



Generative AI-Supported Problem-Solving in Higher Education: Research Trends, Knowledge Structure, and Educational Implications

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ABSTRACT

Purpose of the study: This study aims to map the research trends, intellectual structure, and emerging themes related to generative artificial intelligence (GenAI)-supported problem-solving in higher education. The study also identifies dominant contributors, thematic developments, collaboration patterns, and future research directions within this rapidly growing field.

Methodology: This study employed a bibliometric analysis approach using 458 Scopus-indexed articles published between 2021 and 2026. Performance analysis and science mapping techniques were conducted using VOSviewer and Biblioshiny from the Bibliometrix package in RStudio. The analyses included co-occurrence, co-authorship, citation, overlay visualization, and thematic mapping to explore the knowledge structure of the field.

Main Findings: The findings revealed a rapid increase in publications after 2023 following the emergence of ChatGPT and large language models (LLMs). China and the United States dominated publication productivity and citation impact. Keyword and thematic analyses identified problem-solving, students, and teaching as the main driving themes, while ChatGPT, AI literacy, metacognition, and human-AI collaboration emerged as rapidly developing research topics in higher education.

Novelty/Originality of this study: This study provides one of the first comprehensive bibliometric mappings specifically focused on the intersection of GenAI and problem-solving in higher education. Unlike previous studies that broadly examined AI in education, it reveals the intellectual structure, thematic evolution, collaboration patterns, and emerging research directions in this field. The findings provide valuable insights for lecturers, educational evaluators, and curriculum developers in identifying emerging competencies, assessment priorities, and pedagogical strategies related to problem-solving and AI-enhanced learning in higher education.

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1. INTRODUCTION

The rapid pace of digital transformation over the past few decades has fundamentally reshaped the landscape of higher education. The integration of artificial intelligence (AI) into various aspects of learning, teaching, and academic management has emerged as one of the most significant developments in contemporary education. The growing demand for 21st-century competencies has encouraged higher education institutions not

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only to equip students with disciplinary knowledge but also to foster critical thinking, adaptability, and problem-solving skills that are relevant to an increasingly dynamic world [1], [2]. Research on AI in higher education has expanded across a broad spectrum of areas, including intelligent tutoring systems, learning analytics, personalized content recommendation, and AI-based automated assessment [3]-[5]. As AI technologies become more accessible, higher education institutions worldwide have increasingly adopted AI-driven solutions to enhance learning experiences and improve the efficiency of educational processes [6]. The presence of AI within the academic ecosystem not only offers promising new opportunities but also raises important concerns regarding ethics, equity, and institutional readiness in responding to the emerging era of technology-enhanced education [7].

In recent years, higher education institutions have placed increasing emphasis on preparing students with competencies that extend beyond disciplinary knowledge. Among these competencies, problem-solving has been widely recognized as a key outcome of higher education because it enables students to analyze complex situations, evaluate possible solutions, and make reasoned decisions in real-world contexts [8], [9]. Effective problem-solving is also closely associated with other higher-order cognitive abilities, such as critical thinking, creativity, and metacognitive regulation, which are considered essential for learning and professional success in the 21st century [10]. Consequently, educational researchers and policymakers have shown growing interest in how these competencies can be developed and assessed through innovative pedagogical approaches and technology-enhanced learning environments [11]. The assessment of these competencies has become increasingly important because traditional assessment methods often struggle to capture the complex cognitive processes involved in authentic problem-solving and higher-order thinking tasks. As higher education continues to undergo digital transformation, increasing attention has been directed toward understanding how emerging technologies can support the development and assessment of problem-solving skills and other higher-order cognitive competencies [12], [13].

Among the many advancements in AI, the emergence of generative AI (GenAI), particularly large language models (LLMs) such as ChatGPT, GPT-4, Google Gemini, and Claude since late 2022, has introduced an unprecedented paradigm shift in the history of educational technology [14], [15]. Unlike conventional AI systems that are primarily reactive and limited to specific tasks, GenAI is capable of generating new content, explaining concepts contextually, providing personalized and adaptive feedback, and engaging in natural interactions that closely resemble human communication [16], [17]. The ability of GenAI to understand, respond to, and generate natural language in various formats has created extensive opportunities for transforming learning experiences in higher education settings [18]. These opportunities include a wide range of applications, such as personalized academic tutoring, support for scientific writing, facilitation of case-based discussion, and interactive assistance in solving complex problems. Nevertheless, the emergence of this technology has also raised significant concerns regarding academic integrity, students' cognitive dependency, and the potential for bias and inaccuracies in AI-generated content [19], [20]. This complex dynamic has encouraged the academic community to critically and comprehensively examine how GenAI can be integrated responsibly and effectively into the higher education ecosystem.

Among the various domains of GenAI implementation in education, problem-solving has emerged as one of the most strategic and relevant areas of focus. Problem-solving ability is considered a core 21st-century competency that is essential for higher education graduates in navigating the complexities of the workplace, social life, and rapidly evolving global challenges [8], [9], [21]. Higher education institutions bear the responsibility not only of equipping students with content knowledge, but also of fostering higher-order cognitive processes embedded in authentic and meaningful problem-solving activities. In this context, GenAI offers remarkable potential as a cognitive partner capable of guiding students through step-by-step problem-solving processes while supporting exploratory thinking through critical and reflective dialogue [22]. As the adoption of GenAI continues to expand across higher education institutions, the volume of empirical research examining this topic has grown exponentially at an unprecedented rate in the history of educational technology. Researchers have extensively explored various dimensions of this phenomenon, including students' and lecturers' perceptions and acceptance of GenAI [23], the benefits and risks associated with its use in learning processes [24], [25], the implications of academic policies and ethical considerations surrounding AI implementation in higher education [26], [27], as well as the pedagogical challenges and issues of equitable access arising from the adoption of this technology [19], [28].

Although several bibliometric studies and systematic reviews have attempted to map the development of AI research in higher education more broadly [29]-[31], studies that specifically and comprehensively focus on the intersection between GenAI and problem-solving in higher education remain limited. Previous bibliometric studies have generally explored AI in education from a broad perspective without thoroughly investigating how GenAI is utilized to support problem-solving processes in academic settings [3], [32]. Furthermore, existing reviews have rarely analyzed the intellectual structure, collaboration patterns, thematic evolution, and educational implications of GenAI-supported problem-solving research in higher education. A literature review examining the development of AI in education also highlighted a persistent gap between

technological advancement and its pedagogical implementation, particularly in relation to higher-order cognitive processes associated with problem-solving [18]. More importantly, many previous reviews were conducted before or during the early emergence of advanced GenAI models and therefore were unable to capture the rapid expansion of research that has occurred since the widespread adoption of ChatGPT and other LLMs.

