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AI-Based Learning Transformation in Secondary Schools: A Systematic Literature Review Study

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Abstract

This study aims to map the development of research and scientific publications on artificial intelligence (AI)-based learning transformation at the secondary school level. Using a Systematic Literature Review (SLR) approach, this study analyzed 4,558 scientific articles indexed in Scopus and published between 2019 and 2024. Article selection was conducted following the PRISMA protocol, and bibliometric analysis was performed using VOSviewer to visualize author collaboration networks, topic distributions, and keyword clusters. The findings reveal five major thematic clusters in AI-related educational research. Although one cluster is dominated by studies situated in medical and clinical contexts, this prominence reflects the broader landscape of AI-in-education research rather than the direct instructional level, as many medical studies serve as methodological precursors for AI tools later adapted for secondary education, such as simulation-based learning, assessment automation, and immersive technology development. The most dominant cluster, however, concerns the integration of AI into adaptive learning, personalized instruction, and data-driven curriculum design, which aligns directly with secondary school applications. This study contributes to strengthening the conceptual foundation and research mapping of AI-based learning transformation while identifying future directions for technological innovation in secondary education. The main limitation lies in the exclusive reliance on Scopus data, which narrows the scope of literature coverage. Future research is encouraged to incorporate additional databases such as Web of Science and EBSCO to achieve a more comprehensive and balanced overview.

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artificial intelligence in education; personalized learning; adaptive learning technology; chatgpt and generative ai

INTRODUCTION

The transformation of learning suppoted artificial intelligence (AI) in secondary school environments has shown a growing trend in recent years (Dave & Patel, 2023; Sihag, 2024). This development reflects not only rapid technological advancements (Favero, 2024; Ifenthaler et al., 2024; Katsarou et al., 2023; Mincer et al., 2024) but also increasing educational demands for adaptive, personalized, and efficient learning systems. Various countries have begun integrating AI into secondary education as part of broader shifts toward smart learning ecosystems (Jing et al., 2023). Taylor, Gupta, and Jung (2024) demonstrate how visualization and machine learning strengthen student-centered learning in smart classrooms, while, Zhang et al. (2023) highlight the role of AI in supporting flexible and responsive smart education systems. In thecontext of developing countries, Sihag and Vibha (2024) show how AI tools are being adopted to reform secondary education despite persistent infrastructural and digital divide issues. These studies collectively illustrate the global momentum toward AI-driven transformation in secondary education.

Previous research has produced valuable insights but also reveals persistent challenges in

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AI implementatio While AI has been shown to enhance differentiated learning, classroom management, and real-time feedback (Malviya et al., 2023; Niu et al., 2019; J. Zhang et al., 2023), its adoption often faces obstacles such as limited teacher readiness, technological constraints, and widening gaps in digital access. (Sihag, 2024). Furthermore, although AI-based learning environments can promote interactivity and student-centered pedagogy, many educators lack sufficient pedagogical and technological preparation to optimize AI-enabled tools (Taylor et al., 2024). These limitations indicate that prior studies tend to examine AI implementation descriptively rather than critically evaluating the systemic, infrastructural, or pedagogical challenges that shape its effectiveness. Existing research therefore offers fragmented insights that have not yet been mapped comprehensively.

Despite the increasing number of studies on AI in secondary education (Bozkurt, 2023; Lin & Su, 2024; T. Zhang et al., 2023), there remains a gap in systematic evidence synthesis. Much of the prior work relies on case studies (Bonami et al., 2020; Connolly et al., 2023; Mincer et al., 2024; Murala, 2024; Schwieger et al., 2024; Wang et al., 2022), experimental designs (Kirchner et al., 2023; Ma & Chen, 2024; Sam et al., 2020; Shamim et al., 2024; Y. Zhang, 2022), or narrative reviews These approaches provide valuable findings but do not offer structured, data-driven mapping of publication trends, thematic distributions, or knowledge gaps. To date, no comprehensive Systematic Literature Review (SLR) supported by large-scale bibliometric tools has been conducted to synthesize the research landscape of AI-driven learning transformation specifically at the secondary school level.

Given this gap, this study employs a Systematic Literature Review (SLR) combined with bibliometric analysis to map the development of AI-based learning research in secondary education. Using Scopus-indexed publications and analytical tools such as VOSviewer and CiteSpace, this study aims to reveal publication trends, thematic clusters, and conceptual linkages across the literature. The focus of this study is to answer the main question: How has research on AI-based learning transformation in secondary schools evolved based on reputable scientific publications? By synthesizing 4,558 articles from the Scopus database, this study provides a comprehensive overview of the global research landscape and identifies emerging directions, dominant themes, and research gaps that remain open for further exploration. This contribution is expected to support future empirical and theoretical advancements in AI integration within secondary education.

