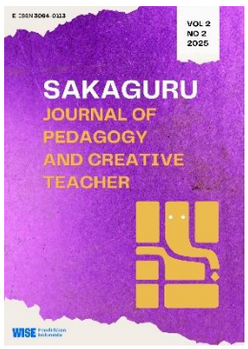

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Research Article

Mapping the Landscape of AI-Enhanced Collaborative Learning: Evolution and Constraints

Juan Luis Cabanillas-García[1*]

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Abstract

This study maps the scientific evolution of AI-enhanced collaborative learning over the past decade (2014–2024) through a comprehensive bibliometric analysis using the Bibliometrix R-package. A total of 660 documents retrieved from the Scopus database were analyzed to identify publication trends, key authors, thematic clusters, and research collaborations. Results indicate exponential growth since 2021, coinciding with the democratization of generative and machine-learning technologies. The field is marked by strong interdisciplinarity—bridging computer science, education, and engineering—and by geographic concentration in the United States and China. Thematic mapping reveals three consolidated lines of inquiry: technological innovation, pedagogical applications, and ethical-social challenges, with a clear transition toward advanced topics such as federated and adversarial learning. Despite this progress, regional inequality and limited empirical validation persist. The study contributes a structured overview of the field, highlighting both conceptual consolidation and critical gaps, and proposes future directions for developing inclusive, context-aware, and ethically responsible frameworks for AI-mediated collaborative education.

Keywords: AI-enhanced Collaborative Learning; Bibliometric Analysis; Educational Data Mining; Machine Learning; Pedagogical Innovation

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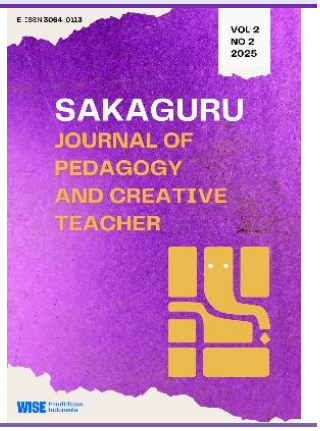


INTRODUCTION

Artificial intelligence (AI)-mediated collaborative learning combines the principles of peer-to-peer collaboration with the use of intelligent technologies that personalize learning, facilitate interaction, and optimize educational processes. This synergy has given rise to an emerging field that seeks to enhance learning by integrating adaptive algorithms, intelligent tutors, and recommendation systems into collaborative environments. Despite the sustained growth of publications in this area, there is a lack of integrative studies that analyze its evolution, thematic trends, and emerging challenges from a bibliometric perspective. This absence limits the comprehensive understanding of the field and hinders the identification of established lines of research and critical gaps.

Given this need, this study seeks to answer the research question: How has the field of AI-enhanced collaborative learning evolved over the last decade in terms of scientific production, thematic trends, and emerging challenges? To this end, an exhaustive bibliometric analysis of the scientific literature is carried out, in order to offer a structured vision of the development of the area and guide future research, with the general objective stated: To analyze the evolution, thematic trends, and emerging challenges in the field of AI-powered collaborative learning through a bibliometric study of scientific literature published over the last decade. To respond, the following specific objectives have been formulated:

- EO1: To examine the temporal evolution of publications and emerging trends related to AI-driven approaches, tools, and applications in collaborative learning environments.
- EO2: To identify the most relevant scientific production in the field of AI applied to collaborative learning in terms of authors, sources, institutions, and countries.
- EO3: To analyze co-citation networks in order to determine key collaborations and influential research lines.
- EO4: To classify the main topics addressed using keyword co-occurrence analysis, with the aim of mapping the existing knowledge.
- EO5: To identify current research gaps and challenges in the integration of AI and collaborative learning, providing guidance for future research directions.

The collaborative learning

Collaborative learning is a student-centered pedagogical approach that promotes social interaction, collective problem-solving, and the shared construction of knowledge through group work. This methodology is based on socio-constructivist foundations, particularly Vygotsky's theories, which highlight the role of the social environment in knowledge construction, as well as on situated learning and dialogic learning approaches [1]. Unlike traditional teacher-centered instruction, collaborative learning fosters an active environment in which students participate collaboratively in academic tasks with a common purpose, developing both cognitive and social skills [2].

Among the key principles guiding this educational practice is the formation of heterogeneous groups, which involves bringing together students with different ability levels, experiences, and cultural backgrounds. This diversity fosters exposure to multiple perspectives, which enriches debate and stimulates critical thinking. Furthermore, the explicit

teaching of collaborative skills, such as effective communication, conflict resolution and group decision-making, which are essential to ensure productive and equitable interaction between participants, is highlighted [3].

The effects of collaborative learning on the educational process have been widely documented. First, an improvement in the understanding and application of complex concepts has been demonstrated, especially in disciplines that require critical thinking and problem-solving, such as design and engineering [4]. Second, constant interaction with peers generates greater confidence and self-esteem in students, who receive immediate feedback and emotional support during the development of tasks [5]. Furthermore, teamwork often leads to greater efficiency in project execution, as the diversity of ideas and approaches facilitates innovation and more informed decision-making [6].