The urgency of this study arises from the unprecedented growth of GenAI applications in higher education and the increasing interest in their potential to support students' problem-solving processes and higher-order cognitive development. Although research output in this area has increased substantially in recent years, the literature remains fragmented across disciplines, educational contexts, and technological approaches, making it difficult for researchers, educators, and policymakers to obtain a comprehensive understanding of current developments. The novelty of this study extends beyond its thematic focus by providing a comprehensive bibliometric mapping of publication trends, intellectual structures, collaboration networks, thematic evolution, and educational implications associated with GenAI-supported problem-solving research in higher education. By offering a systematic overview of this rapidly evolving field, the study contributes to a deeper understanding of how GenAI is being positioned within efforts to foster problem-solving and higher-order thinking competencies in higher education.

Therefore, this study aims to analyze the research trends and knowledge structure of GenAI-supported problem-solving in higher education through a comprehensive bibliometric approach. Specifically, this study was designed to address the following research questions (RQs):

- RQ1. What are the publication patterns and growth trends of research on GenAI and problem-solving in higher education during the study period?
- RQ2. Which authors, institutions, and countries are the most productive and influential in this research field based on scientific performance analysis?
- RQ3. What dominant research themes and intellectual clusters have emerged in this literature, and how does the relationship among these themes shape the knowledge landscape of the field?
- RQ4. What are the future directions of research based on the identified trends and thematic maps?

The findings of these four research questions are expected to contribute theoretically by providing a comprehensive knowledge map of GenAI and problem-solving in higher education, while also offering practical contributions in the form of future research directions that may serve as references for researchers, educators, curriculum developers, and broader stakeholders in the field of educational technology.

2. RESEARCH METHOD

2.1. Research Design

This study employed a bibliometric analysis approach to map research trends and the knowledge structure related to the use of GenAI in supporting problem-solving in higher education. Bibliometric analysis was selected because it enables the systematic and quantitative examination of large volumes of scientific data, while also revealing evolutionary patterns and structural relationships among research constituents [33], [34]. The overall research procedure followed the framework proposed by Donthu et al., which consists of four main steps: (1) defining the objectives and scope of the study, (2) selecting appropriate bibliometric analysis techniques, (3) collecting data, and (4) conducting the analysis and reporting the findings [35].

2.2. Data Source and Search Strategy

The data for this study were retrieved from the Scopus database, which was selected due to its extensive coverage of reputable international journals across various disciplines and its compatibility with bibliometric analysis software through metadata export features [36], [37]. The literature search process was conducted using a search string constructed with Boolean operators. The search strategy incorporated keywords related to AI, problem-solving, and the context of higher education. The search query used in this study was as follows:

TITLE-ABS-KEY ("artificial intelligence" OR "AI" OR "generative AI" OR "genAI" OR "ChatGPT" OR "GPT" OR "large language model" OR "LLM") AND ("problem solving" OR "problem-solving") AND ("higher education" OR "tertiary education" OR "postsecondary education" OR "post-secondary education" OR universit OR college* OR "higher learning" OR "academic institution*" OR undergraduate* OR postgraduate* OR "graduate education" OR "tertiary institution*")*

The search was conducted in May 2026 and covered publications from 2021 to 2026. This time span was selected to focus the analysis on the most recent developments in the use of GenAI in learning environments, particularly following the rapid rise of ChatGPT and LLMs in higher education since 2022. The

search terms were designed to capture studies related to AI, with particular emphasis on emerging GenAI technologies such as ChatGPT, GPT-based systems, and LLMs in higher education. Broad descriptors related to higher education were included to maximize the retrieval of potentially relevant publications. The final dataset was subsequently refined through predefined screening, eligibility assessment, and data-cleaning procedures.

2.3. Article Selection Process

The article selection process was conducted in several stages to ensure the relevance and quality of the bibliometric dataset. The process included identification, screening, eligibility assessment, and final inclusion of articles. Figure 1 presents the flowchart of the article selection procedure employed in this study.

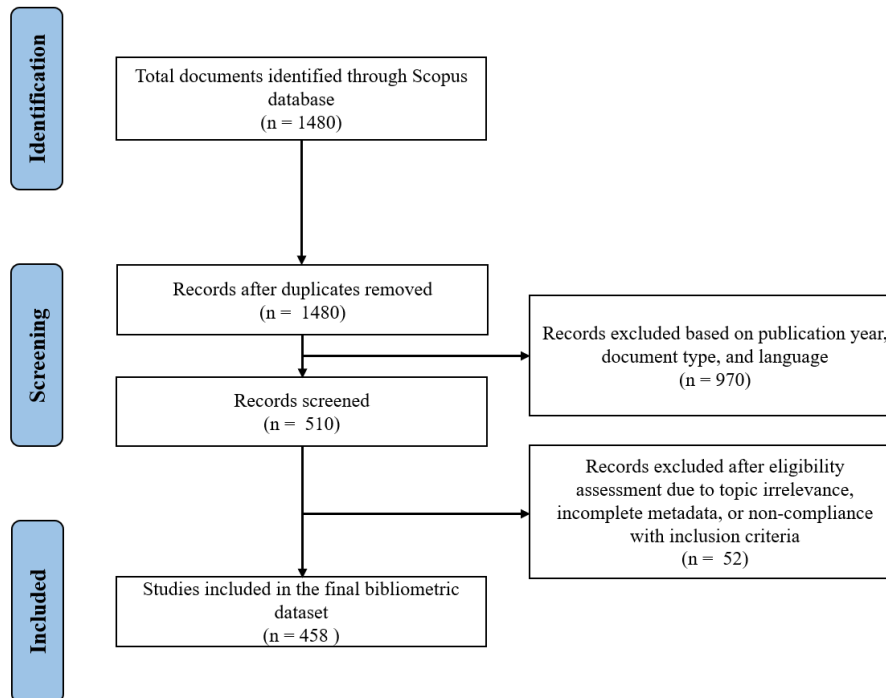


Figure 1. Flowchart of the Article Selection Process for Bibliometric Analysis

To improve transparency and replicability, explicit inclusion and exclusion criteria were established before the screening and eligibility assessment stages. The criteria used in selecting articles are presented in Table 1.