LITERATURE REVIEW

TThe rapid development of artificial intelligence (AI) has triggered significant changes in the education sector, particularly at the secondary school level. AI is no longer viewed simply as a technological innovation, but as a strategic approach intended to personalize learning and increase instructional efficiency. Numerous studies highlight how AI can support personalized learning pathways, automate assessment, and improve classroom management (Taylor et al., 2024; T. Zhang et al., 2023). However, these studies tend to emphasize the benefits of AI without adequately addressing its limitations. For instance, while personalization is often praised, many studies do not explain how such systems function in diverse classrooms where data readiness, digital literacy, and resource availability vary widely. Thus, the existing research presents an optimistic perspective but lacks deeper exploration of factors that influence real-world implementation.

In practice, the integration of AI in learning involves multiple educational actors, including teachers, school leaders, technology developers, and policymakers. This complexity shows that successful AI implementation requires not only technological readiness but also leadership capacity, policy alignment, and intersectoral collaboration. Sihag and Vibha (2024) emphasizes the importance of collaboration in contexts where digital infrastructure remains uneven. Meanwhile, access gaps (Fadhel et al., 2024; Kryvenko & Chalyy, 2023), limited pedagogical readiness, and insufficient policy support (Hendriani, 2024; Nagler et al., 2023; Wood, 2007) pose additional challenges. These varied constraints demonstrate that AI adoption cannot be evaluated solely from a technological standpoint; rather, it must consider how human, cultural, and institutional factors

interact with new technologies. This complexity indicates the need for a broader and more systematic analysis to understand how contextual factors shape the success or failure of AI integration.

Research on AI-based learning transformation at the secondary school level has increased significantly in recent years. Many studies examine how AI supports personalized learning, accelerates assessment, and provides real-time feedback to enhance learning processes (Taylor et al., 2024; J. Zhang et al., 2023). Other works focus on AI as a decision-making tool for teachers, especially in classroom management, curriculum planning, and student behavior analysis. Most of these studies use quantitative or mixed-methods approaches to measure AI effectiveness. However, they often investigate AI tools in isolated or ideal conditions, making it difficult to generalize their findings across different types of schools, particularly those with limited infrastructure. The inconsistency of contexts, methods, and outcomes across studies creates a fragmented understanding of AI's true impact, highlighting the need for a systematic synthesis of the literature.

Another strand of research addresses the social and cultural dimensions of AI implementation. Studies by Chen et al. (2023) and Montecinos et al. (2018) emphasize that school culture plays a crucial role in determining whether technological innovations, including AI, can be successfully adopted. Leadership support, organizational culture, and continuous teacher training are recurring factors in successful technology integration. Conversely, limitations such as low digital literacy among teachers and students or insufficient training opportunities often hinder AI adoption (Smeaton, 2023). Karakose (2021) further illustrates that disparities in leadership competencies create uneven outcomes across schools. Collectively, these findings indicate that even when technologies are available, human and organizational readiness remain key determinants of their effectiveness. The contrast between successful cases and recurring obstacles reinforces the fragmented nature of the current research landscape.

Overall, the reviewed studies reveal diverse and sometimes conflicting findings: some emphasize the potential and benefits of AI, while others show persistent structural, cultural, and pedagogical barriers. This diversity creates uncertainty about the actual conditions under which AI improves learning outcomes. Therefore, a systematic and comprehensive mapping of the literature is needed to synthesize these varied findings, identify research trends, clarify conceptual inconsistencies, and determine the unresolved challenges in the integration of AI into secondary education.

METHOD

This study employs a qualitative Systematic Literature Review (SLR) approach supported by bibliometric analysis. The research questions, including the central and sub-questions, have been presented in the Introduction to maintain a clear conceptual flow and avoid repetition in the methodology. The focus of this study is to systematically map the development of AI-based learning transformation research at the secondary school level. Bibliometric techniques were used to identify trends, thematic clusters, and collaboration patterns within the selected publications.

To ensure transparency and replicability, the article selection process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, which consists of four stages: identification, screening, eligibility, and inclusion. Before describing these stages, the inclusion and exclusion criteria were established to guide the selection process. The inclusion criteria were as follows: (1) the article must be written in English; (2) the article must be indexed in Scopus; (3) the publication must fall within the period 2019–2024; (4) the article must focus on artificial intelligence, educational technology, personalized learning, AI in education, or secondary school learning; and (5) the article must be a scientific, peer-reviewed journal publication. Conversely, exclusion criteria consisted of: (1) articles not written in English; (2) publications outside the 2019–2024 period; (3) articles not related to the specified AI and education keywords; (4) non-scientific publications such as editorials or book chapters; and (5) articles unavailable in full-text form.