However, despite its many benefits, collaborative learning also presents challenges that must be carefully addressed. These include uneven workload distribution, difficulty reaching consensus in large groups, and the potential for interpersonal conflicts. These obstacles require structured planning by the teacher, as well as monitoring and evaluation mechanisms that ensure equitable participation and meaningful learning for all group members [7]. In this way, collaborative learning is consolidated as a powerful pedagogical strategy, provided that appropriate conditions for its development are implemented.

AI-Enhanced Collaborative Learning

The incorporation of AI into collaborative learning environments is significantly transforming the way students interact with content, their peers, and the educational process in general. This integration not only fosters greater participation and engagement but also allows for the design of more personalized, interactive, and effective learning experiences [8]. Through intelligent algorithms and adaptive technologies, AI mediates learning, dynamically adjusting content, facilitating immediate feedback, and stimulating collaboration among students. Furthermore, it mediates with technological resources that enrich students' digital competence [9] [10].

One of the main contributions of AI in this context is the personalization of learning. AI-based systems, such as machine learning algorithms, make it possible to adapt specific learning paths for each student based on their pace, proficiency level, interests, and particular needs [11]. This personalization capability has been shown to have a positive impact on both motivation and academic performance, as students tend to be more engaged when they perceive the content to be relevant and appropriate to their profile [12]. Furthermore, this personalization fosters greater autonomy in learning, reinforcing individual commitment within collaborative contexts.

In terms of interaction, AI-powered technologies, such as intelligent tutoring systems and educational chatbots, create more dynamic and immersive learning spaces. These tools not only facilitate immediate access to information and support but also stimulate active participation, especially in collaborative environments where constant interaction between students is required [13]. Recent research shows that the use of these resources increases engagement levels by providing richer and more stimulating learning scenarios [14]. In this way, AI does not replace human collaboration, but rather enhances it, acting as a facilitator of key cognitive and social processes in learning.

However, the integration of AI into education also raises a number of challenges and ethical considerations. Among the most relevant are data privacy, the responsible use of algorithms, and ensuring equitable access to these technologies [15]. There is a risk that, if not adequately addressed, these technologies will contribute to widening existing gaps in educational contexts, particularly affecting students with less access to technological resources [16]. Therefore, it is essential that the implementation of AI-based solutions is accompanied by inclusive educational policies and ethical frameworks that ensure equity, transparency, and the protection of students' rights.

METHODS

Research Design

This research is framed within a descriptive, quantitative approach with retrospective analysis [17], employing bibliometric techniques to explore scientific production related to AI-assisted collaborative learning from 2014 to 2024. Through bibliometrics, we aim to obtain an objective and measurable view of the field's development, analyzing both the volume of publications and the dynamics of academic collaboration and predominant thematic areas [18].

This methodological strategy allows us to identify the most relevant actors in the field (authors, institutions, journals, and countries), as well as to establish connections between them through the study of co-authorship and co-citation networks. Likewise, keyword co-occurrence analysis is used as a tool to identify consolidated thematic clusters and emerging trends within the field [19]. The purpose of this design is to offer a structured overview of accumulated knowledge, identifying evolutionary trends, theoretical gaps, and future opportunities for research. In this way, the aim is to provide evidence that guides the advancement of studies related to the application of AI in collaborative learning environments [20].

Document search and selection process

The document search process was carried out in the Scopus database, chosen for its breadth, reliability, and high indexing quality in the scientific field [21]. To identify relevant literature on AI-mediated collaborative learning, the search equation "artificial intelligence" AND "collaborative learning" was used, considering its precision and relevance to capturing the core thematic of the study. In addition to these main terms, other related expressions such as machine learning, "AI in education," "group learning," "computer-supported collaborative learning," and "intelligent tutoring systems" were identified as recurring keywords during the screening.

The initial search yielded 1,137 documents, which were filtered using defined inclusion criteria: publications between 2014 and 2024, written in English and classified as scientific articles or conference papers, excluding reviews, book chapters, editorial notes, abstracts, and any document not directly related to the topic. After applying these criteria and a preliminary review of titles, abstracts, and keywords, the final corpus consisted of 660

documents, which then proceeded to the analysis phase. The database used can be accessed openly in the Zenodo repository (https://doi.org/10.5281/zenodo.15768206).

Data analysis

The analysis of the bibliometric data was carried out using the R statistical environment and the Bibliometrix package, an open-source tool specifically designed for the quantitative analysis of scientific production [22]. This tool allows for a comprehensive treatment of the bibliometric process, ranging from data collection and cleaning to its analysis, visualization, and interpretation. In particular, specific functions were used for the descriptive analysis of the literature, as well as for the construction of co-authorship, co-citation, and keyword co-occurrence networks [23]. Likewise, visualizations were used to identify patterns, trends, and structural relationships within the field of study, favoring a rigorous and visually accessible analysis of the scientific evolution of the researched area [24]. This methodological choice not only guarantees the traceability and reproducibility of the analysis, but also allows for an in-depth exploration of the intellectual and collaborative dynamics of the research area [25].