Table 1. Inclusion and Exclusion Criteria

Criteria	Inclusion Criteria	Exclusion Criteria
Publication Type	Journal articles	Conference papers, book chapters, editorials, notes, letters
Language	English-language publications	Non-English publications
Publication Year	2021–2026	Publications before 2021
Research Topic	Studies related to AI or GenAI applications supporting problem-solving within higher education contexts	Studies unrelated to education or problem-solving
Educational Context	Higher education context	Primary education, secondary education, clinical, industrial, or non-educational contexts
Metadata Quality	Complete bibliographic metadata available	Incomplete bibliographic metadata
Relevance	Relevant to the study objectives based on title, abstract, and keywords	Irrelevant to the study objectives

The initial search conducted in the Scopus database yielded 1,480 records. Duplicate verification indicated that no duplicate records were present in the dataset. During the screening stage, 970 records were excluded based on publication year, document type, and language criteria, resulting in 510 records for further evaluation. Subsequently, title, abstract, and keyword screening, together with eligibility assessment, were

performed to determine the relevance of each publication to the study objectives. A total of 52 records were excluded due to topic irrelevance, incomplete metadata, or non-compliance with the inclusion criteria. After the screening, eligibility assessment, and data-cleaning procedures, 458 articles were retained for the final bibliometric analysis.

2.4. Data Cleaning and Validation

Following the article selection process, the dataset underwent a data-cleaning and validation procedure to ensure the quality, consistency, and reliability of the bibliometric analysis. In addition, studies primarily related to medical applications, clinical diagnosis, pure algorithm optimization, or computer engineering without a clear educational context were excluded from the dataset. The data-cleaning process included duplicate verification, metadata checking, and keyword harmonization. Metadata fields such as author names, affiliations, publication years, source titles, and author keywords were reviewed to identify inconsistencies and incomplete records. Keyword harmonization was performed to standardize variations in terminology referring to similar concepts, thereby improving the accuracy of network visualization and thematic analysis. The cleaned dataset was subsequently reviewed and validated before being exported for bibliometric analysis. These procedures are considered essential in bibliometric research because the quality of metadata directly affects the validity and reliability of the resulting scientific mapping [38].

2.5. Bibliometric Analysis Techniques

The data were analyzed using two primary bibliometric approaches: performance analysis and science mapping [39], [40]. Performance analysis was employed to examine publication growth, the most productive authors, countries with the highest publication contributions, and citation trends within this research domain. In contrast, science mapping was used to explore the intellectual structure of the field by identifying relationships among research themes, collaboration networks, and emerging research directions.

Several bibliometric techniques were applied in this study. Performance analysis was used to examine annual publication trends and scientific productivity. Citation analysis was conducted to identify the most influential articles, authors, and sources within the field. Co-occurrence analysis was employed to reveal dominant research themes and conceptual relationships among keywords, while co-authorship analysis was used to examine collaboration patterns among countries. For keyword co-occurrence analysis, a minimum occurrence threshold of five was applied. Full counting was used to construct the keyword network and identify dominant thematic relationships. In addition, thematic mapping was performed to identify the development, maturity, and future directions of research themes related to GenAI-supported problem-solving in higher education.

The bibliometric network analyses and visualizations were performed using VOSviewer and Biblioshiny from the Bibliometrix package in RStudio [41]. VOSviewer was utilized to visualize keyword networks, collaborations, and citation relationships because of its ability to generate clear and informative network-based visualizations. Meanwhile, Biblioshiny was used to support thematic mapping. To ensure alignment between the research objectives and analytical procedures, each research question was addressed using specific bibliometric techniques, as presented in Table 2.

Table 2. Relationship Between Research Questions and Bibliometric Techniques

Research Questions	Bibliometric Techniques
RQ1. Publication patterns and growth trends	Performance analysis and publication trend analysis
RQ2. Productive and influential authors, institutions, and countries	Productivity analysis and citation analysis
RQ3. Dominant themes and intellectual clusters	Co-occurrence analysis, co-authorship analysis, and network visualization
RQ4. Future research directions	Thematic mapping and trend analysis

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Publications Patterns and Growth Trends

Figure 2 illustrates the publication growth trend of research on GenAI-supported problem-solving in higher education during the 2021-2026 period. Overall, the number of publications increased substantially from year to year. In 2021, the number of publications remained relatively low, with only 8 articles identified. This number increased to 21 articles in 2022 and further rose to 37 articles in 2023. A more pronounced increase began to emerge in 2024, with a total of 83 publications, before reaching a temporary peak of 200 publications in 2025. Meanwhile, by May 2026, a total of 109 publications had already been recorded during the data collection process. This figure indicates that research on GenAI-supported problem-solving in higher education continues to grow rapidly and is likely to increase by the end of 2026.

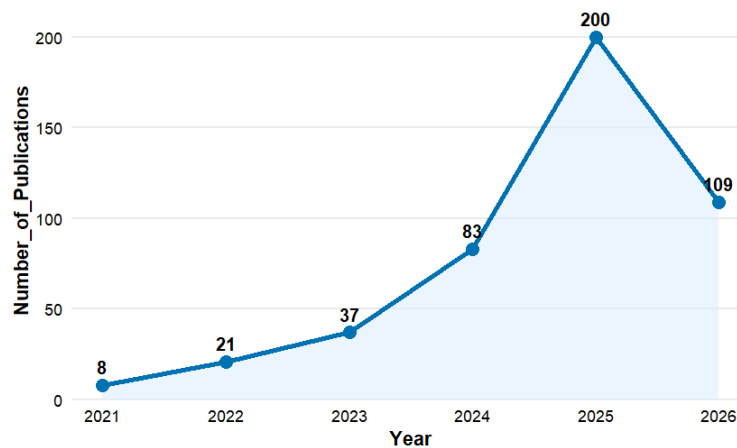


Figure 2. Publication Growth Trends

Figure 3 presents the annual citation trends of research related to GenAI-supported problem-solving in higher education. Overall, the number of citations showed a substantial increase over time, reaching its peak in 2024 with a total of 2,454 citations. In 2021, the citation count was still relatively low, with 216 citations recorded, before increasing to 933 citations in 2022 and 1,380 citations in 2023. Citation growth accelerated considerably in 2024, reflecting the rising academic interest and influence of this research area, before reaching 1,302 citations in 2025. Meanwhile, the total number of citations in 2026 remained relatively low at 52 citations, as the data collection process was conducted in May 2026, meaning that publications from that year had only a limited citation window.

