Critical Thinking in Problem-Based Learning within Higher Education: A Bibliometric and Visualization Analysis Using VOSviewer and Citespace

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ABSTRACT

To systematically reveal the research landscape and the evolutionary trends of research hotspots on critical thinking within Problem-Based Learning (PBL) in higher education, this study adopts a bibliometric approach. Journal articles and review papers published between 2000 and 2025 were retrieved from the Web of Science (WoS) Core Collection and analyzed through statistical and visual mapping techniques. The results indicate a steady growth in research output in this field, reflecting a continuously increasing level of academic attention. China ranks among the leading contributors in terms of publication volume, while Asian institutions, particularly The Hong Kong Polytechnic University and The University of Hong Kong, occupy central positions in institutional collaboration networks. However, the overall density of author collaboration networks remains relatively low, suggesting that cross-institutional and interdisciplinary cooperation requires further strengthening. Relevant studies are mainly published in journals such as Nurse Education Today and BMC Medical Education. The research focus has gradually shifted from validating instructional effectiveness to exploring underlying mechanisms, interdisciplinary integration, and instructional system optimization, highlighting the synergistic roles of collaborative learning, cognitive scaffolding, authentic problem contexts, and technological and organizational support in fostering higher-order thinking skills. Overall, research on PBL and critical thinking in higher education is transitioning from theoretical exploration toward the optimization of instructional practice. Looking ahead, with the continued advancement of digitalization and blended learning, this field is expected to further expand its application contexts, deepen research content, and enhance research quality and innovation through strengthened collaborative networks.

Keywords: Problem-based learning, Critical thinking, Visualization analysis, CiteSpace, VOSViewer

INTRODUCTION

Critical thinking, as one of the core competencies of the 21st century, is widely regarded as an important indicator of individuals' social adaptability and innovative capacity, as well as a key determinant of national competitiveness. It is also a crucial objective for promoting social progress and achieving high-quality talent cultivation (Barta, Fodor, Tamas, & Szamoskozi, 2022). In the context of higher education, rapid technological advancement, increasingly complex information environments, and the diversification of professional demands require students not only to acquire systematic disciplinary knowledge but also to develop a high level of critical thinking skills to address complex problems encountered in academic inquiry and real-world contexts (Almulla, 2023; Jia & Tu, 2024). Consequently, fostering critical thinking has become a central concern of higher education systems worldwide and continues to attract sustained scholarly attention (Zhang et al., 2025).

Among the various instructional strategies designed to promote critical thinking, Problem-Based Learning (PBL) has been recognized for its distinctive advantages, particularly its student-centered orientation and emphasis on learning driven by authentic problems (Anggraeni, Prahani, Suprapto, Shofiyah, & Jatmiko, 2023). Grounded in

constructivist learning theory, PBL engages students in a series of learning processes—such as problem analysis, goal setting, information seeking, collaborative inquiry, and reflective synthesis—through which learners actively construct knowledge and develop higher-order thinking skills, including analysis, reasoning, and evaluation (Santos-Meneses, Pashchenko, & Mikhailova, 2023). Within this instructional approach, the role of teachers shifts from traditional transmitters of knowledge to facilitators and guides of learning, thereby supporting the gradual development and sustained enhancement of students' critical thinking abilities (Nicholus, Muwonge, & Joseph, 2023).

In recent years, the number of empirical studies examining the effects of PBL on critical thinking in higher education has increased substantially, with most research focusing on its impact on critical thinking skills and dispositions. However, the findings remain inconclusive. While some studies have demonstrated that PBL yields significantly better outcomes than traditional instructional approaches (Darmawati & Mustadi, 2023), others have reported no significant differences between the two (Manuaba, -No, & Wu, 2022). Scholars have suggested that such inconsistencies may be attributable to various contextual factors, including disciplinary domains, instructional duration, scaffolding design, students' prior cognitive foundations, and group size (Kong, Qin, Zhou, Mou, & Gao, 2014; Liu & Pásztor, 2022). These discrepancies highlight the need for a more comprehensive and macroscopic perspective to examine the overall research landscape and to clarify the conditions and boundaries under which PBL effectively promotes critical thinking.

Despite the growing body of literature, research on "PBL and critical thinking" has predominantly relied on experimental studies or case-based analyses. As a result, research perspectives remain relatively fragmented, and existing findings exhibit a certain degree of dispersion (Alreshidi & Alreshidi, 2023; Masek & Yamin, 2011). There is still a lack of systematic integration of research findings concerning the overall status, knowledge structure, and developmental trends of this field within higher education. In particular, bibliometric studies that provide macro-level analyses and visual representations of the field are relatively scarce. Moreover, traditional narrative literature reviews are limited in their ability to reveal structural relationships among research themes, patterns of scholarly collaboration, and the evolution of research frontiers, thus constraining a comprehensive understanding of the field's development trajectory.

