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Comprehensive bibliometric analysis of artificial intelligence and E-Learning research trends (2014–2024)

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Abstract: This study conducts a comprehensive bibliometric analysis of research on AI in e-learning from 2014 to 2024, addressing the lack of a systematic overview of this rapidly evolving interdisciplinary field. Using the Scopus database and Biblioshiny package in R, we analyzed 282 documents from 127 sources to map research trends, key contributors, collaboration patterns, and emerging themes through co-citation networks, relational patterns, and keyword co-occurrence analysis. Results reveal 31.28% annual growth in publications, with China, the United States, and India as leading contributors. IEEE Access emerged as the most prolific journal (23 publications), while Intel Labs and Purdue University led institutional contributions. International collaborations comprised 24.47% of publications, highlighting the field's global nature. Key emerging technologies include generative AI, immersive technologies (VR/AR), and personalized learning systems, alongside growing attention to ethical considerations. The field has evolved from basic technological applications toward sophisticated, interdisciplinary implementations addressing complex educational challenges, with increasing focus on personalization, immersive experiences, and ethical frameworks. Findings guide educational practitioners in implementing evidence-based AI technologies, help policymakers address geographical disparities in research and implementation, and provide researchers with a roadmap of emerging subfields for future investigation, emphasizing contextual adaptation for effective implementation across diverse educational settings.

Keywords: *Artificial intelligence, Bibliometric analysis, Educational technology, E-Learning, Research trends.*

1. Introduction

The integration of Artificial Intelligence (AI) and E-Learning technologies has evolved into a transformative synergy that fundamentally redefines contemporary digital education ecosystems [1, 2]. This technological convergence transcends conventional educational boundaries, enabling personalized learning experiences that adapt to individual learner needs through intelligent data processing and real-time feedback mechanisms [3, 4]. Unlike traditional E-Learning implementations that primarily deliver passive digital content, AI-enhanced educational platforms create adaptive learning systems capable of analyzing learning patterns, identifying knowledge gaps, and automatically adjusting content difficulty to optimize learning outcomes [5, 6].

The transformative potential of AI in education manifests across multiple dimensions, creating a paradigm shift from standardized to personalized educational approaches. Research demonstrates that AI technologies can process vast amounts of educational data to generate actionable insights, enabling more precise identification of learning difficulties and allowing for evidence-based pedagogical innovations [7, 8]. These advancements represent a significant evolution from early intelligent tutoring systems toward sophisticated learning environments that can adapt in real-time to student needs, providing unprecedented levels of educational customization [9, 10].

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From an educator's perspective, the integration of AI within E-Learning platforms reveals new dimensions in teaching practices through comprehensive learning analytics [2, 11]. AI's capability to process large-scale learning data allows educators to precisely identify patterns of learning difficulties, measure teaching strategy effectiveness, and initiate appropriate pedagogical innovations. Beyond functioning as administrative tools, AI systems serve as pedagogical assistants that enhance educators' capabilities in designing adaptive and personalized learning experiences. Digital classrooms generate rich data streams that, when processed by AI algorithms, reveal insights into learning dynamics that would be difficult to identify through conventional observation methods [1, 6].

At the institutional level, AI technologies integrated with E-Learning offer transformative instruments for educational leaders and policy makers. Administrative dashboards powered by AI analytics enable monitoring of institutional performance both holistically and granularly, identifying learning trends and measuring program effectiveness with unprecedented precision [3]. The ability to process various educational metrics simultaneously provides a robust foundation for strategic decision-making and resource allocation. AI-based predictive systems can alert leaders to potential challenges before they become systemic issues, enabling proactive interventions that optimize resource allocation and enhance educational outcomes [12, 13].

For students and parents as end-users, AI-enhanced learning platforms deliver substantial benefits through personalization and detailed progress tracking. These systems provide comprehensive reports on students' cognitive development and learning trajectories with a precision impossible to achieve through conventional assessment methods [5, 11]. Advanced AI applications can even begin to measure affective domains through sentiment analysis and natural language processing applied to student interactions, providing a more holistic picture of learner development. This data-driven approach enables parents to better support children's individual learning needs and helps students progress according to their own pace and preferred learning styles [8, 14].

The current technological landscape in AI-enhanced education encompasses several rapidly developing areas. Generative AI models such as large language models (LLMs) are transforming content creation, assessment practices, and instructional support [13, 15]. Research demonstrates these technologies can significantly reduce teacher workload while maintaining or improving educational quality [11]. Simultaneously, immersive technologies such as virtual reality (VR) and augmented reality (AR) integrated with AI are creating experiential learning environments that simulate real-world scenarios with unprecedented fidelity [16].

Other emerging technologies include intelligent tutoring systems enhanced by deep learning, educational data mining for personalized learning pathways, and AI-powered collaborative learning environments [17]. The integration of Internet of Things (IoT) with AI further extends the potential for comprehensive learning analytics by incorporating data from various sources and learning contexts [7]. These advancements collectively point toward an increasingly interconnected and intelligent educational ecosystem that transcends institutional and geographical boundaries, promoting greater democratization of quality education access [12].