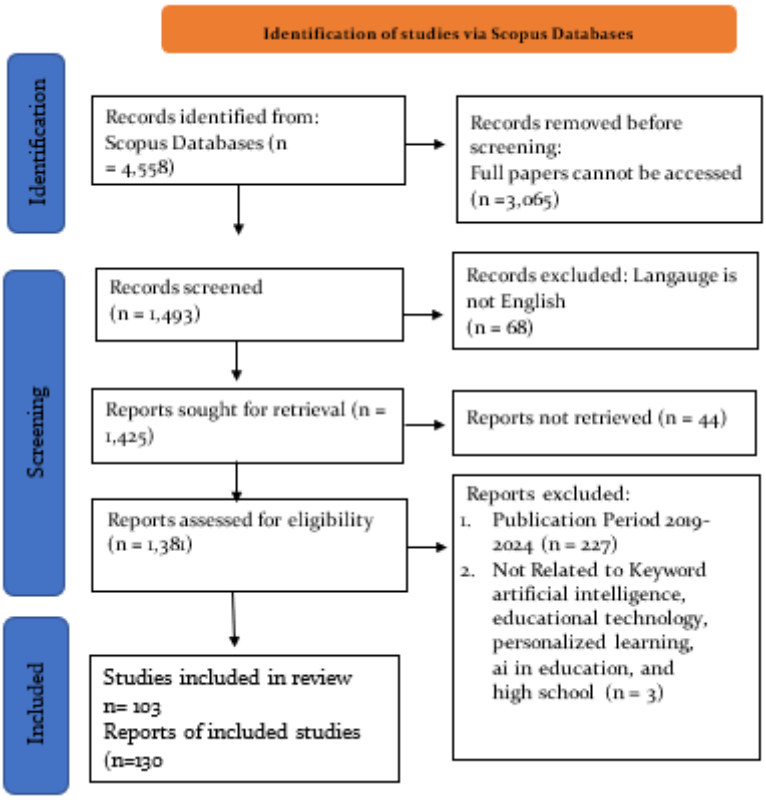

Diagram 1. Stages of article retrieval

The broader publication window of 2019–2024 was intentionally selected despite the primary analytical focus on the latest developments from 2022–2024. This decision ensures methodological rigor for two reasons. First, earlier publications (2019–2021) are needed to provide historical context and establish baseline trends before the recent surge of AI-related studies after the COVID-19 pandemic. Second, bibliometric analyses require sufficient longitudinal data to accurately detect shifts in publication volume, keyword emergence, and thematic evolution. Without including the earlier years, the analysis of research acceleration during 2022–2024 would lack meaningful comparative grounding. Thus, while the primary emphasis of interpretation is on the past two years, earlier publications play a methodological role in trend validation.

In the identification stage, a total of 4,558 records were retrieved from the Scopus database. To ensure repeatability, the exact search string used was:

(TITLE-ABS-KEY(”artificial intelligence” OR ”AI” OR ”machine learning” OR ”deep learning”) AND TITLE-ABS-KEY(”education” OR ”learning” OR ”educational technology”) AND TITLE-ABS-KEY(”secondary school” OR ”high school” OR ”K-12”)).

This initial retrieval also applied filters for document type (article), language (English), and source type (journal). From the 4,558 records, 3,065 were removed because they were not accessible in full-text form. During the screening stage, 1,493 articles were assessed, and 68 were excluded because they were not written in English. In the retrieval process, an additional 44 articles could not be downloaded and were subsequently removed. This left 1,381 articles for the eligibility assessment. In the eligibility stage, articles were evaluated more closely based on the predetermined inclusion and exclusion criteria. A total of 1,251 articles were excluded because they did not meet these criteria. Specifically, 227 publications fell outside the 2019–2024 timeframe, 954 did not correspond to the main keywords related to AI in education, and 70 were not scientific research articles.

Finally, a total of 130 articles met all eligibility criteria and were included in the final analy-

sis. Among these, 108 publications were used as the primary dataset for bibliometric visualization and thematic categorization, while the remaining 22 articles served as supplementary references to enrich the discussion and interpret emerging research patterns.

RESULT AND DISCUSSION

Based on Scopus data, the publication trend illustrates a consistent upward trajectory in scientific output related to artificial intelligence, educational technology, personalized learning, and associated themes between 2019 and 2024. In 2019, the number of publications was minimal, with only about three documents recorded. This figure increased moderately to seven documents in 2020 and eight documents in 2021, indicating an early stage of scholarly engagement with the topic. A more pronounced rise emerged in 2022, when publication output reached 19 documents, followed by 28 documents in 2023, signaling a strengthening academic interest in the field.

The most substantial surge occurred in 2024, when the number of publications exceeded 70 documents, marking a significant intensification of global research activity. This escalation reflects the growing prominence of themes such as AI integration in education, adaptive and personalized learning technologies, and the expansion of digital platforms within schooling contexts. Overall, the graph demonstrates a clear transition from exploratory research efforts toward a phase of consolidation, in which AI-driven educational innovation has become a central and increasingly dominant topic within contemporary scientific discourse.