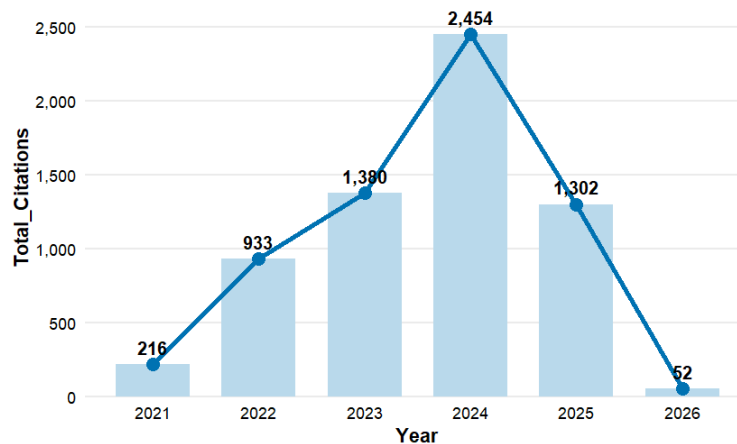


Figure 3. Annual Citation Trends

3.1.2. Performance Analysis

Table 3 presents the most productive and influential authors in research related to GenAI-supported problem-solving in higher education. Based on the number of publications, Hwang, Gwo-Jen, was identified as the most productive author with a total of 6 publications and 280 citations. Several other authors, including Chang, Ching-Yi; Huang, Yueh-Min; Hsin-Yu; Wu, Ting-Ting; Clark, Ted M.; Kong, Siu Cheung; and Omeh, Christian Basih, each contributed 4 publications to this research field.

In terms of scientific influence, Chang, Ching-Yi, recorded the highest number of citations with a total of 361 citations, indicating a substantial academic impact within this field of study. Meanwhile, Huang, Yueh-Min; Lee, Hsin-Yu; and Wu, Ting-Ting each obtained 255 citations, reflecting their significant contributions to the development of research on GenAI and problem-solving in higher education. These findings indicate that publication productivity does not always correspond directly to citation impact, as authors with a similar number of publications may demonstrate different levels of scientific influence.

Table 3. Most Productive and Influential Authors

No.	Author	Number of Publications	Total Citations
1	Hwang, Gwo-Jen	6	280
2	Chang, Ching-Yi	4	361
3	Huang, Yueh-Min	4	255
4	Lee, Hsin-Yu	4	255
5	Wu, Ting-Ting	4	255
6	Clark, Ted M.	4	178
7	Kong, Siu Cheung	4	25
8	Omeh, Christian Basil	4	5

Table 4 presents the most highly cited articles in the field. The article receiving the highest number of citations was *Solving Olympiad Geometry without Human Demonstration* by Trinh et al. (2024) [42], with a total of 359 citations. The high citation count of this article indicates that the use of AI to solve complex problems and support problem-solving abilities has become a major focus in AI-based education research. In addition, several other highly cited articles focused on the use of ChatGPT, chatbots, and LLMs to enhance students' creativity, higher-order thinking skills, and self-regulated learning [43]. This trend reflects the growing academic interest in the integration of GenAI into teaching and learning practices in higher education.

Table 4. Most Cited Articles

No.	Author	Title	Year	Source	Citations
1	Trinh et al.	Solving olympiad geometry without human demonstrations [42]	2024	Nature	359
2	Urban et al.	ChatGPT improves creative problem-solving performance in university students: An experimental study [44]	2025	Computers and Education	272
3	Chang et al.	Promoting students' learning achievement and self-efficacy: A mobile chatbot approach for nursing training [45]	2022	British Journal of Educational Technology	249
4	Lee et al.	Empowering ChatGPT with guidance mechanism in blended learning: effect of self-regulated learning, higher-order thinking skills, and knowledge construction [43]	2024	International Journal of Educational Technology in Higher Education	192
5	Lin & Chen	Artificial Intelligence (AI) – integrated educational applications and college students' creativity and academic emotions: students and teachers' perceptions and attitudes [46]	2024	BMC Psychology	178
6	Tsai et al.	Exploring the use of large language models (LLMs) in chemical engineering education: Building core course problem models with ChatGPT [47]	2023	Education for Chemical Engineers	158
7	Clark	Investigating the use of an artificial intelligence chatbot with general chemistry exam questions [48]	2023	Journal of Chemical Education	128
8	Ayanwale et al.	Examining artificial intelligence literacy among pre-service teachers for future classrooms [49]	2024	Computers and Education Open	126
9	Bucea-Manea-Tonis et al.	Artificial intelligence potential in higher education institutions enhanced learning environment in Romania and Serbia [50]	2022	Sustainability	125
10	Li	Effects of a ChatGPT-based flipped learning guiding approach on learners' courseware project performance and perceptions	2023	Australasian Journal of Educational Technology	92

Figure 4a presents the countries with the highest number of publications, while Figure 4b illustrates the countries with the highest citation counts. Based on publication output, China emerged as the most productive country with a total of 88 publications, followed by the United States with 71 publications and Taiwan with 32 publications. In addition, the United Kingdom and India contributed 26 and 23 publications, respectively. In

terms of citation impact, the United States ranked first with a total of 1,316 citations, followed by China with 1,052 citations and Taiwan with 949 citations. The United Kingdom also demonstrated considerable scientific influence, accumulating 608 citations. These findings indicate that countries with strong AI research ecosystems and technological development play a dominant role in advancing research on GenAI and problem-solving in higher education, both in terms of publication productivity and scientific impact.