Despite the transformative potential of AI in E-Learning, a systematic understanding of the evolution, emerging trends, and collaboration patterns in this rapidly developing field remains limited. While several bibliometric studies have examined related areas, significant gaps exist in the comprehensive mapping of AI in E-Learning research. Li and Wong [9] conducted a bibliometric analysis of AI in personalized learning but focused primarily on the intellectual structure rather than collaboration patterns and emerging technologies. Similarly, Wu and Yu [10] examined AI chatbots in language education but with a narrower scope than the broader AI-E-Learning landscape. Baber, et al. [15] investigated ChatGPT-focused literature but did not address the broader spectrum of AI technologies in education.

These previous bibliometric studies, while valuable, have been limited in either temporal scope, technological focus, or methodological approach. No comprehensive analysis has yet mapped the full decade of development from 2014 to 2024—a period of unprecedented growth and transformation in

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both AI capabilities and E-Learning implementation. Furthermore, existing studies have not adequately addressed the complex interrelationships between different technological approaches, application contexts, and international collaboration networks that characterize this interdisciplinary field.

To address these gaps, this study aims to conduct a comprehensive bibliometric analysis of research on AI in E-Learning from 2014 to 2024, with the following specific research questions:

1. How has the volume, impact, and geographic distribution of AI in E-Learning research evolved over the past decade?
2. Who are the key contributors (authors, institutions, and countries) in this field, and what are their patterns of collaboration?
3. What are the emerging technological subfields, methodological approaches, and application contexts within AI and E-Learning research?
4. What future research directions can be identified based on keyword trends and thematic evolution?

This research contributes to the literature by providing a systematic mapping of an increasingly important interdisciplinary field during a critical period of development. By identifying research trends, key contributors, and collaboration patterns, this study uncovers important insights that can accelerate AI-based educational innovation. The analysis employs established bibliometric frameworks [18] to examine co-citation networks, relational patterns, scientific collaboration, and keyword co-occurrence, providing a multi-dimensional perspective on the field's evolution.

2. Methods

This study employs a bibliometric approach to analyze various articles related to Artificial Intelligence (AI) and E-learning, sourced from the Scopus database. Scopus provides a significant advantage as one of the largest academic databases, offering extensive coverage of scholarly publications, making it a primary data source for scientific research [19]. Scopus's robust features enable researchers to refine searches and apply specific criteria tailored to research needs, with the data subsequently exported to Microsoft Excel for further mapping and analysis [20, 21]. The process of identifying and reviewing relevant publications was structured and guided by the PRISMA framework (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [22]. Rigorous search criteria and filtering processes were implemented to ensure the inclusion of publications that align closely with the research objectives, thus maximizing the relevance and accuracy of the dataset.

The data search was conducted on December 6, 2024, focusing on articles published within the period of 2014–2024. Advanced search criteria were applied to ensure the relevance of the retrieved data to the research objectives. The keywords utilized in the advanced query feature included "E-Learning," "Artificial Intelligence," "AI," "E – Learning," "Education," "Artificial Intelligence (AI)," and "Artificial Intelligence Technologies." Further filtering was performed by selecting only articles published in peer-reviewed academic journals. For the subject area, restrictions were applied to "Computer Science" and "Social Sciences," as the latter represents the domain most closely associated with education, given that Scopus does not offer a specific "education" category. Figure 1 provides a systematic visual representation of the entire search process, illustrating the methodology employed in retrieving and selecting the literature for analysis.