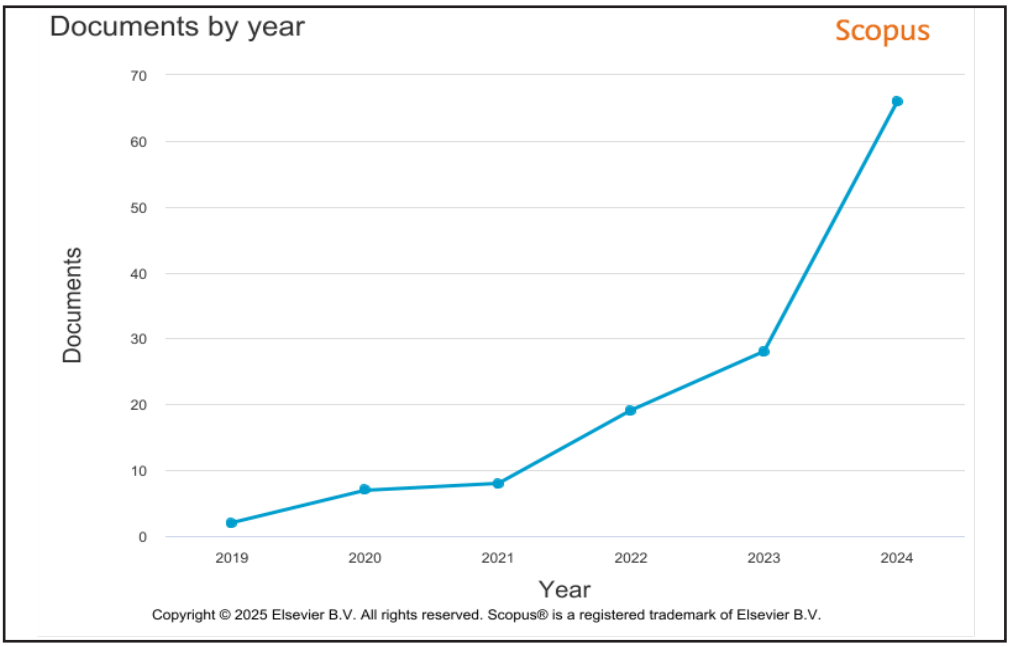

Figure 1 Publication trend by year

The data in Figure 2, "Documents by Subject Area," shows that scientific publications on the topics of artificial intelligence and educational technology are diverse and cross-disciplinary. The field of Medicine ranks first with a proportion of 22%, indicating that research related to this topic is widely applied in the context of medical education, healthcare training, and the use of AI for simulation and clinical learning. This is followed by the Social Sciences field at 21.5%, which signifies a significant focus on social dimensions, such as human interaction with learning technology, educational policies, and the social implications of AI implementation in the education sector.

Next, Computer Science ranks third with a 15% contribution to total publications. This shows that the technical aspects of developing and implementing AI-based systems in learning are an important focus in academic literature. This is followed by Engineering at 4.7% and Bioche-

mistry, Genetics, and Molecular Biology at 4.2%, which are likely related to STEM (Science, Technology, Engineering, and Mathematics) education and the need for personalized learning in exact sciences.

Additionally, the fields of Multidisciplinary, Professional Health, Mathematics, Neuroscience, and Psychology each contribute smaller but significant percentages, ranging from 2.8% to 3.7%. This reflects that the issues being studied are complex and touch on various aspects, ranging from cognitive processing in AI-based learning to the adaptation of technology in teaching across different levels and contexts. Meanwhile, the "Other" category (16.8%) indicates contributions from various other fields that are not specifically classified but remain relevant to the research topic. These findings show that studies on artificial intelligence in educational technology are interdisciplinary and continue to evolve in various scientific field.