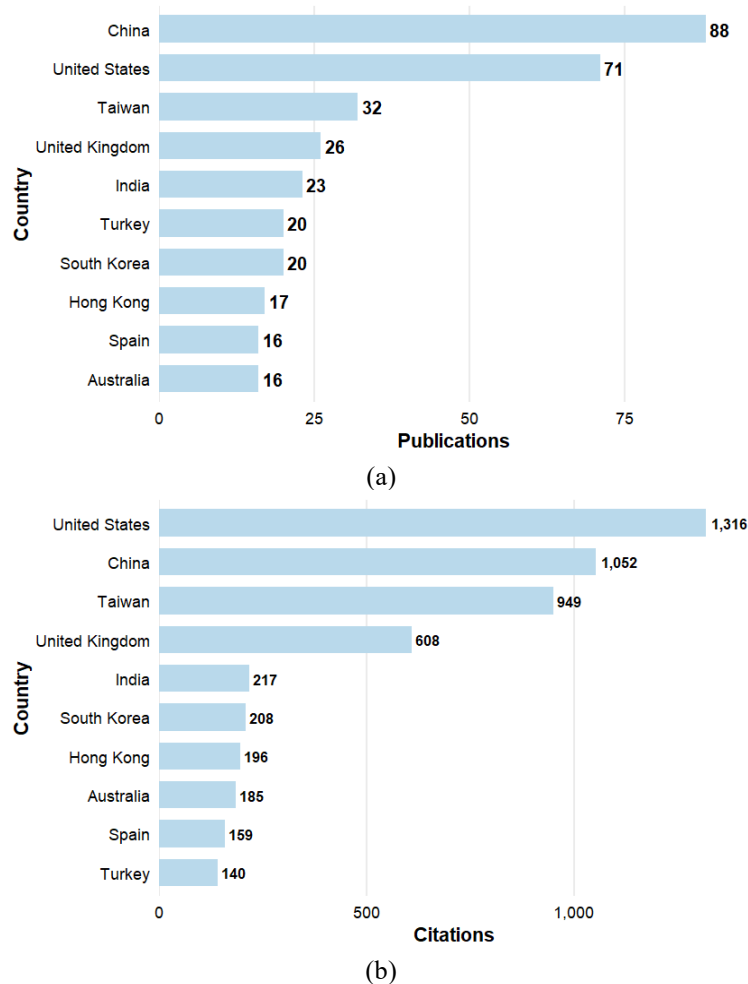


Figure 4. Country Contributions in GenAI-Supported Problem-solving Research: (a) Publication Output and (b) Citation Impact

Interestingly, citation impact does not always correspond directly to publication volume. For example, Taiwan achieved 949 citations from 32 publications, demonstrating a relatively high citation-to-publication ratio compared with several other countries. This finding suggests that scientific influence is shaped not only by research productivity but also by factors such as publication quality, research novelty, journal visibility, and participation in international research collaborations.

Figure 5 illustrates the international collaboration network in research related to GenAI-supported problem-solving in higher education. The visualization shows that the United States and China occupy the most dominant positions and demonstrate strong collaborative connections with many other countries. This is reflected in the larger node sizes and the numerous connecting lines linking these countries to others within the research network. In addition, Taiwan, India, Germany, Hong Kong, and Turkey also exhibit relatively active collaborative relationships in advancing research within this field. Based on the network structure, the research collaborations appear to form several interconnected international clusters. The United States demonstrates collaborative links with countries across Asia, Europe, and South America, whereas China shows particularly strong connectivity with Hong Kong, Turkey, and Germany.

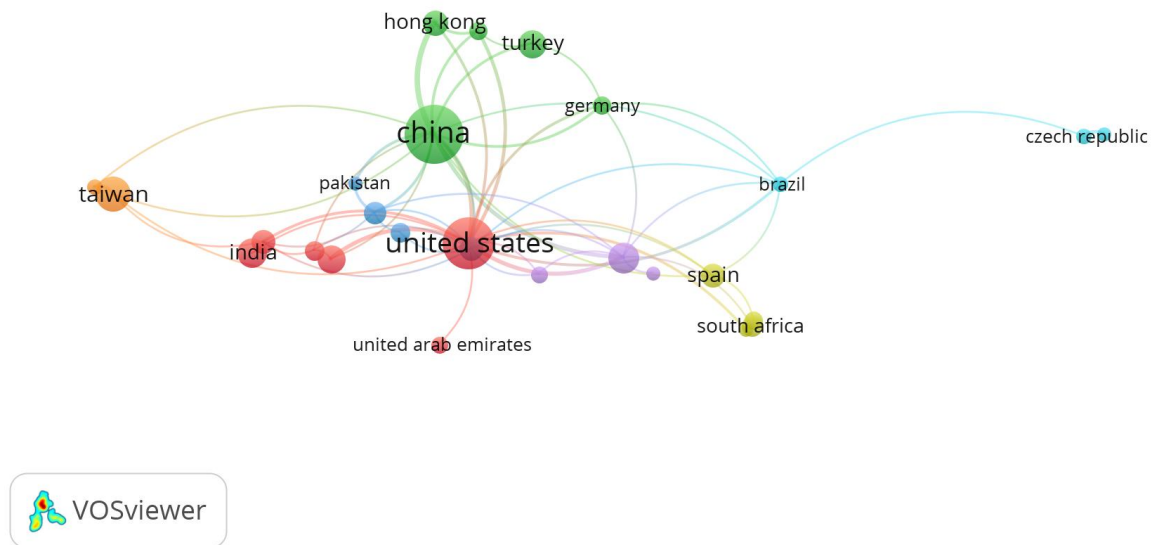


Figure 5. Country Collaboration Network

From a regional perspective, ASEAN countries were not prominently represented within the major collaboration clusters identified in this study. The absence or limited visibility of countries such as Indonesia, Malaysia, Thailand, and Vietnam suggests that research on GenAI-supported problem-solving in higher education remains concentrated within a relatively small group of countries. These findings highlight significant opportunities for ASEAN higher education institutions to strengthen international collaboration and expand research capacity in the rapidly growing field of GenAI-enhanced learning.

3.1.3. Intellectual Structure Research

Figure 6 presents the keyword co-occurrence network. The visualization reveals several interconnected research clusters that collectively form the knowledge structure of this field. The keywords artificial intelligence and ChatGPT appear as the most dominant nodes and demonstrate strong connections with a wide range of other topics, indicating that these themes have become central to the development of research in recent years. In addition, keywords such as problem-solving, critical thinking, computational thinking, machine learning, and digital literacy also exhibit strong relationships, suggesting that research on GenAI in higher education is closely associated with the development of students' thinking skills and digital competencies.

Based on the network visualization, research in this field appears to have evolved into several major thematic clusters. The first cluster focuses on the use of GenAI and ChatGPT in learning environments, encompassing topics such as LLMs, chatbots, and AI literacy. The second cluster is associated with the development of thinking and problem-solving skills, including critical thinking, computational thinking, problem-solving skills, and metacognition. Other clusters highlight the relationship between GenAI and innovative learning approaches, such as project-based learning, design thinking, STEM education, and human-AI collaboration. These findings indicate that research on GenAI-supported problem-solving in higher education extends beyond the development of AI technologies themselves. Instead, the literature increasingly emphasizes how these technologies can be utilized to support learning processes, foster higher-order thinking skills, and drive pedagogical transformation in higher education.