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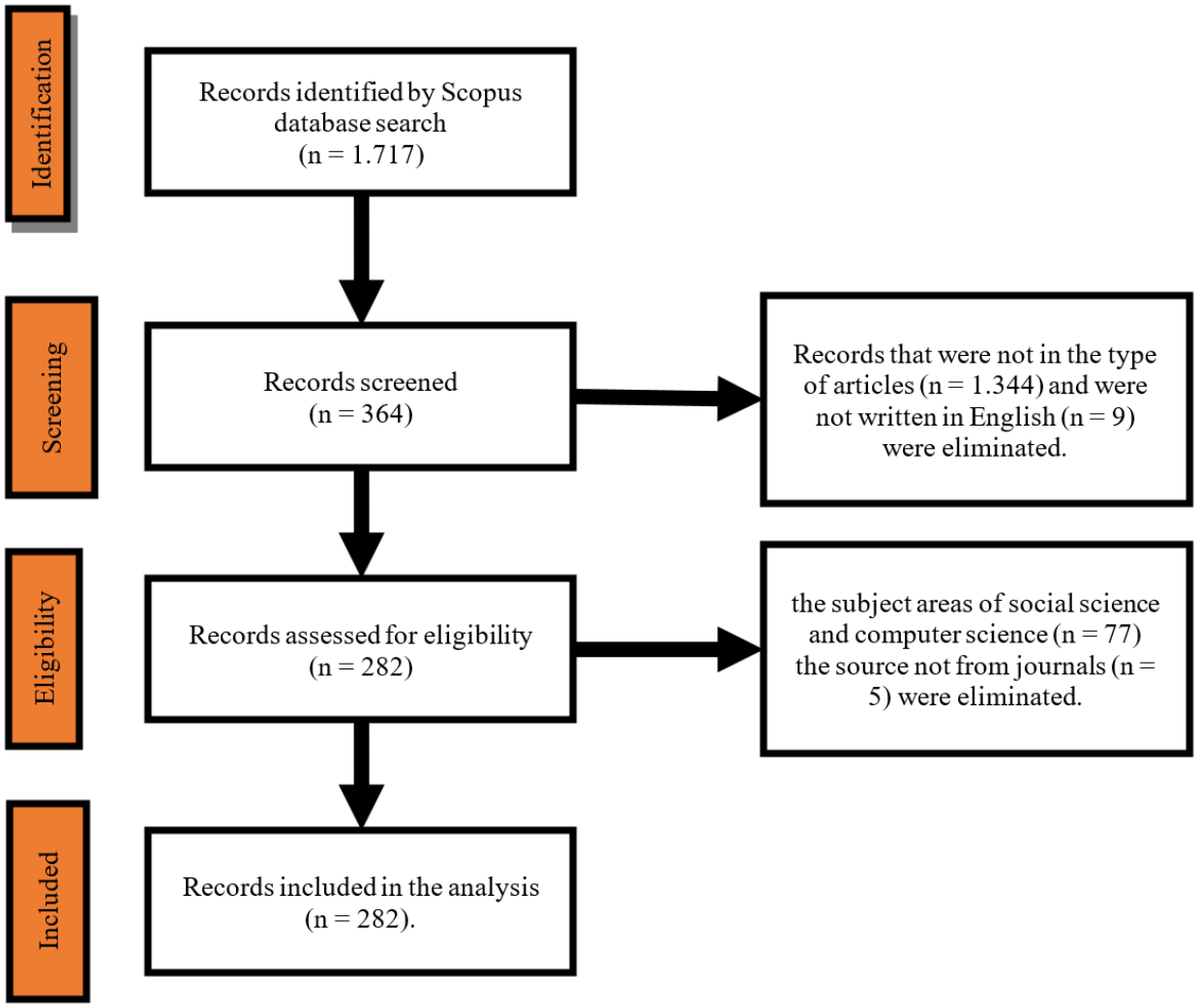

Figure 1.
Selection of the publications included in the research by PRISMA method.

Upon obtaining and tabulating the data in Microsoft Excel, further analysis was conducted using the R programming language, specifically utilizing the Biblioshiny package. Biblioshiny, a web-based application integrated within the bibliometric package of R, played a pivotal role in performing bibliometric analysis and generating data matrices. These matrices facilitated the exploration of various bibliometric dimensions, including co-citation networks, relational patterns, scientific collaboration, and co-occurrence analysis of keywords. Biblioshiny's robust analytical capabilities support a comprehensive examination of the bibliometric characteristics of the selected literature [18]. The bibliometric results serve as a reliable tool for assessing and analyzing publications indexed within the chosen database [23]. Furthermore, well-executed bibliometric analysis holds significant potential to foster advancements in science by uncovering meaningful and novel research insights [24].

3. Results

The bibliometric analysis reveals significant patterns in the evolution of AI in e-learning research from 2014 to 2024. Figure 1, shows that pur analysis of 282 documents from 127 sources demonstrates a substantial annual growth rate of 31.28% in publications, indicating rapidly increasing scholarly

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interest in this field. The average document age of 2.34 years suggests that this research area is relatively young and dynamic, with most contributions being recent.

Figure 2.
Bibliometric Analysis Result.

This result shows the most contributed countries over time, it reveals a clear geographical distribution of research productivity in AI and e-learning studies. On table 1, we can see that China emerges as the dominant contributor with 279 publications, substantially leading the global research output. The United States follows as the second most productive country with 128 publications, less than half of China's output. India ranks third with 72 publications, demonstrating significant contribution from the Asian region.

Table 1.
Most Countries Research Production.

Region	Frequency
China	279
USA	128
India	72
Saudi Arabia	37
Norway	36
UK	32
Spain	31
Germany	22
Morocco	20
South Korea	20

The Middle Eastern presence is marked by Saudi Arabia's 37 publications, placing it fourth in the global ranking. European contributions are led by Norway (36 publications) and the United Kingdom (32 publications), followed closely by Spain with 31 publications. Germany also shows notable presence with 22 publications. Rounding out the top ten are Morocco and South Korea, each contributing 20 publications to the field.

The bibliometric analysis identified several authors who have made notable contributions to the field of AI in e-learning. The "Most Relevant Authors" chart on figure 3 highlights 10 authors, each contributing two publications during the examined 10-year period (2014–2024). These authors include Suliman A. Alsuhibany, Chunhai Cui, Milena Ilić, Ahmad Jalal, Jihyun Kim, Valentin Kuleto, Oliva M. D. Martins, Kelly Merrill, Jeongmin Park, and Mihaela Radu.