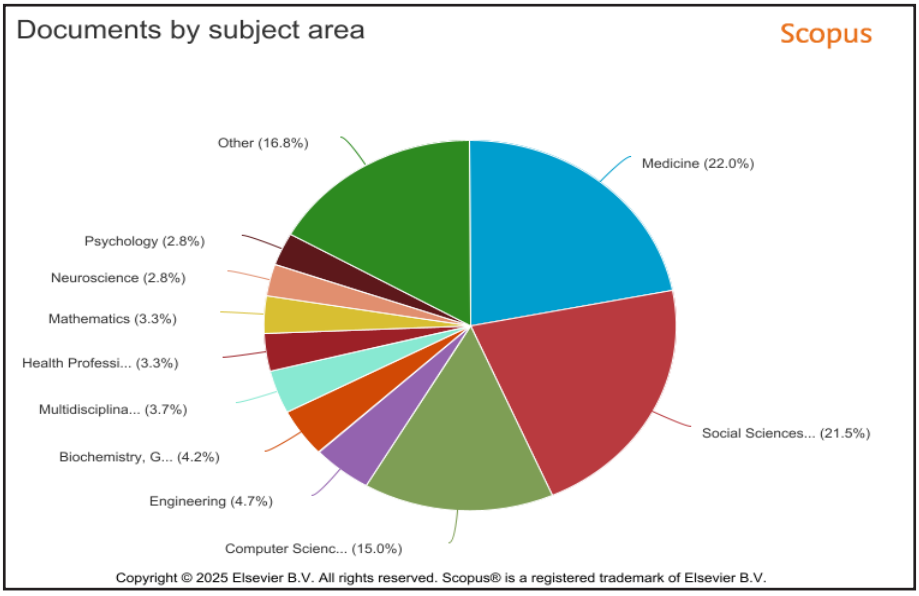

Figure 2 Distribution of Documents Based on Field of Study

In Figure 3, based on documents by country or territory, it can be seen that scientific publications related to artificial intelligence and educational technology mostly originate from China, with nearly 25 documents. This shows that China is the country with the highest contribution to the development and application of AI in the education sector, which is in line with their national policy to accelerate digital transformation and technology-based educational innovation. The second and third positions are held by the United States and the United Kingdom, with over 20 and 18 documents, respectively. These two countries have strong research and education ecosystems, as well as advanced digital infrastructure, which support the exploration and adoption of AI in learning. India ranks fourth with approximately 13 documents, indicating a positive trend in the involvement of academics from developing countries in the global discourse on educational technology.

Next, countries such as Italy, Australia, Ireland, Japan, Singapore, and Spain each contributed around 6–9 documents. This indicates that interest and attention to this topic is global and involves various countries from different continents, including Asia, Europe, and Oceania. These findings reinforce the understanding that the issue of artificial intelligence in education has become an international concern, not only in developed countries but also in countries with rapid technological growth. Additionally, this reflects the potential for cross-national collaboration in research and development of AI-based learning solutions.

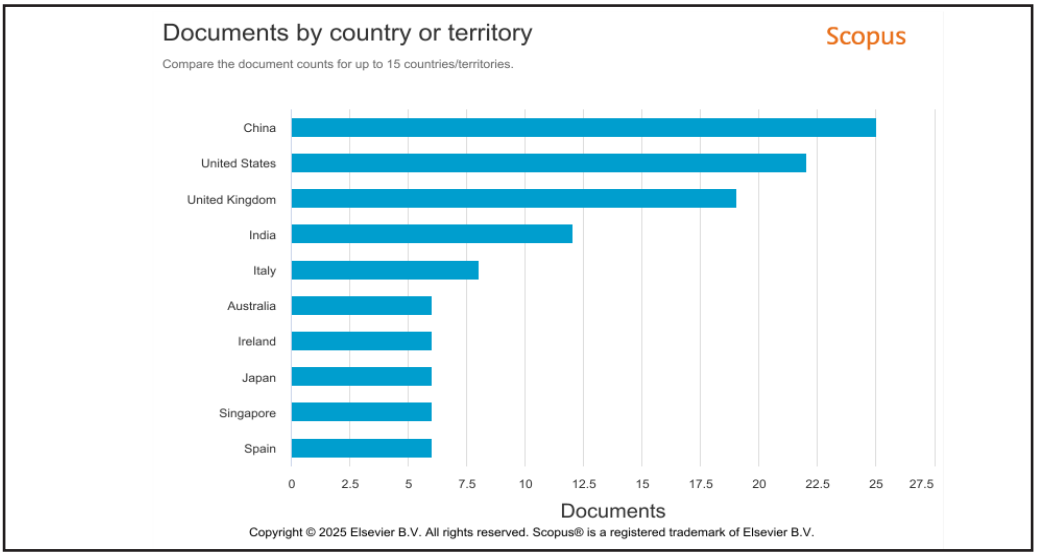

Figure 3 Documents by Country or Region

The visualization of the author collaboration network displayed through VOSviewer shows the relationships and connections between researchers in publications related to specific topics, such as artificial intelligence in education. Each colored cluster represents a community of authors who are connected through research collaboration. There are several main groups that appear quite dense and indicate a high level of collaboration, such as the cluster consisting of Bajunaid, Khalid – Bakhaidar, Mohamad – Alsayegh, Ahmad (red), and Caton, Natasha – Del Papa, Joshua (blue). This indicates the presence of groups of authors who are actively working in productive research teams and have close connections in publicatio