RESULTS AND DISCUSSION

Temporal evolution of publications

Figure 1 represents the temporal evolution of the number of scientific publications related to AI-enhanced collaborative learning between 2014 and 2024. The data presented shows a clearly upward trend, albeit with distinct phases of growth. During the period between 2014 and 2020, the volume of publications remained relatively stable, with slight fluctuations and moderate growth. This trend suggests an initial phase of exploration of the topic, in which academic interest was still limited and the field was consolidating.

From 2021 onwards, and especially from 2022 onwards, exponential growth is evident, with a significant increase in the number of published articles. In 2024, the peak of the series is reached, with more than 200 publications, reflecting strong momentum in research on the use of AI in collaborative learning environments. This increase coincides with the rise of more accessible and powerful AI technologies, such as generative models and machine learning platforms, which have sparked renewed interest in their educational applications.

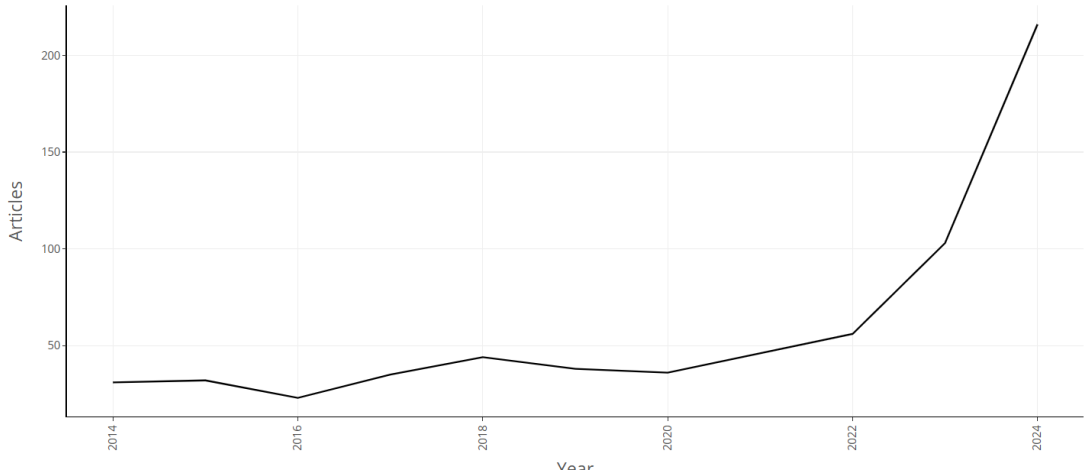


Figure 1. Annual scientific production

Most relevant scientific production

Figure 2 shows the most relevant sources of scientific production on AI-enhanced collaborative learning, highlighting those with the largest number of publications during the period analyzed. "Lecture Notes in Computer Science" leads by far (64 documents), indicating a strong presence of this topic in technological and computational conferences and publications. Next in importance are the ASEE Annual Conference and Exposition (14 documents), CEUR Workshop Proceedings (13), Advances in Intelligent Systems and Computing, and IEEE Access (both with 11 documents), reinforcing the applied, interdisciplinary, and technological innovation-oriented approach in learning contexts.

The distribution shows that research on this topic is mostly being published in sources that combine education with engineering, computer science, and AI, demonstrating a clear interest in improving learning environments through the use of emerging technologies. This trend also reveals a bias toward dissemination at scientific conferences and proceedings, suggesting a constantly evolving field that prioritizes the rapid updating and sharing of results.