Figure 3.
Most Relevant Authors.

Authors	Number of Documents
Suliman A. Alsuhibany	2
Chunhai Cui	2
Milena Ilic	2
Ahmad Jalal	2
Jihyun Kim	2
Valentin Kuleto	2
Oliva M. D. Martins	2
Kelly Merrill	2
Jeongmin Park	2
Mihaela Radu	2

On the Table 2, the bibliometric analysis highlights the most relevant publication sources contributing to research on AI in e-learning. Among the analyzed sources, IEEE Access emerges as the most prolific journal, publishing 23 articles during the study period. This demonstrates its critical role in disseminating cutting-edge research on educational AI technologies, likely due to its broad scope and emphasis on rapid dissemination of interdisciplinary advancements.

Following IEEE Access, Computer-Aided Design and Applications ranks second with 13 publications. This journal's contributions suggest the significant role of AI-based design and simulation technologies in e-learning systems. Two journals tied for third place, Computational Intelligence and Neuroscience and the International Journal of Emerging Technologies in Learning, with 11 publications each. These journals reflect the interdisciplinary efforts bridging computational intelligence and innovative educational practices.

Furthermore, Computers and Education, one of the most respected journals in educational research, contributes 8 articles, emphasizing its commitment to exploring AI-driven educational transformations. Other notable sources include Computers and Education: Artificial Intelligence and Sustainability (Switzerland), each with 7 publications. The inclusion of Sustainability highlights the interest in investigating the sustainable integration of AI technologies into e-learning practices. Rounding out the list are Applied Mathematics and Nonlinear Sciences (6 publications), the British Journal of Educational

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Technology (6 publications), and the International Journal of Artificial Intelligence in Education (6 publications). These journals further demonstrate the convergence of AI, mathematics, and educational research.

Table 2.
Most Relevant Source.

Sources	Articles
IEEE Access	23
Computer-Aided Design and Applications	13
Computational Intelligence and Neuroscience	11
International Journal of Emerging Technologies in Learning	11
Computers and Education	8
Computers and Education: Artificial Intelligence	7
Sustainability (Switzerland)	7
Applied Mathematics and Nonlinear Sciences	6
British Journal of Educational Technology	6
International Journal of Artificial Intelligence in Education	6

The bibliometric analysis key affiliations that have been instrumental in advancing research on AI in e-learning within the 2014–2024 timeframe. As we can see on table 3, among these, Intel Labs and Purdue University lead as the most influential contributors, each producing 12 publications during the study period. Their substantial outputs reflect a strong institutional focus on integrating AI technologies into education, with a likely emphasis on applied and experimental research. The University of Michigan follows with 10 publications, emphasizing its prominence in educational technology innovation. King Abdulaziz University contributes 9 publications, indicating significant research activity from the Middle East, particularly in the integration of AI within regional educational frameworks.

Other prominent institutions include Universiti Malaya with 8 publications, showcasing Malaysia's emerging role in AI and e-learning research in Southeast Asia. Harbin Engineering University and South China Normal University each contribute 7 publications, underscoring China's continued dominance and investment in this domain. Beihang University strengthens this trend, demonstrating a strong national commitment to advancing AI applications in education. Specialized research centers such as the Guangdong Engineering Technology Research Center of Smart Learning, with 6 publications, highlight the integration of AI-driven smart learning systems. The Mohammed VI Polytechnic University, contributing 6 publications, reflects increasing research contributions from Morocco, further emphasizing the globalization of AI and e-learning research.

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Table 3.
Most Relevant Affiliations.

Affiliation	Articles
Intel Labs	12
Purdue University	12
The University of Michigan	10
King Abdulaziz University	9
Universiti Malaya	8
Harbin Engineering University	7
South China Normal University	7
Beihang University	6
Guangdong Engineering Technology Research Center of Smart Learning	6
Mohammed VI Polytechnic University	6

To uncover emerging subfields and potential areas for future investigation. Data result showed us the analysis of trend topics reveals significant insights into the evolving landscape of AI in e-learning research, highlighting emerging subfields and potential areas for further investigation. The chart illustrates the prominence and temporal evolution of various research terms from 2014 to 2024, offering a comprehensive overview of the field's dynamic and interdisciplinary nature.

Table 4.
Trend Topics.