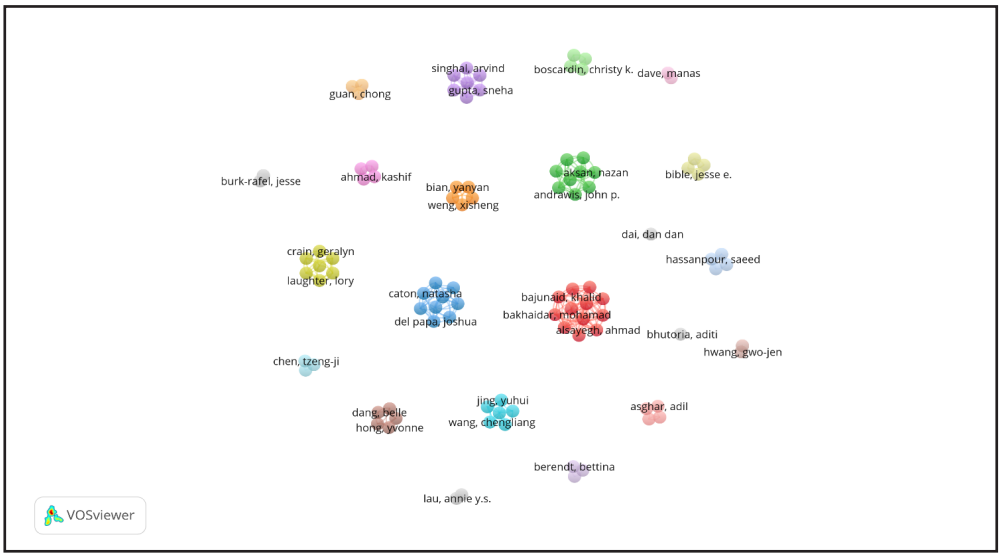

Figure 4 Distribution of authors based on topic clusters

Figure 5 is a visualization of the keyword cluster network from scientific publications analyzed using VOSviewer software. Each color in the network represents a group of keywords (clusters) that are closely related based on their occurrence in the literature. The red cluster is dominated by keywords such as learning, teaching, development, and integration, indicating a focus on the use of artificial intelligence (AI) technology, such as ChatGPT, in the field of education. This topic covers curriculum development, learning processes, and the integration of digital technology in teaching. The green cluster represents the medical and clinical fields, with keywords such as “patient,” “trial,” “group,” and “performance.” This indicates the use of AI in clinical research,

group testing, and patient performance analysis. Meanwhile, the purple cluster, with keywords like “chatgpt,” “question,” “accuracy,” and “ai chatbot,” reflects interest in the effectiveness and accuracy of AI-based chatbots in answering questions or supporting communication processes. Other clusters, such as blue and yellow, are associated with topics like metaverse, perception, attitude, training, and skill, indicating exploration of immersive technology and its impact on perception, attitude, and user skill development. Overall, this visualization shows that ChatGPT and related AI technologies are at the center of attention across various fields, particularly education, healthcare, and digital innovatio

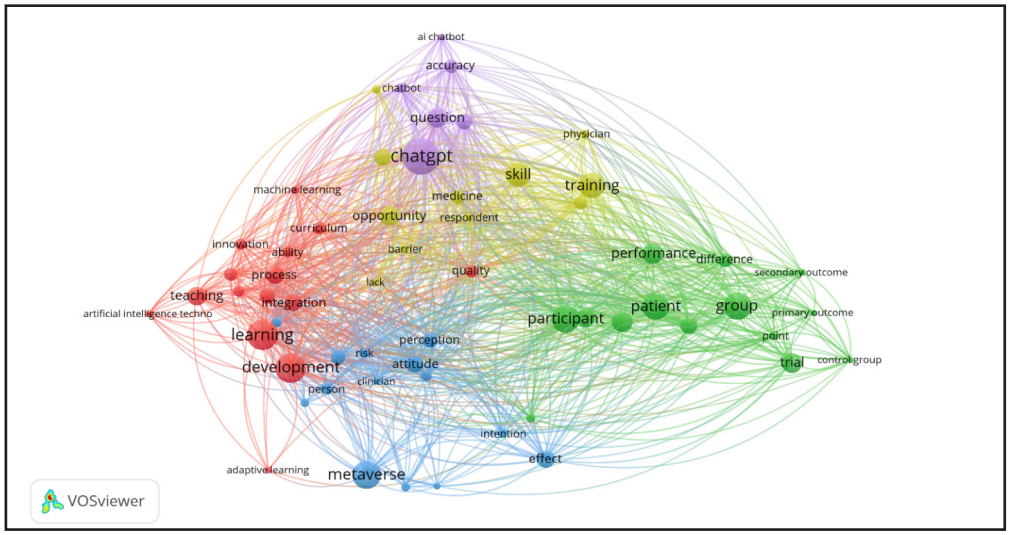

Figure 6 Topic clusters in studies on the application of AI in learning

Based on the visualization results from VOSviewer, five main clusters were obtained that represent interconnected research themes in the study of artificial intelligence, learning, and education. Each cluster has a group of keywords that indicate the focus and direction of the research topic. The following is a tabular representation of each cluster and its interpretation:

Table 1 Cluster Table and Main Topics

No.	Claster	Keyword Topics	Number of Items
1	Cluster 1 (Red)	ability, adaptive learning, AI technology, big data, curriculum, development, innovation, integration, learning, machine learning, process, quality, teacher, teaching, technique	15
2	Cluster 2 (Green)	control group, difference, group, intervention, outcome, participant, patient, performance, point, primary outcome, program, secondary outcome, term, trial	14
3	Cluster 3 (Light Blue)	adoption, attitude, clinician, effect, higher education, implication, intention, metaverse, perception, person, researcher, risk, trust, virtual reality	14
4	Cluster 4 (Yellow)	barrier, generative AI, lack, medical education, medical student, medicine, opportunity, physician, respondent, skill, training	11
5	Cluster 5 (Purple)	accuracy, AI chatbot, chatbot, ChatGPT, question, response	6

These five clusters indicate that research on artificial intelligence and digital technology in

education and healthcare is currently developing rapidly in a multidisciplinary direction. Clusters 1 and 3 represent educational approaches and digital transformation in learning, while clusters 2 and 4 emphasize experimental approaches and the application of AI in the medical field. Cluster 5 specifically highlights the role of ChatGPT and chatbots as communication and educational tools being explored across various fields. This visualization not only illustrates the interconnections between concepts but can also serve as a foundation for identifying research gaps and directions for deeper exploration of topics, such as the integration of the metaverse in medical education or the evaluation of chatbot effectiveness in medical education.