In response to these gaps, the present study draws on data from the Web of Science Core Collection and employs bibliometric and visualization methods, utilizing tools such as VOSviewer and CiteSpace. By constructing knowledge maps from multiple dimensions—including authors, institutions, countries/regions, journals, keywords, and cited references—this study systematically examines the research landscape, thematic hotspots, and evolutionary trends of studies on "PBL and critical thinking" in higher education. The findings aim to provide education researchers and practitioners with a comprehensive and structured overview of the knowledge base, thereby deepening the overall understanding of research on PBL as a means of fostering critical thinking.

Based on these objectives, the study addresses the following research questions:

RQ1: What is the current research status of studies on PBL and the promotion of critical thinking in higher education?

By analyzing publication trends, core authors, national and institutional distributions, and highly cited literature, this question seeks to reveal the structural characteristics of knowledge in this field.

RQ2: What are the major research hotspots and their evolutionary trends in this field?

Through keyword co-occurrence analysis, clustering, and burst detection, this question aims to identify key research themes and elucidate their developmental trajectories.

METHODOLOGY

Research Tools

This study conducted data retrieval and screening based on the Web of Science Core Collection database and employed two widely used bibliometric software tools—VOSviewer (v1.6.20) and CiteSpace (v6.4.R1)—to construct knowledge maps and perform visualized analyses. These tools were used to systematically present the

research status, hotspots, and developmental trends of studies on critical thinking within Problem-Based Learning (PBL) in higher education.

VOSviewer is a bibliometric visualization tool specifically designed for mapping knowledge networks. It enables accurate visualization of co-authorship, institutional collaboration, country-level distribution, and keyword co-occurrence networks. While ensuring analytical accuracy, VOSviewer also provides strong visual clarity, making it particularly useful for identifying core research forces and revealing the knowledge structure of a research field (Martins, Gonçalves, & Branco, 2024). CiteSpace, developed by Chen (2004), is one of the most widely applied tools for knowledge mapping and is especially suitable for detecting research frontiers and analyzing thematic evolution (Geng, Zhu, & Maimaituerxun, 2022). By conducting keyword burst detection and time-slicing analysis, this study identifies shifts in research themes across different periods, thereby uncovering the evolutionary trajectory and potential future directions of research on PBL and critical thinking.

As noted by Chen (2006), CiteSpace generates visualized knowledge maps through bibliometric analysis, which effectively display the knowledge structure, developmental patterns, and distribution characteristics of a research field, and facilitate the exploration of research hotspots, intellectual frontiers, and emerging trends.

Data Source

The literature data were retrieved from Clarivate Analytics' Web of Science (WoS) Core Collection database. Specifically, the Science Citation Index Expanded (SCI-EXPANDED, 1990–present) and the Social Sciences Citation Index (SSCI, 1990–present) were selected as citation indexes. An advanced search strategy was employed using the Topic Search (TS) field. Based on the search strategy proposed by Yu and Zin (2023), the following query was applied: TS = ((("PBL" OR "problem-based learning" OR "problem based learning") AND ("critical thinking" OR "think critically") AND (university OR college OR undergraduate OR "higher education" OR "tertiary education"))). The publication time span was limited to 2000–2025, and only document types classified as "articles" and "reviews" were included. A total of 225 publications meeting the research criteria were retrieved. The literature search was conducted on January 2, 2026. The detailed screening and selection process is illustrated in Figure 1.

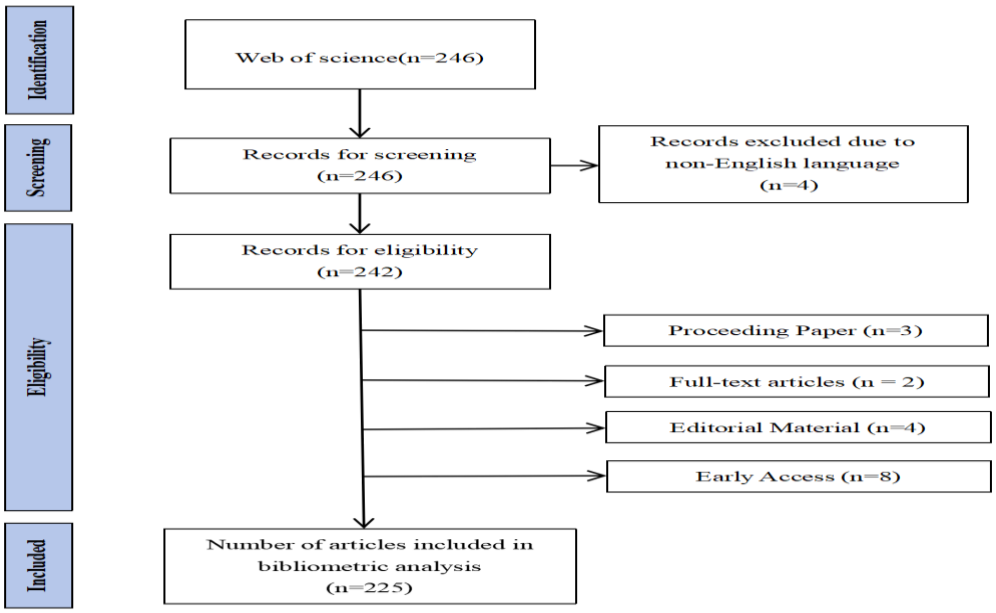

Figure 1: PRISMA flow diagram

Data Analysis

In the analysis of the research landscape, VOSviewer was employed to construct collaboration networks of authors and institutions. By examining network structure, node size, and link strength, influential research entities and their collaboration patterns were identified. To further reveal the spatial distribution and