Topic/Term	Emergence Period	Term Frequency	Trend Analysis
Artificial Intelligence in Education	2021-2024	High (≈250)	Predominant research focus, especially from 2021 onward
Intelligent Tutoring System	2021-2024	High (≈250)	Exhibits upward trajectory, emphasizing adaptive learning systems
Digital Technologies	2023-2024	High (≈250)	Demonstrates significant growth post-2020
Virtual Reality	2022-2023	Medium (≈150)	Increasing prominence after 2020, focusing on immersive technologies
Curricula	2022-2023	Medium (≈150)	Evolving post-2020, integrating with technological frameworks
Artificial Intelligence Technologies	2022-2023	Medium (≈150)	Rising trend, emphasizing practical applications
E-learning	2021-2023	High (≈200)	Fundamental concept with consistent significance throughout the period
Artificial Intelligence	2020-2023	High (≈200)	Emerges prominently after 2020, indicating broadened conceptual focus
Students	2021-2023	Medium (≈150)	Accentuates student-centered learning approaches
Higher Education	2020-2023	Low (≈100)	Concentrates on tertiary education contexts
Massive Open Online Course	2018-2023	Low (≈100)	Regains attention circa 2022, correlated with pandemic implications
Collaborative Learning	2020-2022	Low (≈100)	Develops within remote learning contexts
Active Learning	2017-2023	Low (≈100)	Emphasizes participatory pedagogical methodologies
Websites	2018-2023	Low (≈100)	Supportive infrastructure for e-learning environments
Education	2016-2018	Low (≈100)	Foundational concept evolving into more specialized domains
Flipped Classroom	2015-2020	Low (≈50)	Initially emerges and subsequently resurfaces post-pandemic

Our trend topic analysis, as we can see on Table 4, The term "artificial intelligence in education" consistently dominates, particularly from 2021 onward, reflecting its centrality in research. Closely related terms such as "artificial intelligence technologies" and "intelligent tutoring system" exhibit similar upward trajectories, indicating a growing interest in the application of AI-driven tools to enhance educational processes. The frequent co-occurrence of these terms underscores a sustained focus

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on personalized and adaptive learning systems. Other closely related subfields, including "digital technologies," "virtual reality," and "curricula," also display growth in frequency, particularly post-2020. These trends suggest an increased emphasis on integrating immersive technologies and AI to create comprehensive learning ecosystems. The term "higher education" features prominently, indicating that much of the research focuses on tertiary education contexts, where the implementation of digital and AI-driven solutions is most impactful.

Emerging themes such as "massive open online courses" (MOOCs), "collaborative learning," and "flipped classroom" appear in earlier years but gain renewed attention around 2022 and beyond. This resurgence may stem from the COVID-19 pandemic and subsequent shifts toward hybrid and flexible learning environments. Similarly, terms like "active learning" and "students" emphasize learner-centered approaches, fostering engagement and adaptability in e-learning systems. The rise of "e-learning" as a term demonstrates its foundational role in the research, complementing more specialized topics. The interplay between AI technology, educational frameworks, and pedagogical models is evident, offering fertile ground for future exploration. Notably absent from earlier years, terms like "artificial intelligence" emerge strongly after 2020, suggesting a broader conceptual and technical focus, beyond specific applications.

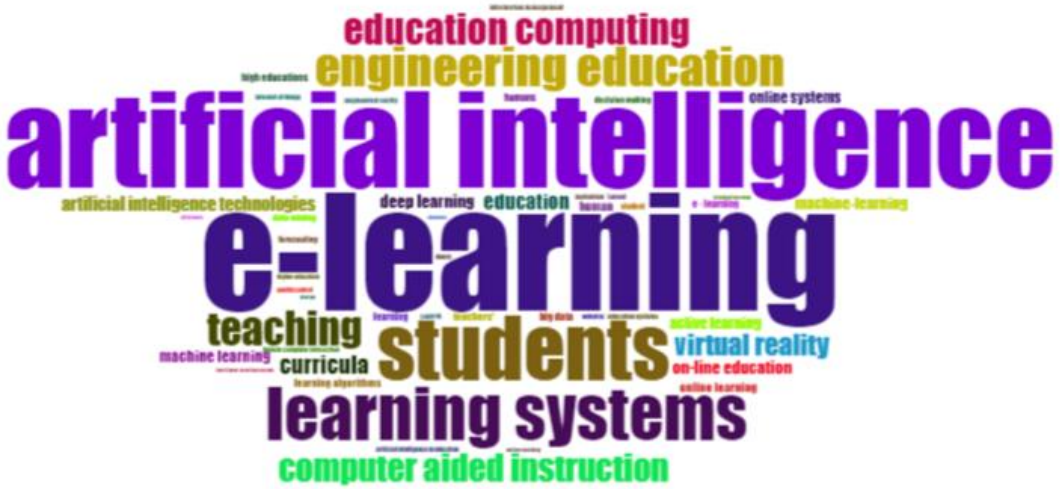

Figure 4.
Keywords.

The keyword analysis on figure 4 reveals critical insights into emerging subfields and potential directions for future research in the domain of AI in e-learning. The word cloud visualization emphasizes the prominence of key terms and their frequency of occurrence, offering a snapshot of the dominant topics in the field. At the center of the research field, "artificial intelligence" and "e-learning" are the most frequently used keywords, signifying their fundamental roles. These terms anchor the discourse, pointing to their centrality in addressing issues related to AI-driven educational innovations. Surrounding these central terms, other prominent keywords include "students," "learning systems," and "teaching," which highlight the field's focus on learner-centric approaches and the integration of AI tools in educational practice.