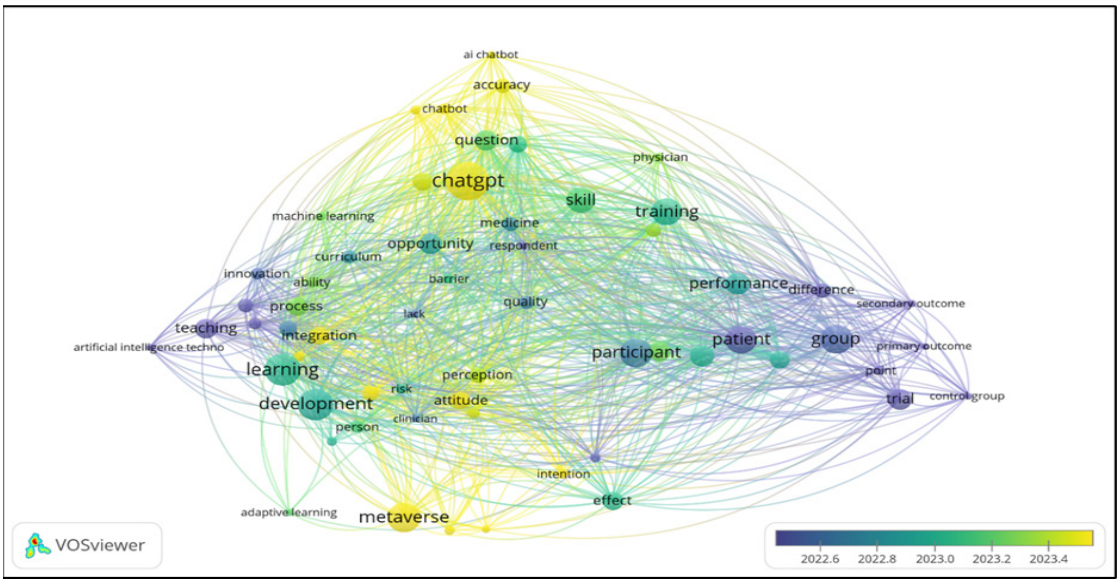

Figure 7 Trends in research topics from 2022 to 2024

The results of bibliometric analysis using VOSviewer show the development trends of research themes from 2022 to 2023 based on the emergence and interrelationships of keywords in the literature. This visualization depicts interconnected topics in a network map, with color gradients from dark blue (2022) to bright yellow (2023) representing the chronological emergence of keywords. Keywords such as chatgpt, accuracy, question, attitude, and metaverse are displayed in bright yellow, indicating that these topics are the most recent and currently being extensively researched, particularly throughout 2023 and into early 2024. This indicates an increase in interest in new technologies, particularly ChatGPT and its integration into various fields such as education, skill training, and professional development. Meanwhile, keywords such as trial, group, and patient, which are colored blue, tend to appear earlier in the literature, pointing to a research approach based on trials or interventions that dominated the early period. Additionally, keywords such as learning, development, and training, which are in the middle of the color spectrum, indicate that these topics have had a stable research focus since mid-2022 to 2023. This mapping provides an overall picture of the shift in research focus from conventional approaches toward the exploration of more innovative and adaptive new technologies.

Studies on the transformation of AI-based learning at the secondary school level over the past two years have shown rapid progress (Bozkurt, 2023; Rojas & Chiappe, 2024). Based on the results of a bibliometric analysis of 4,558 articles reviewed in the Scopus database, it appears that from 2022 to 2024 there has been a sharp increase in the number of scientific publications related to this topic. While only three articles were recorded in 2019, by 2024 that number had increased dramatically to more than 70 articles. This surge reflects the growing global academic attention to the issue of AI integration in education, which is closely tied to the impact of the COVID-19 pandemic as a catalyst for educational digitalization.

This upward trend also indicates that AI has transformed from merely a supporting te-

chnology into an integral part of learning system design. As shown in keyword analysis using VOSviewer software, topics such as adaptive learning, AI technology, personalized learning, and machine learning are the dominant keywords that appear in the selected articles. This reinforces the findings of Taylor, Gupta, and Jung (2024), who state that AI supports the creation of smart classrooms with a student-centered learning approach. With the ability to provide real-time feedback and tailor content based on individual needs, AI enables a learning model that is far more personalized and efficient than conventional models.