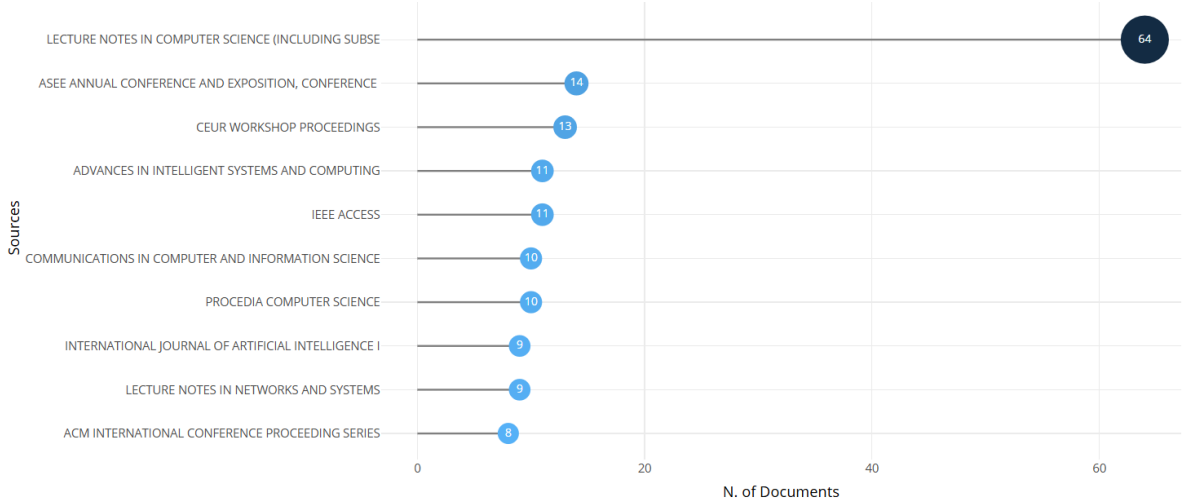


Figure 2. Most relevant sources

Figure 3 identifies the most relevant authors in the field of AI-enhanced collaborative learning, considering both scientific productivity and academic impact. Nguyen A. tops the list with 9 publications, 1,739 citations, and an h-index of 18, consolidating his position as the most influential researcher. He is followed by Chen X., Hayashi Y., Liu X., Wang J., and Zhang Y., each with 7 documents. In particular, Hayashi Y. has 83 publications and 435 citations, while Xiping Liu, with 6 documents, presents 362 citations and an h-index of 10, reflecting a high relative impact. Other notable authors with 6 publications are Aleven V., Dang B., Li X., and Liu Y., who also contribute significantly to the development of the field. These results reveal an active scientific community, but concentrated in a core of researchers who lead the production and trends in this area of study.

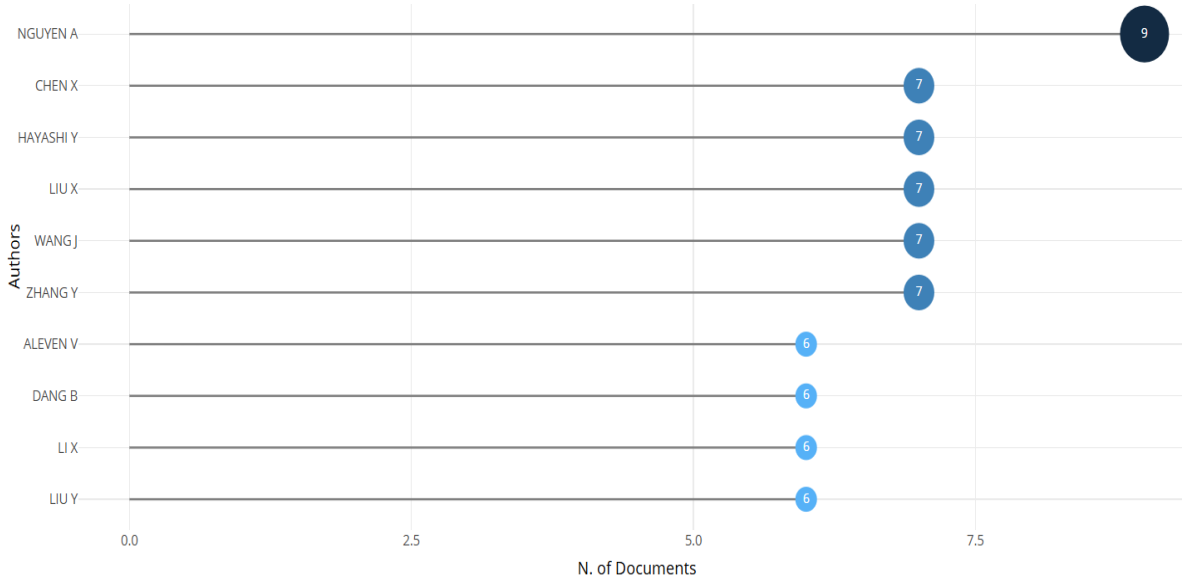
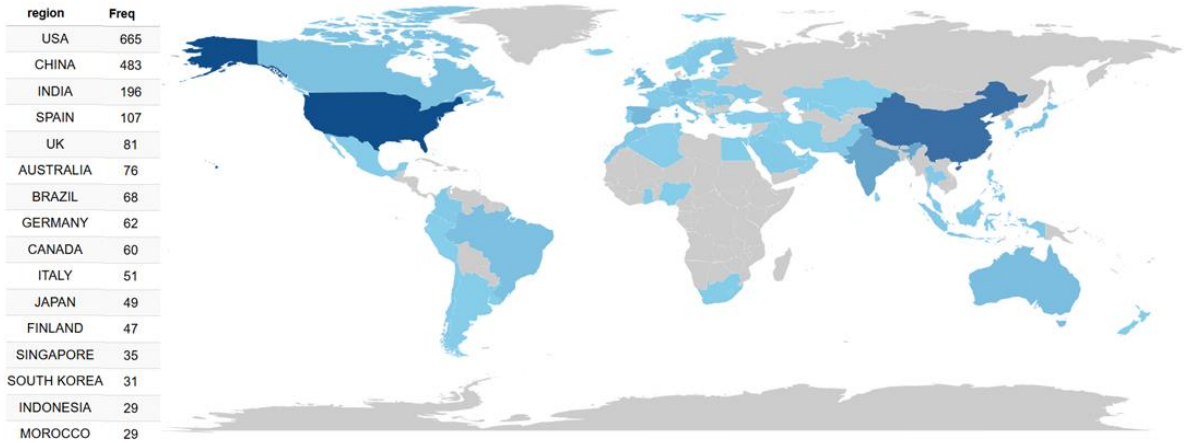


Figure 3. Most relevant documents

Figure 4 presents a global map of scientific production on AI-enhanced collaborative learning, segmented by country and accompanied by a table showing the frequency of publications by region. The analysis reveals that research in this field is clearly led by the United States (665 publications), followed by China (483), highlighting the predominance of these two powerhouses in both technological innovation and educational research. They are followed at a considerable distance by countries such as India (196), Spain (107), and the United Kingdom (81), which show an active presence, albeit with a smaller volume.