Several specialized subfields emerge from the keyword analysis. For instance, "deep learning" and "machine learning" highlight the advanced AI techniques increasingly applied in adaptive and intelligent tutoring systems. Terms like "virtual reality" and "computer-aided instruction" suggest a growing interest in immersive and interactive technologies as transformative tools in e-learning environments. The inclusion of "curricula," "engineering education," and "education computing"

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indicates research addressing the design and implementation of AI-enhanced curricula, particularly in technical and STEM education. Another notable theme is the emphasis on "education technologies" and "online education," pointing to the broader integration of AI in digital and distance learning contexts.

Emerging terms like "educational data mining" suggest active exploration of data-driven strategies for understanding and enhancing learning behaviors. This aligns with the broader trend of utilizing AI to generate actionable insights for personalized and effective learning interventions. The focus on "students" and "teaching" indicates a continuing emphasis on addressing the needs of learners and educators, emphasizing practical applications of AI for improving engagement, motivation, and outcomes. The prominence of "learning systems" further underlines the ongoing development of AI-powered platforms designed to deliver personalized and adaptive educational experiences. In order to see the collaboration patterns and knowledge flows in the interdisciplinary domain of AI in e-learning. Table 5 highlights distinct patterns of international collaboration in AI and e-learning research, reinforcing the global and interdisciplinary nature of this field. Based on the "Collaboration Country" table, several noteworthy bilateral collaborations emerge, shedding light on knowledge flows and co-authorship networks.

Table 5.
Country Collaboration.

From	To	Frequency
China	Australia	12
China	Hong Kong	12
China	India	10
China	Malaysia	9
China	USA	8
Korea	Pakistan	7
Saudi Arabia	Jordan	7
Saudi Arabia	Pakistan	6
USA	Saudi Arabia	6

Table 5 shows that China demonstrates its pivotal role in driving international collaborations, forming strong research ties with India and the United States, with five co-authored studies each. These partnerships emphasize China's leadership in fostering cross-border knowledge exchange while tackling global challenges in AI-driven education. Other notable collaborations include China's partnerships with Malaysia, Australia, and Hong Kong, each contributing three studies. These collaborations highlight the regional networks within Asia-Pacific and China's influence in extending knowledge-sharing initiatives.

Similarly, Korea and Pakistan exhibit a robust partnership, with four co-authored studies, reflecting the growing role of South Asian countries in the AI and e-learning research landscape. Saudi Arabia also emerges as a key collaborator, forming three-study partnerships with both Pakistan and Jordan, as well as a separate cluster of collaboration with the United States. These linkages underscore the Middle East's engagement in advancing AI applications in education, particularly in alignment with global technological advancements. The analysis shows that 24.47% of the publications involve international co-authorship, showcasing the interdisciplinary and transnational nature of this research domain. Furthermore, the average of 3.57 co-authors per document indicates a strong tendency toward multi-author, collaborative research efforts, fostering comprehensive and innovative outcomes that benefit from diverse perspectives.

4. Discussion

4.1. Evolution and Trends in AI and E-Learning Research (2014-2024)

Our bibliometric analysis reveals significant patterns in how AI and e-learning research has evolved over the past decade. Notably, the field demonstrates robust annual growth of 31.28% in publications,

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which strongly aligns with previous observations about AI's transformative potential in education [6, 25]. This exponential increase validates earlier predictions about AI's transformative potential in education and indicates accelerating research momentum in this domain. The geographical distribution of research output presents an interesting pattern that both supports and extends existing literature. Our findings show China emerging as the dominant contributor with 279 publications, followed by the United States (128 publications) and India (72 publications). This pattern aligns with Karina and Kastuhandani [26] observations regarding these nations' leadership in educational AI innovation, while also revealing new insights about the global research landscape.

In terms of institutional contributions, our analysis identifies several key research centers, with Intel Labs and Purdue University leading with 12 publications each, followed by the University of Michigan with 10 publications. This institutional clustering supports [12] emphasis on the importance of strong institutional frameworks in driving AI innovation in education. Furthermore, the prominent role of specialized research centers, such as the Guangdong Engineering Technology Research Center of Smart Learning, demonstrates the increasing institutionalization of AI in e-learning research. The publication patterns show interesting temporal developments. Pre-2020 research primarily focused on foundational technologies like intelligent tutoring systems and learning analytics [27] while post-2020 research has shifted toward more sophisticated applications including real-time analytics and generative AI tools [28, 29]. This evolution mirrors the broader technological advancement trajectory described in our introduction [5, 11].