Meanwhile, Zhang et al. (2022) emphasize that the existence of AI-based smart education systems also opens up opportunities to design adaptive curricula and supports data-driven decision-making by teachers and school principals. Cluster 1 of the bibliometric results shows a strong correlation between keywords such as curriculum, development, teaching, and integration, indicating that AI research in education is closely related to instructional development and learning management.

On the other hand, the distribution of documents based on scientific fields also shows that studies on AI in learning are multidisciplinary. The data shows that the field of Medicine occupies the largest share (22%), followed by Social Sciences (21.5%) and Computer Science (15%). This indicates that AI-based learning is not only viewed from a technological perspective but also from a social and applied approach, such as in medical simulations, clinical skill training, and changes in students' learning behavior.

The presence of Psychology and Neuroscience in the list also signifies that AI is seen as having the potential to support cognitive understanding and personalized learning interventions based on student data analysis. This diversity of disciplines reflects the interdisciplinary approach outlined by Wahyudin et al. (2024), ho noted that studies on technology and social movements (in their context) require an approach from multiple fields of study. The same applies to AI-based learning transformation, which cannot be separated from policy, social, pedagogical, and even psychological aspects.

The visualization of author collaboration also shows a productive network of researchers from various countries and institutions, with China, the United States, and the United Kingdom as the top contributors to publications. This aligns with the digital transformation policies in these countries, particularly China, which has integrated AI into its national education policy. However, developing countries like India, despite becoming more active, still face various limitations. Sihag and Vibha (2024) note that the main obstacles to AI implementation in India are the digital divide and low infrastructure readiness. These findings are also relevant to the Indonesian context, which faces similar challenges, particularly in terms of disparities in access and teachers' digital competencies.

In addition to technical and infrastructure issues, another equally important challenge is the readiness of educational actors, particularly teachers and school principals. A study by Karakose (2021) shows that managerial competencies and school organizational culture are key factors in the successful adoption of AI. Clusters in keyword analysis, such as those covering barriers, training, skills, and opportunities, underscore the importance of continuous training for educators to be able to adapt and optimize the use of AI technology.

Interestingly, the cluster discussing ChatGPT, AI chatbots, and accuracy has become a particular focus in the 2023–2024 period. This topic has seen a rapid increase in literature as technologies like ChatGPT begin to be explored as tools for academic learning and communication. Recent research highlights that while ChatGPT offers various conveniences such as answering students' questions or providing summaries of materials, aspects of accuracy and ethical use remain subjects of debate. This indicates that the exploration of generative AI in education has not yet reached its full potential but is currently undergoing critical evaluation by researchers and practitioners.

Meanwhile, the cluster discussing topics such as the metaverse, virtual reality, perception, and attitude reflects interest in immersive approaches to learning. Research in this cluster exami-

nes how students' and educators' perceptions of cutting-edge technologies like virtual reality can influence engagement and motivation in learning. These findings align with Arets et al. (2020) study, which emphasizes the importance of understanding the dynamics of technology-social interactions in the implementation of new media, including AI.

Based on all these findings, it can be concluded that research on AI-based learning transformation is progressive and multidimensional. However, implementation challenges remain significant, both from technical aspects (access, infrastructure) and social aspects (human resource readiness, technological literacy, and ethical use). Therefore, an educational policy approach is needed that is not only oriented toward technological innovation but also considers the readiness of the educational ecosystem as a whole. Teacher training, infrastructure provision, and inclusive policies are essential prerequisites for making AI a driver of sustainable learning transformation.

CONCLUSION

The closing section of the discussion should not reiterate the study's overall findings but instead clarify how the present work advances the scholarly conversation on AI-based learning transformation. The bibliometric evidence demonstrates that research in this domain is transitioning toward a more consolidated and diversified stage, marked by rapid growth in AI-driven personalization, increasing exploration of generative AI tools, and strengthened interdisciplinary connections between education, medicine, and computer science. These developments reveal meaningful shifts in the field, indicating that AI is no longer viewed solely as a technological add-on but as a driver of pedagogical, institutional, and methodological change. As such, the study's mapping of thematic concentrations and collaborative structures offers a refined landscape through which emerging research priorities can be identified and more systematically examined.

These insights open several critical pathways for future inquiry. Subsequent research is needed to evaluate the pedagogical validity, ethical implications, and long-term learning impacts of generative AI applications within secondary-school settings. Additionally, the disparities in digital readiness, teacher competencies, and policy support across various educational contexts highlight the necessity of examining AI integration through an equity- and capacity-oriented lens. Further exploration could also focus on cross-sector collaborations, particularly between educational institutions and technology developers, to better understand how innovation ecosystems influence adoption patterns in schools. By emphasizing these forward-looking directions, the discussion section reinforces the study's intellectual contribution and clearly distinguishes its purpose from that of the conclusion, while positioning the findings as a catalyst for deeper theoretical development and more contextually grounded empirical research.

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