Other countries with notable contributions are Australia, Brazil, Germany, Canada, Italy, and Japan, all with more than 45 publications, indicating significant participation in the global academic debate. A greater concentration of production is observed in regions of the Northern Hemisphere and the Asia-Pacific region, while Africa and Latin America (with the exception of Brazil) are poorly represented. This highlights a geographic inequality in the generation of knowledge on this topic, reflecting disparities in access to emerging technologies, educational infrastructure, and research funding.



region	Freq
USA	665
CHINA	483
INDIA	196
SPAIN	107
UK	81
AUSTRALIA	76
BRAZIL	68
GERMANY	62
CANADA	60
ITALY	51
JAPAN	49
FINLAND	47
SINGAPORE	35
SOUTH KOREA	31
INDONESIA	29
MOROCCO	29

Figure 4. Most productive countries

Mapping Research Collaboration

Figure 5 represents the historical co-citation network in the field of AI-assisted collaborative learning, showing a remarkable evolution since its origins between 2014 and 2016, when the seminal article by Adamson et al. (2014) [26] laid the theoretical-methodological foundations, influencing authors such as Rummel et al. (2016) [27] and Viswanathan SA (2018) [28]. During the intermediate period (2018–2020), research was oriented towards more technical aspects and human interaction with AI, represented by authors such as Wunnasri et al. (2018) [29] and Dowell et al. (2019) [30], while others such as Yang et al. (2020) [31] and Sankaranarayanan et al. (2019–2020) [32] [33] broadened the focus towards practical applications. In the most recent stage (2021–2024), a significant consolidation and growth is observed, highlighting Zheng et al. (2021) [34] and its connections with Nguyen et al. (2023) [35] and Ouyang F. (2023) [36], who lead a mainstream focused on the implementation of specific smart systems in collaborative contexts. Likewise, recent contributions by Li et al. (2024) [37] and Chen et al. (2022) [38] reflect a renewal of the field with contributions that are gaining more and more recognition.

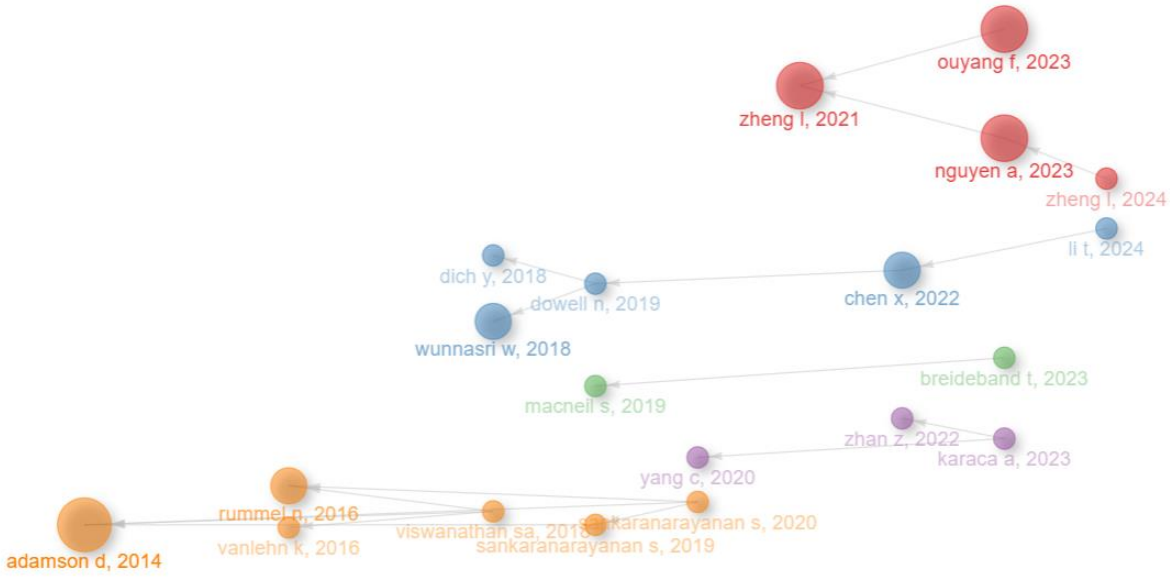


Figure 5. Historic co-citation network

Knowledge Mapping on Collaborative Learning and AI

The word cloud in Figure 6 reveals a strong interrelationship between the concepts of "artificial intelligence" and "collaborative learning," which have emerged as the most frequently cited terms in the scientific literature of the last decade. This co-occurrence suggests that AI is not studied in isolation, but rather in close connection with pedagogical approaches focused on student collaboration. Alongside these core terms, others such as "learning systems," "federated learning," "students," "machine learning," and "deep learning" stand out, indicating an expansion of academic interest in specific technologies that enable the automation, personalization, and optimization of collaborative learning environments. Pedagogical terms such as "active learning," "teaching," and "education computing" also appear, reflecting the effort to integrate AI into meaningful educational practices. These

terms point to a convergence between technological advances and participatory pedagogical models, in which interaction, personalization, and intelligent support are central axes.