Most significantly, the analysis of publication sources reveals IEEE Access as the leading journal with 23 publications, followed by Computer-Aided Design and Applications with 13 publications. This distribution suggests that while AI in e-learning remains technically oriented, it is increasingly attracting attention from diverse academic disciplines, supporting the interdisciplinary nature of the field highlighted by Yu [13]. These findings make several important contributions to our understanding of the field's evolution. First, they provide empirical evidence for the exponential growth in research interest. Second, they identify key institutional and geographical centers of excellence. Third, they trace the field's progression from basic technological applications to more sophisticated implementations. This comprehensive mapping offers valuable insights for researchers and practitioners seeking to understand the field's development trajectory and identify potential collaboration opportunities.

4.2. Key Contributors, Collaboration Patterns and Knowledge Flows within AI and E-Learning Research

The interdisciplinary nature of AI in e-learning research has fostered dynamic collaboration patterns and knowledge flows across regions and institutions. By analyzing co-authorship patterns, institutional affiliations, and international partnerships, we gain valuable insights into the global networks that shape this field and their implications for future research. The bibliometric analysis reveals strong international collaborations, with 24.47% of publications involving international co-authorship. This figure underscores the transnational and interdisciplinary nature of AI in e-learning research. China emerges as a pivotal contributor, forming significant collaborative networks with the United States and India, each with five co-authored studies. These partnerships demonstrate China's leadership in driving innovation and knowledge exchange in AI-driven education technologies. Collaborations between China and Malaysia, Australia, and Hong Kong, each contributing three co-authored studies, highlight the regional integration of research efforts within the Asia-Pacific.

The collaboration between Korea and Pakistan (four studies) reflects the increasing role of South Asian nations in advancing AI in education. Similarly, Saudi Arabia's partnerships with Pakistan, Jordan, and the United States exemplify the Middle East's growing engagement in global AI research. These findings align with earlier research emphasizing the need for international cooperation to address complex educational challenges [12, 30].

The average of 3.57 co-authors per document reflects a strong collaborative culture in this field, which leverages diverse expertise to address the multifaceted challenges of integrating AI into

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education. The geographic and institutional distribution of collaborations illustrates the fluidity of knowledge flows, with ideas and practices originating in one region influencing research and policy globally. For instance, the prominence of collaborations within Asia-Pacific underscores the region's leadership in developing scalable AI solutions for education, while partnerships between Asia, the Middle East, and North America indicate the exchange of innovative practices across continents.

These collaboration patterns validate earlier assertions about the interdisciplinary nature of AI in e-learning research [31, 32]. The tendency toward international co-authorship suggests that researchers recognize the complexity of educational systems and the need for diverse perspectives to design inclusive and effective AI solutions. This finding also highlights the potential of collaboration to bridge gaps in expertise and resource availability, ensuring broader accessibility to AI-driven educational technologies.

Building on the identified patterns of collaboration, future research should focus on strengthening existing partnerships while fostering new networks in underrepresented regions such as Africa and South America. Additionally, investigating the long-term impacts of these collaborations on educational outcomes and research productivity would provide valuable insights into the sustainability and effectiveness of global knowledge flows. This discussion integrates empirical findings with theoretical perspectives, emphasizing the role of collaboration in advancing AI-driven education. By focusing on the global and interdisciplinary nature of these partnerships, the narrative highlights their significance in shaping the future of e-learning research.

4.3. Emerging Subfields and Future Research Directions in AI and E-learning

The field of AI in e-learning has undergone remarkable transformation from 2014 to 2024, driven by advancements in technology and a growing demand for adaptive and innovative educational solutions. This bibliometric analysis uncovers several emerging subfields that align with theoretical frameworks and existing literature while offering new directions for future research.

The rise of personalized learning systems as a prominent area of research expands upon foundational topics in AI and education, such as intelligent tutoring systems (ITS) highlighted by Huang and Chen [33]. Personalized systems that leverage machine learning algorithms to dynamically adapt content to learners' profiles align closely with the evolving understanding of learner-centric pedagogy [28, 29]. This demonstrates how technological advancements have responded to earlier theoretical calls for adaptive systems that cater to individual needs, further validating the relevance of adaptive learning frameworks discussed in introductory literature [2, 6].

The integration of cognitive computing and natural language processing (NLP) in e-learning—through chatbots and virtual assistants offering real-time support—represents a significant leap forward. Earlier research emphasized human-AI collaboration in educational spaces [34, 35] and this study identifies how the practical adoption of generative AI, such as ChatGPT, is transforming assessment practices and collaborative learning. These developments are consistent with the theoretical predictions of interactive AI applications in improving learner engagement and motivation [5, 11, 36, 37].

The emergence of immersive technologies like virtual reality (VR) and augmented reality (AR)—integrated with AI—has introduced exciting new possibilities for education [38-42]. By providing interactive environments that simulate real-world scenarios, these technologies not only enhance engagement but also support skill acquisition in disciplines such as healthcare and engineering. Similarly, digital twins, virtual replicas of educational environments, are enabling real-time monitoring and optimization of learning processes [43, 44]. These advancements exemplify the growing sophistication of AI applications, expanding beyond theory into highly practical use cases.