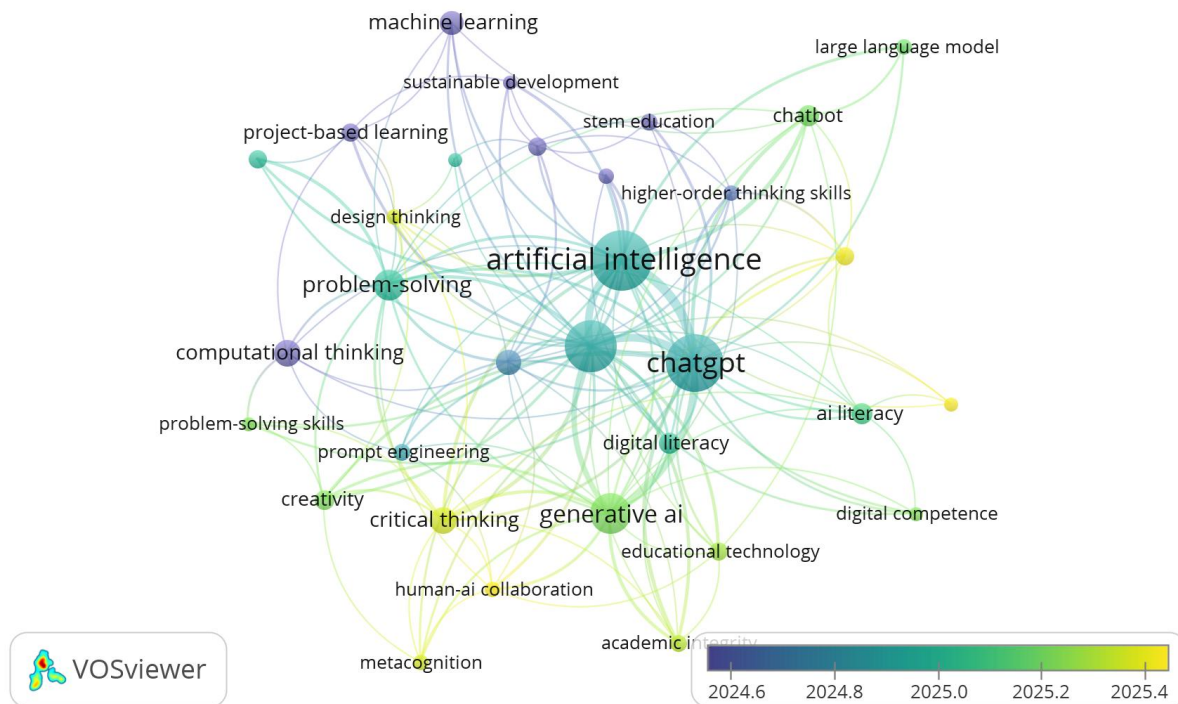


Figure 6. Overlay Visualization of Research Trends and Keyword Networks

To further interpret the educational significance of the identified themes, several prominent keywords emerging from the co-occurrence network can be viewed in relation to problem-solving and its assessment in higher education. Keywords such as critical thinking, metacognition, and AI literacy appear closely connected to problem-solving, suggesting that contemporary GenAI research increasingly conceptualizes problem-solving as a multidimensional competency involving reasoning, self-regulation, and responsible AI use. Table 5 summarizes the educational significance of these emerging themes within the context of GenAI-supported problem-solving.

Table 5. Educational Significance of Emerging Research Themes

Emerging Theme	Relationship to Problem-Solving	Educational Significance
Problem-solving	Core theme	Assessment of authentic and complex problem-solving performance
Critical thinking	Supports problem-solving	Evaluation of reasoning and evidence-based decision-making
Metacognition	Supports problem-solving	Assessment of planning, monitoring, and reflection processes
AI literacy	Enables AI-supported problem-solving	Evaluation of responsible and effective AI use

The findings presented in Table 5 indicate that problem-solving functions as the central competency within the identified research landscape, while critical thinking, metacognition, and AI literacy emerge as complementary competencies that support effective problem-solving processes. This pattern suggests that current GenAI research increasingly views problem-solving not as an isolated skill, but as a multidimensional competency that integrates reasoning, self-regulation, and responsible use of AI technologies in learning environments.

3.1.4. Emerging Trends and Future Research Directions

Figure 6 also presents an overlay visualization illustrating the evolution of research topics based on the average year of keyword occurrence. Earlier-emerging topics are represented in blue, including *machine learning*, *computational thinking*, and *project-based learning*. In contrast, more recent and rapidly developing topics are represented in green to yellow, such as ChatGPT, GenAI, *AI literacy*, *human-AI collaboration*, *critical thinking*, and *metacognition*. These findings indicate a noticeable shift in research focus from the development of

AI systems and learning technologies toward studies emphasizing human-AI interaction, the development of higher-order thinking skills, AI literacy, and the optimization of GenAI use in supporting problem-solving in higher education.

The rapid emergence of AI literacy as a research theme reflects growing recognition that students and educators require competencies beyond merely using AI tools. As GenAI becomes increasingly integrated into learning activities, learners must develop the ability to critically evaluate AI-generated information, understand the limitations and ethical implications of AI systems, and make informed decisions regarding their use. Consequently, AI literacy has become an essential competency for effective participation in AI-enhanced learning environments.

Figure 7 presents the thematic map, which reveals that themes such as *problem-solving*, *students*, and *teaching* are positioned within the motor themes quadrant, indicating that these topics demonstrate both high centrality and strong developmental relevance within the field. Meanwhile, themes such as *artificial intelligence*, ChatGPT, and *higher education* are located within the basic themes quadrant, suggesting that these topics serve as the foundational pillars underpinning the development of this research area. In addition, themes related to *internet/web-based learning* are positioned within the emerging or declining themes quadrant, indicating a shift in scholarly attention toward the use of GenAI and LLMs in supporting learning and problem-solving.

The dominance of problem-solving as a motor theme can be explained by its central role as a core competency in higher education and a key component of 21st-century learning. Unlike content acquisition alone, problem-solving requires students to analyze complex situations, evaluate alternative solutions, and apply knowledge in authentic contexts. The emergence of GenAI has further strengthened scholarly interest in this area because these technologies can provide cognitive scaffolding, immediate feedback, and interactive support during the problem-solving process. Consequently, problem-solving has evolved from being merely a learning outcome to becoming a central context in which GenAI applications are developed, implemented, and evaluated.

Based on these findings, future research should place greater emphasis on the development of GenAI-based learning models capable of supporting students' problem-solving abilities more effectively and sustainably. Furthermore, longitudinal and experimental studies are needed to evaluate the impact of GenAI on critical thinking, metacognitive skills, creativity, and human-AI collaboration within higher education contexts.