The keyword timeline below reveals a clear thematic evolution: while in the early years (2013–2017) more general terms such as “e-learning,” “computers,” “intelligent tutoring systems,” and “mobile devices” predominated, in recent years (2020–2024) advanced concepts such as “federated learning,” “adversarial machine learning,” “contrastive learning,” and “data privacy” have emerged strongly. This transition reflects a technical sophistication in the field, consistent with the rise of new AI-based technologies that promote distributed collaboration, data security, and adaptive learning. Furthermore, the persistence of terms such as “students,” “teaching,” “education,” and “active learning” over time indicates that, despite technological advances, pedagogical concerns remain a structural component of academic discourse. These trends are aligned with current educational movements toward more inclusive, personalized, and learner-centered models, where AI acts as a facilitator of collaborative work rather than a substitute for the teacher.

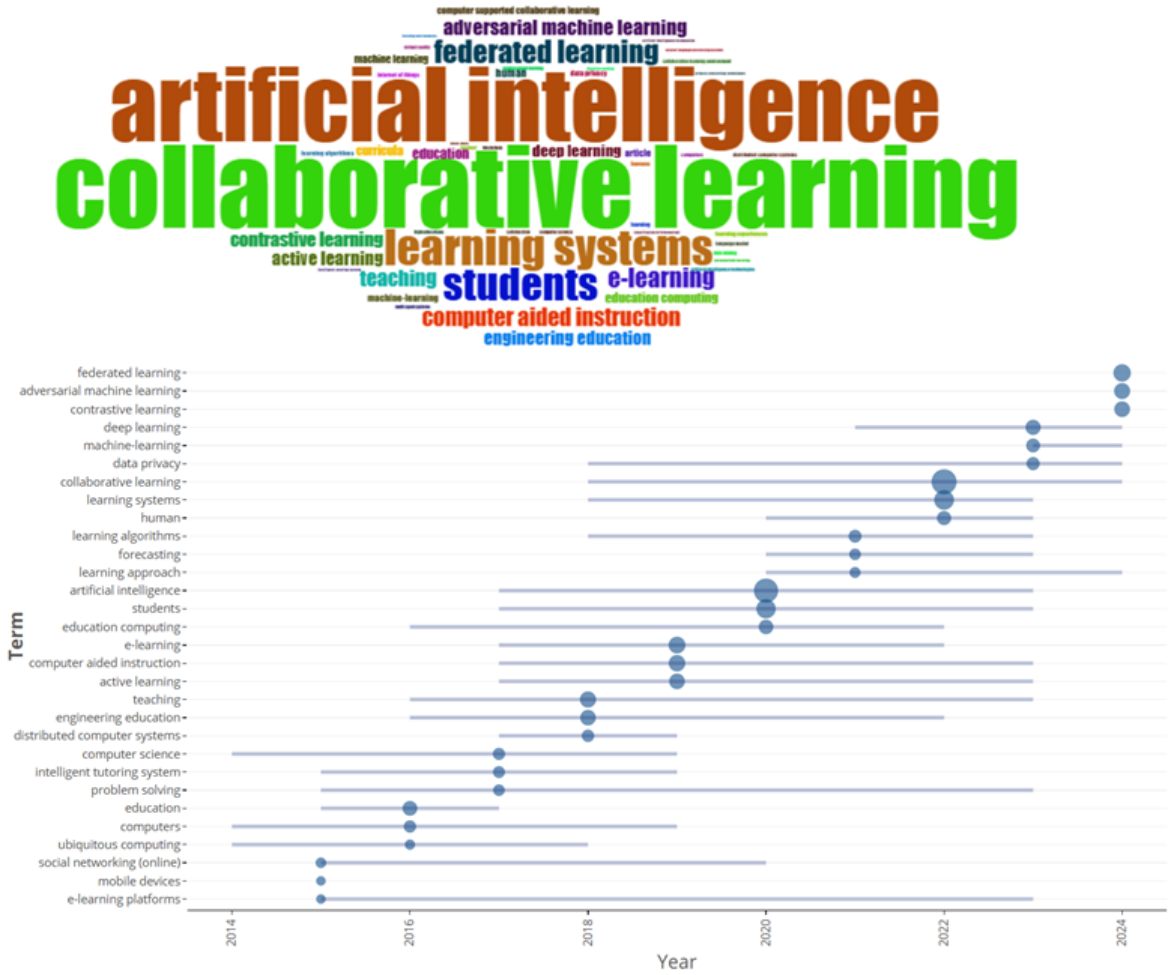


Figure 6. Relevant topics and their temporal evolution

Figure 7 represents the keyword co-occurrence network, which visually displays the thematic relationships between the main terms present in the scientific literature on AI-enhanced collaborative learning. The most prominent node is “collaborative learning,” which appears in the center of the network with the largest and thickest field, indicating its central