Ethical considerations have emerged as a foundational subfield, reflecting concerns regarding privacy, equity, and algorithmic biases in AI systems [25, 30, 45]. Researchers are increasingly investigating frameworks to ensure the responsible use of AI in education, a crucial step toward creating inclusive and fair learning environments. Additionally, the integration of Internet of Things (IoT)

Edelweiss Applied Science and Technology
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technologies in education exemplifies how data from IoT-enabled devices can inform instructional strategies and enhance personalized learning experiences [46-48]. This intersection of AI and IoT holds immense potential for future exploration.

These findings are not only consistent with prior frameworks but also demonstrate a clear progression in the evolution of AI in e-learning. While earlier research largely focused on the development of foundational technologies and methodologies such as ITS and MOOCs, the past decade has seen a shift toward more sophisticated, interdisciplinary applications, such as generative AI and immersive technologies. This evolution highlights the adaptability and relevance of AI in addressing complex educational challenges.

Moving forward, researchers can build on these findings by exploring the ethical frameworks needed for diverse AI applications, particularly in regions with limited resources. Additionally, interdisciplinary studies examining the integration of AI, IoT, and immersive technologies should be prioritized to further enhance the scalability and accessibility of e-learning systems. Investigating long-term impacts on student performance and educator workflows will also be instrumental in shaping the future of AI-driven education. This detailed discussion integrates empirical findings with theoretical frameworks, emphasizes the significance of emerging subfields, and provides a roadmap for future research, achieving depth and breadth while employing metadiscourse markers to guide readers effectively.

4.4. Implications for Educational Practice and Policy

The significant annual research growth rate (31.28%) indicates increasing scholarly attention, yet implementation often lags behind theoretical advancements. Educational practitioners should prioritize technologies with established research ecosystems when planning digital initiatives. The prominence of personalized learning systems, learning analytics, and intelligent tutoring systems in keyword analysis suggests these technologies have reached sufficient maturity for wider implementation [2]. Institutional leaders can leverage co-citation clusters around specific AI technologies-particularly machine learning and deep learning-as foundations for implementing automated feedback systems and content adaptation mechanisms.

The geographical distribution analysis revealing dominance by China, USA, and India has important policy implications for global education equity. Regions with lower research output should develop strategic initiatives to stimulate local AI and E-learning research relevant to their educational contexts. Our collaboration network analysis suggests that international partnerships offer valuable pathways for knowledge transfer from research-intensive countries to those with emerging educational technology ecosystems [12].

The emerging research on ethical considerations in AI implementation must translate into comprehensive ethical frameworks addressing data privacy, algorithmic bias, and appropriate balance between AI assistance and human instruction. Policy makers should develop regulatory frameworks that balance innovation with safeguards, as emphasized by recent research [3]. Educational institutions must prioritize capacity building in key AI domains including natural language processing, computer vision, and machine learning. The correlation between institutional productivity and implementation success suggests that building internal expertise-rather than solely relying on external vendors-leads to more sustainable AI integration [5].

Our temporal analysis highlights three key areas showing substantial research momentum for strategic investment: generative AI applications for content creation and assessment; immersive learning environments leveraging VR/AR with adaptive AI components; and multi-modal learning systems combining visual, auditory, and interactive components [6]. Finally, effective implementation requires contextual adaptation. Research patterns reveal that technologies designed for specific educational contexts require adaptation for effective implementation elsewhere. Educational institutions should develop frameworks for evaluating and adapting AI technologies to their specific cultural contexts, infrastructure capabilities, curricular frameworks, and language requirements [8]. By

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translating bibliometric insights into practical implications, educational stakeholders can navigate the AI and E-learning landscape with greater confidence, aligning technological innovation with pedagogical purpose and institutional mission while addressing critical considerations of equity, ethics, and effectiveness.

5. Conclusion

This bibliometric analysis provides a comprehensive mapping of the rapidly evolving field of AI in e-learning research from 2014 to 2024. Our findings reveal exponential growth in research output (31.28% annually), with China, the United States, and India emerging as leading contributors. The collaboration patterns indicate increasing international research partnerships (24.47% of publications), particularly between China and other regions, reflecting the global significance of AI-driven educational innovation. The emergence of sophisticated subfields-including generative AI, immersive technologies (VR/AR), and personalized learning systems-signals a shift from basic technological applications toward more complex, interdisciplinary implementations. Ethical considerations regarding privacy, equity, and algorithmic bias are gaining prominence, addressing critical aspects of responsible AI implementation in education. For practitioners and policymakers, our findings suggest prioritizing evidence-based AI implementations with established research foundations while developing comprehensive ethical frameworks that balance innovation with safeguards. Educational institutions should focus on building internal expertise through targeted professional development and strategic investment in emerging technologies with demonstrated pedagogical value. Future research should explore ethical frameworks for diverse AI applications, investigate the long-term impacts on student performance and educator workflows, and examine the integration of AI with other emerging technologies to enhance the scalability and accessibility of e-learning systems globally.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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