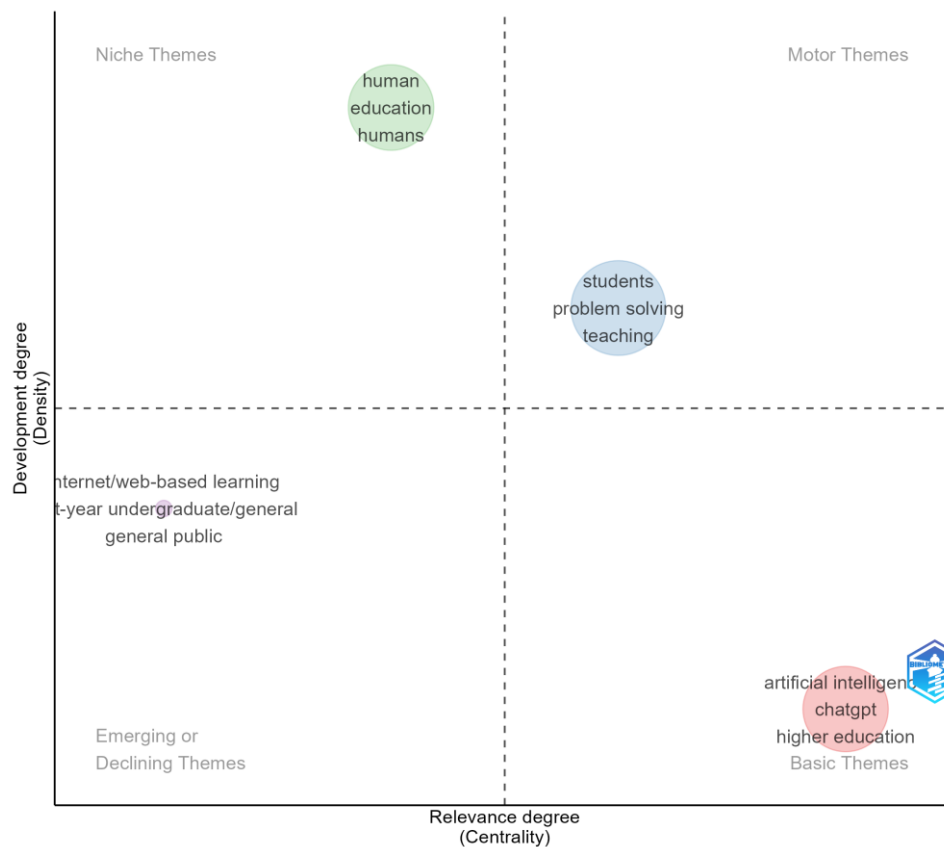


Figure 7. Thematic Map

3.2. Discussion

The findings of the bibliometric analysis indicate that research on GenAI-supported problem-solving in higher education has grown remarkably rapidly in recent years, particularly following the emergence of ChatGPT and various LLMs in late 2022. The substantial increase in publication output after 2023 reflects the growing academic interest in the potential of GenAI to support students' problem-solving processes within digital learning environments. This rapid development has been driven not only by advances in AI technology, but also by the increasing demand for 21st-century learning competencies that emphasize critical thinking, creativity, collaboration, and problem-solving as essential skills for higher education students [16], [51]. Within this context, GenAI is increasingly viewed not merely as an automation technology but also as a cognitive support tool capable of assisting students in exploring solutions, analyzing problems, and generating ideas more effectively.

The high citation counts of publications published in 2024 indicates that this period marked a critical phase in the development of research on the use of GenAI to support problem-solving-based learning. Highly cited studies primarily focused on the use of ChatGPT, AI-assisted learning, and AI-supported higher-order thinking skills within higher education contexts. This trend suggests that scholarly attention has gradually shifted from merely exploring AI technologies toward investigating how AI can support students' cognitive processes in solving complex problems. These findings are consistent with previous studies emphasizing that GenAI has considerable potential to support cognitive scaffolding processes, provide immediate feedback, and assist students in developing more adaptive and reflective problem-solving strategies [12], [52].

The dominance of China and the United States in both publication productivity and citation impact indicates that these countries possess highly developed AI research ecosystems and strong digital transformation initiatives in higher education. Large-scale investments in AI development, national policy support related to AI, and the integration of digital technologies into higher education are likely key factors contributing to this dominance. In addition, countries such as Taiwan, the United Kingdom, and South Korea also demonstrate significant contributions to the advancement of research on AI-supported problem-solving. Interestingly, several countries with relatively lower publication outputs still demonstrate high citation impacts, suggesting that research quality and international collaboration play crucial roles in shaping a country's scientific influence. High citation performance may also reflect publication in highly visible international journals, strong collaborative networks, and the novelty of research contributions. These findings indicate that the development of research on GenAI-supported problem-solving is strongly influenced by technological capacity, digital infrastructure, and the culture of educational innovation within each country.

The analysis of the international collaboration network indicates that research on GenAI-supported problem-solving has evolved through extensive global collaboration. The United States and China emerged as the primary hubs within the collaboration network, demonstrating strong connections with numerous other countries. Cross-national collaboration is particularly important because the development of GenAI-based learning requires the integration of multiple disciplines, including AI, cognitive science, educational technology, and learning sciences. Furthermore, international collaboration enables the development of AI-based learning models that are more contextualized and adaptable to diverse global educational needs. In the context of problem-solving, such collaborations can broaden the exploration of how GenAI is utilized to support students' thinking abilities across different academic disciplines and learning cultures [53].

From a regional perspective, ASEAN countries remain relatively underrepresented in the global publication network compared with leading contributors such as China, the United States, and the United Kingdom. Although several ASEAN countries, including Singapore, Malaysia, Indonesia, and Thailand, have demonstrated growing interest in AI-enhanced learning, their overall contribution to GenAI-supported problem-solving research remains limited. This finding suggests substantial opportunities for future collaboration among ASEAN higher education institutions, particularly in developing contextually relevant GenAI applications that address local educational needs and support the assessment of 21st-century competencies.

The results of the keyword co-occurrence analysis reveal that artificial intelligence, ChatGPT, and problem-solving constitute the central themes within the research structure. These findings suggest that GenAI is increasingly being positioned as a cognitive partner in supporting students' problem-solving processes in higher education. In addition, the emergence of keywords such as critical thinking, computational thinking, design thinking, project-based learning, and creativity indicates that current research strongly associates the use of GenAI with the development of higher-order thinking skills. This trend reflects a paradigm shift from viewing AI merely as an information-delivery tool toward utilizing AI as a thinking aid and solution-exploration partner within problem-based learning environments. In other words, GenAI is increasingly being used to support students throughout processes of analysis, reflection, evaluation, generation of alternative solutions, and creative idea development during problem-solving activities [16], [54].