role as a thematic focus of research. Directly connected to this node is “artificial intelligence,” another prominent node that demonstrates the growing fusion between these two fields. This interconnection suggests that much of recent scientific production focuses on exploring how AI can enrich collaborative learning processes. The nodes are grouped into three thematic communities differentiated by color:

1. The red cluster, strongly linked to the central node of “collaborative learning,” includes terms associated with emerging technologies such as “federated learning,” “reinforcement learning,” “adversarial machine learning,” “multi-agent systems,” and “blockchain.” This cluster represents the most innovative line of research, focused on integrating advanced AI techniques to design intelligent, secure, and personalized collaborative environments.
2. The green cluster is grouped around "students," "education," "e-learning," and "intelligent tutoring systems," and reflects a more pedagogical and applied perspective. Here, we see an interest in how these technologies impact real-life teaching and learning processes, especially in formal educational contexts. The connection between these terms and "artificial intelligence" and "learning systems" indicates a focus more oriented toward practical implementation in the classroom.
3. The blue cluster is related to technical concepts such as "data privacy," "machine learning," "deep learning," and "internet of things." It represents a more computational dimension, focused on the development of models, algorithms, and structures that support the operation of AI tools applied to learning.

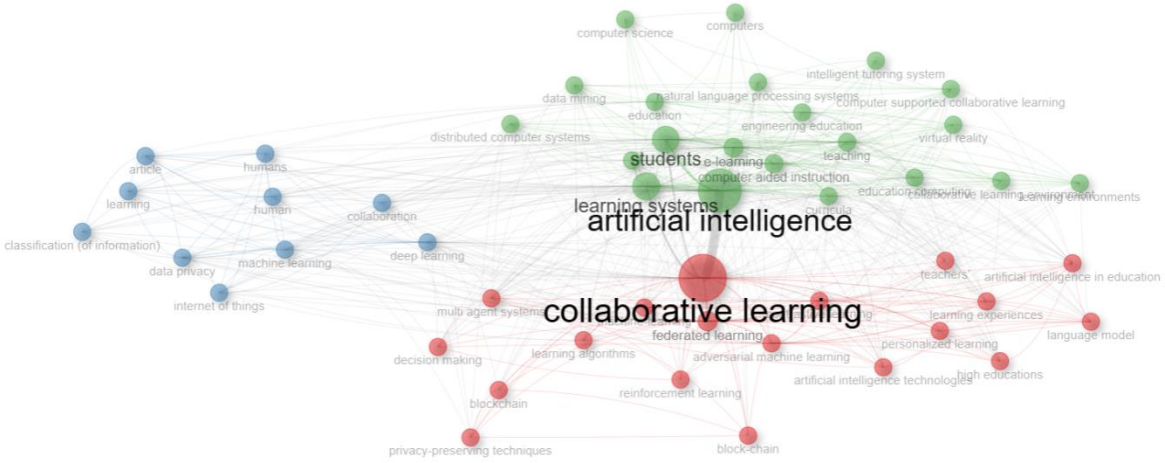


Figure 7. Co-occurrence keywords network

Discussions

The results show that the field of AI-enhanced collaborative learning has experienced recent and accelerated expansion, consolidating itself as an emerging and increasingly relevant area within educational and technological research [39]. This pattern suggests a fertile environment for future research and an increasingly active and committed scientific community exploring this thematic pairing. Furthermore, the results show a clear concentration of publications in the proceedings of specialized congresses and conferences [40], which can be interpreted as a deliberate strategy by the scientific community to promote

real-time knowledge transfer. This predominance of conferences as dissemination spaces reflects the interest in sharing advances, tools, and innovative experiences among peers, facilitating interdisciplinary dialogue and immediate feedback. This fosters a dynamic collaborative ecosystem that drives the development and practical application of AI in collaborative learning environments [41].

On the other hand, the results show a hegemony of the global north and technologically developed countries in scientific production linked to AI and collaborative education, where China, the United States and Europe carry out most of the scientific production in this area, as happens in other areas of science [42] [43]. This fact poses challenges in terms of equity and inclusion of knowledge and technological infrastructure [44]. This geographical distribution suggests the need to promote international collaboration networks that integrate voices from the global south and allow contextualizing technological innovations to diverse educational realities.

