Machine Learning (ML) are increasingly being explored for their potential to deliver personalized instruction, conduct real-time assessments, and enable adaptive learning paths. Their association with keywords such as "teaching" and "curriculum" underscores their growing importance in instructional design.
2. Blockchain, while still a peripheral technology, is increasingly recognized for its role in digital credentialing, maintaining student data integrity, and verifying learning records—an essential innovation, particularly in online or hybrid schooling contexts.
3. Digital transformation involves not only technological updates but also changes at the institutional and systemic levels, including infrastructure, policies, and teaching methods.
4. Knowledge Management, historically a focus in organizational studies, is now becoming part of the K–12 education conversation. It emphasizes issues like institutional memory, teacher collaboration, and establishing sustainable professional learning ecosystems.

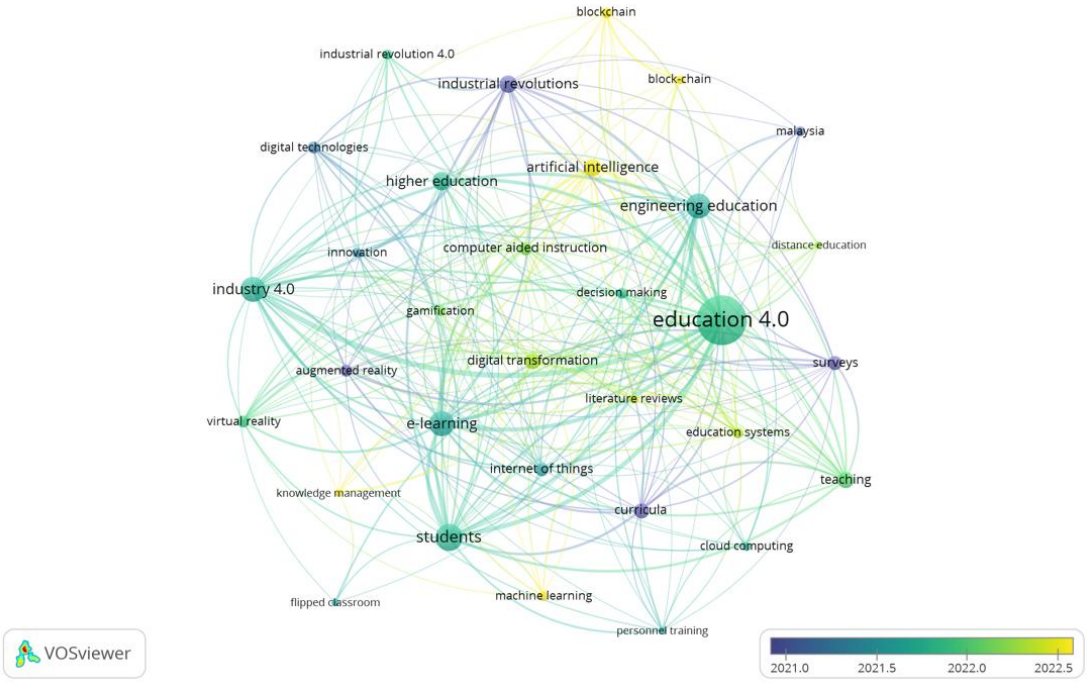

Fig. 7. Keyword Novelty

Table 1. Novelty Keywords in Education 4.0 (K–12 Asia) and Future Research Directions

Keyword	Thematic Focus Description	Potential Future Research
Artificial Intelligence	AI in teaching, smart delivery, and personalization	Ethics, fairness, and the development of AI-powered learning systems
Machine Learning	Learning pattern recognition, assessment analytics	Predictive tools, adaptive assessments
Blockchain	Digital credentialing, record security	Applications for diplomas, attendance, and honesty tracking
Digital Transformation	Institutional change in pedagogy and school management	Frameworks for sustainable digital leadership
Knowledge Management	Teacher collaboration, institutional memory	Teacher professional learning platforms, knowledge retention systems

4. Conclusion

This study effectively accomplished its primary objective: to systematically map, visualize, and analyze the progression of Education 4.0 research in K–12 education across Asia from 2015 to 2025. By employing a rigorous bibliometric methodology using VOSviewer and the bibliometrix package in R, it identified key trends in scientific publications, thematic developments, and collaboration networks.

The results indicate that India, Malaysia, and Indonesia are now the top contributors to the discussion, particularly in advancing the integration of artificial intelligence, digital transformation, and immersive technologies within the school education sector. Thematic clustering reveals a convergence of pedagogical innovation with technological advances, while keyword trend data indicate a shift toward innovative, data-driven educational systems.

These findings confirm Asia's crucial role in shaping Education 4.0 worldwide but also reveal notable disparities. Most research is based on single-country collaborations, emphasizing the importance of enhancing international partnerships and sharing knowledge. Additionally, the appearance of keywords such as blockchain and knowledge management points to emerging research fields that are still underdeveloped, particularly at the K–12 level.

Although this study has its strengths, it also has limitations. It only utilized literature indexed in Scopus, potentially missing relevant local or regional sources that are not included in international databases. The bibliometric approach helps map structures but does not reflect practical aspects, such as curriculum integration, teacher preparedness, or student participation. Addressing these areas requires detailed, context-specific analysis beyond bibliographic data.

Declaration

Supplementary Materials: The supplementary materials for this study include the full dataset retrieved from Scopus and visualizations generated using VOSviewer and R.

Author Contributions: RNG: Conceptualization, Writing-Initial Draft, Editing and Visualization, Methodology and Review & Editing, NFB, HAK, PAC: Conceptualization, Formal analysis, Methodology and Review & Editing; MSG, BDI: Validation and Monitoring. All authors have read and approved the published version of the manuscript.

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