The rapid emergence of AI literacy as a research theme reflects growing recognition that students and educators require competencies beyond merely using AI tools. As GenAI becomes increasingly integrated into learning activities, learners must develop the ability to critically evaluate AI-generated information, understand

the limitations and ethical implications of AI systems, and make informed decisions regarding their use. This shift has positioned AI literacy as an essential competency for effective participation in AI-enhanced educational environments.

These findings are further supported by the thematic map analysis, which shows that the themes problem-solving, students, and teaching are positioned within the motor themes quadrant. This position indicates that these themes possess both high centrality and strong developmental relevance, making them the primary driving forces in the evolution of this research field. Meanwhile, themes such as artificial intelligence, ChatGPT, and higher education are located in the basic themes quadrant, suggesting that these topics serve as the foundational basis for the development of research on GenAI-supported problem-solving. These results demonstrate that current research is no longer limited to discussing the mere presence of AI technologies in higher education. Instead, the focus has shifted toward understanding how AI can be utilized to support learning activities that are oriented toward students' problem-solving processes [55], [56]. In this sense, problem-solving has evolved beyond being simply a context for AI implementation and has become a central theme shaping the direction of research in this field. The findings contribute to a broader understanding of how GenAI is reshaping research on problem-solving in higher education and provide a foundation for future investigations, educational innovation, and evidence-informed policy development in AI-enhanced learning environments.

3.2.1. Implications for Educational Assessment and Evaluation

The findings of this study have important implications for educational assessment and evaluation in higher education, particularly in relation to the assessment of problem-solving and higher-order thinking skills. The prominence of themes such as problem-solving, critical thinking, metacognition, and AI literacy indicates that current research increasingly views problem-solving as a multidimensional competency involving reasoning, reflection, decision-making, and responsible use of AI technologies. Consequently, assessment practices in higher education may need to move beyond measuring final answers and place greater emphasis on evaluating both problem-solving performance and the cognitive processes involved in problem-solving activities.

GenAI offers considerable potential to support AI-assisted assessment of problem-solving abilities [57], [58]. Through natural language processing and interactive dialogue, GenAI can assist educators in analyzing students' reasoning processes, identifying misconceptions, and providing formative feedback during problem-solving tasks. This enables assessment not only of solution accuracy but also of intermediate reasoning steps, strategy selection, and problem-solving pathways. In addition, automated feedback generated by GenAI can support students in revising their reasoning and refining solution strategies in real time. Such capabilities may help generate richer evidence of students' problem-solving processes and cognitive performance than traditional assessment approaches that primarily focus on task outcomes. In addition, GenAI can facilitate authentic assessment by supporting complex and open-ended problem scenarios that require students to justify decisions, evaluate alternative solutions, and apply knowledge in realistic contexts.

The findings also suggest potential applications of GenAI for assessing competencies closely associated with problem-solving, including critical thinking and metacognitive regulation [59]. By examining students' explanations, arguments, reflections, and solution strategies, GenAI may contribute to the development of higher-order thinking skills assessments that capture not only what students know but also how they approach and solve problems [60]. Furthermore, adaptive assessment systems supported by GenAI may provide more personalized evaluation experiences by adjusting task complexity and feedback according to students' performance levels.

Despite these opportunities, the use of GenAI in problem-solving assessment raises important concerns regarding academic integrity, assessment validity, and reliability [61]. The increasing availability of AI-generated responses may make it difficult to determine the extent to which assessment outcomes genuinely reflect students' independent problem-solving abilities. In addition, although GenAI can provide rapid and consistent feedback, further research is needed to ensure that AI-assisted assessments accurately measure intended learning outcomes and produce reliable results across different educational contexts. Therefore, educational accountability, transparency, and appropriate human oversight remain essential to ensure that the use of GenAI enhances the quality and credibility of problem-solving assessment in higher education.

3.2.2. Limitations and Future Directions

Despite the rapid growth of research on GenAI-supported problem-solving, several research gaps remain evident. Most existing studies still focus on exploring the use of ChatGPT and students' perceptions of AI use in learning, while empirical studies specifically evaluating the long-term effectiveness of GenAI in improving students' problem-solving abilities remain relatively limited. In addition, research within STEM and physics education contexts is still scarce, even though these fields are closely associated with problem-solving and higher-order thinking skills. Issues related to academic integrity and the quality of students' thinking processes are also emerging as important concerns, yet they still require deeper intervention. Therefore, the development of human-AI collaborative problem-solving models within STEM and physics education contexts

represents a particularly promising direction for future research. Future studies should also investigate the validity and reliability of GenAI-supported assessment systems for evaluating problem-solving and AI literacy competencies.

This study also has several limitations that should be acknowledged. First, the analysis was limited to publications indexed in the Scopus database and English-language articles, which may have excluded relevant studies published in other databases or languages. Second, bibliometric analysis primarily focuses on mapping publication trends, collaboration patterns, and thematic structures, but it does not evaluate the methodological quality or empirical rigor of individual studies in depth. Therefore, future studies could combine bibliometric analysis with systematic literature reviews or meta-analytic approaches to provide deeper insights into the pedagogical effectiveness of GenAI in supporting students' problem-solving processes across different educational contexts.

4. CONCLUSION

This study mapped the research landscape of GenAI-supported problem-solving in higher education through a bibliometric analysis of Scopus-indexed publications from 2021 to 2026. The findings reveal a rapid growth of research following the emergence of ChatGPT and LLMs, highlighting increasing scholarly interest in the use of GenAI to support problem-solving and higher-order thinking skills. The analysis identified problem-solving as a central research theme, accompanied by emerging topics such as critical thinking, metacognition, AI literacy, and human-AI collaboration. Furthermore, the results demonstrate that research in this field is shaped by strong international collaboration and is increasingly shifting toward the pedagogical integration of GenAI in higher education. This study contributes by providing a comprehensive overview of publication trends, collaboration networks, and thematic developments in GenAI-supported problem-solving research. Future research should focus on evaluating the long-term effectiveness of GenAI in enhancing students' problem-solving abilities and exploring its implementation within specific disciplinary contexts, particularly in STEM education. The findings provide a useful foundation for researchers, educators, and curriculum developers seeking to integrate GenAI into problem-solving-oriented learning and assessment practices in higher education.

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