Regarding the key themes and emerging limitations of AI-mediated collaborative learning, the results show that in the early years of the analyzed period (2013–2017), studies focused primarily on general educational technologies, such as e-learning, computer-aided instruction, ubiquitous computing, and intelligent tutoring systems. This initial phase reflects a stage of technological adoption focused on digitizing content and offering basic learning support, without a deep integration of AI into collaborative processes. This initial approach corresponds to a more instrumental view of technology, still far removed from the active mediation of learning suggested by authors such as [11] o [13], who emphasize the role of AI in personalizing experiences and fostering meaningful interaction. During this period, AI was beginning to be introduced as a support tool, but without a clear role in personalization processes or in energizing collaboration between students [8].

Since 2018, and especially since 2020, a substantial transformation in the approach to research has been observed. The emergence and consolidation of terms such as machine learning, deep learning, data privacy, federated learning or contrastive learning suggests a growing maturity of the field, where AI is positioned as an active and sophisticated agent in the design of collaborative environments. This thematic evolution is in line with recent literature that points out how AI-based systems allow learning paths to be adapted, promote autonomy and offer immediate feedback, improving both students' engagement and academic performance [11] [12]. Furthermore, technologies such as chatbots or intelligent tutoring systems, which emerge from these developments, have been shown to enhance peer interaction, enriching the educational experience in collaborative contexts [14]. At the same time, the emergence of terms related to data privacy and federated learning responds to growing ethical concerns, as [15] and [16], warn, about the responsible use of AI and the need to ensure equitable access to these technologies.

CONCLUSION

This study concludes that AI-enhanced collaborative learning (AI-ECL) has evolved into a mature and rapidly expanding field positioned at the intersection of artificial intelligence and educational technology. The temporal analysis reveals a clear transition from early exploratory studies (2014–2020) to an accelerated phase of growth since 2021, driven by the proliferation of generative and machine-learning models. The field’s interdisciplinary

character—linking computer science, engineering, and pedagogy—has fostered methodological diversification and innovation in real-world educational applications. However, geographic asymmetries remain evident, with research predominantly concentrated in the Global North, underscoring the need for more inclusive and collaborative international networks. Thematically, the shift from traditional e-learning toward advanced AI frameworks such as deep, federated, and adversarial learning marks a conceptual evolution from tool-based support to AI as a mediating agent of social learning. Future research should prioritize ethical governance, data transparency, and contextual adaptation to ensure equitable access and sustainable integration of AI-mediated collaboration across diverse educational systems.

LIMITATIONS

While this bibliometric study provides a comprehensive view of the evolution, thematic dynamics, and emerging trends in AI-enhanced collaborative learning, several limitations inherent to its design and approach must be considered. First, the restriction to a single scientific database implies partial coverage of the available academic corpus. This methodological decision, which guarantees the homogeneity and quality of metadata, may have excluded significant works published in open repositories, specialized conferences, or journals indexed in other databases such as IEEE Xplore, ERIC, Web of Science, or Google Scholar, which were not also indexed in Scopus. Similarly, the exclusive use of English terms limits the inclusion of scholarly productions in other languages, which is especially relevant in contexts where the development of AI in education is advancing significantly, such as Asia or Latin America. For new research, the scope of data sources should be expanded to include multiple scientific databases and gray literature. This integration would allow for a more representative and heterogeneous analysis of the field. Furthermore, it is suggested that the bibliometric approach be complemented with qualitative or mixed analyses, in order to delve deeper into pedagogical, contextual, or ethical aspects that quantitative indicators do not capture within the content of the documents.

Another limitation relates to the conceptual and terminological ambiguity of the field. Terms such as "AI-enhanced learning," "intelligent tutoring systems," "learning analytics," "computer-supported collaborative learning," or even "adaptive learning" are used somewhat imprecisely or interchangeably in the literature. This lack of consensus hinders precise thematic classification, can generate overlaps between categories, and affect the reliability of co-word and trend analyses. In this sense, bibliometric studies should be complemented with systematic reviews that clarify theoretical and operational frameworks.

Finally, the speed of evolution of the field poses a significant challenge. Scientific production on AI in educational contexts is growing exponentially, requiring continuous updates to avoid gaps and allow for an up-to-date view. The inclusion of preprints and open access articles that have not yet been indexed also represents an opportunity for improvement in capturing recent developments. Furthermore, future publications should explore in greater detail emerging subtopics of high social and scientific relevance, such as equity in access to AI technologies, the ethical implications of using algorithms in educational contexts, teacher training for intelligent collaborative environments, or adaptive personalization for diverse groups. The inclusion of regional and multilingual case studies is also crucial to highlight

developments in peripheral or non-English-speaking contexts, which are traditionally underrepresented in the internationally indexed literature.

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CONFLICT OF INTEREST

"The author declare no conflict of interest."

DECLARATION OF USE OF AI IN SCIENTIFIC WRITING

The author used GPT-4o (Omni), during the preparation of this work to support the improvement of scientific writing and the translation of academic content. Specifically, the tool was employed to refine linguistic clarity, enhance the formal style, and ensure the accurate rendering of specialized terminology from Spanish to English, in alignment with disciplinary conventions. After utilizing the tool/service, the author thoroughly reviewed and edited the content as necessary and assumed full responsibility for the publication's content.

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