collaborative structure of this field, VOSviewer (v1.6.20) was combined with Scimago Graphica for visual analysis. Specifically, Scimago Graphica was used to generate global spatial distribution maps of publications, providing an intuitive representation of research activity levels and academic influence across different countries and regions. To ensure the accuracy and interpretability of network analyses, the processed bibliographic data were imported into VOSviewer (v1.6.20), with the counting method set to full counting. Other parameters were adjusted appropriately based on visual clarity and readability, ensuring that the resulting maps were structurally clear and easy to interpret.

For the analysis of research hotspots, thematic structure, and evolutionary trends, CiteSpace (v6.4.R1) was utilized to conduct keyword co-occurrence analysis, clustering analysis, and burst detection. These analyses were designed to uncover the knowledge structure and evolutionary trajectories of research on PBL and critical thinking. The specific parameter settings were as follows: the processed data were imported into CiteSpace (v6.4.R1), and the time slicing was set to one year (Years per Slice = 1) to capture annual changes in research themes. For network optimization, the Pathfinder pruning algorithm was applied, with both sliced networks (pruning sliced networks) and the merged network (pruning the merged network) enabled to enhance the clarity and interpretability of the network structure. In burst detection visualization, the gamma (γ) value was set to 0.4, while other parameters remained at their default settings. To ensure the robustness and validity of the clustering results, clustering quality was evaluated using the Modularity Q and mean Silhouette scores. In addition, cluster size, link strength, and cluster labels were jointly considered to provide a comprehensive and rigorous interpretation of the clustering outcomes.

RESULTS

Research Landscape

1. Visualization Analysis of Publication Output

Research on Problem-Based Learning (PBL) and critical thinking in higher education has gradually emerged as an important area within educational research since its first appearance in 1991 (Nash, Schwartz, Middleton, Witte, & Young, 1991, published in Academic Medicine). Based on bibliometric statistics for the period from 2000 to 2025, a total of 225 relevant publications were identified. Annual publication output not only reflects the development of a research field but also serves as an indicator of scholars' research activity and overall growth trends (Jiang, Huang, Shi, & Yang, 2025; Xiao, Pan, & Lai, 2025).

From a developmental perspective, research on PBL and critical thinking in higher education can be divided into three main stages (Figure 2).

The initial exploratory stage (2000–2008) was characterized by a relatively low volume of publications, with fewer than five articles published in most years. No publications meeting the inclusion criteria were identified in 2000 and 2004. During this stage, research remained at the level of conceptual exploration and theoretical introduction, and a systematic research framework integrating PBL and critical thinking had not yet been established. Scholarly attention was limited, and studies mainly focused on theoretical discussions and small-scale instructional experiments. Although a slight increase in publication output was observed in 2003, the overall growth trend remained slow.

The steady development stage (2009–2018) began in 2009, when annual publication output increased noticeably and exhibited a relatively stable upward trend. Although slight declines occurred in certain years (e.g., 2011 and 2014), the overall trajectory continued to rise. This stage reflects the growing emphasis in higher education on students' innovative capacity and critical thinking skills, as well as the increasing recognition of PBL as an effective instructional approach. Research directions became more systematic, and both theoretical and empirical studies were progressively deepened. A growing number of empirical investigations based on curriculum design and instructional cases emerged, laying a solid foundation for subsequent development in this field.

The rapid growth stage (2019–2025) marked a period of accelerated expansion, with a sharp increase in annual publication output and peak values reached between 2023 and 2025 (exceeding 30 publications in 2025). In

particular, the widespread adoption of online and blended learning during 2020–2022 further stimulated research interest in PBL, positioning it as a focal topic in educational research. Although publication output declined slightly in certain years (e.g., 2024), the overall level of research activity remained significantly higher than in the previous two stages. Research during this period demonstrates characteristics of theoretical deepening, methodological diversification, and expansion of application contexts, indicating that the integration of PBL and critical thinking has entered a more mature phase and become a prominent direction in higher education research.

In addition, linear regression analysis revealed a significant positive relationship between publication output and time ($R^2 = 0.7167$), with the regression equation $Y = 0.8277*X - 2.52$, indicating a stable overall growth trend in this field. Although fluctuations occurred in individual years, they did not alter the long-term developmental trajectory.

Overall, research on PBL and critical thinking in higher education has experienced a clear developmental trajectory, including an initial stage of low-level exploration, a subsequent period of steady growth, and a recent phase of rapid expansion. In recent years, the field has not only experienced sustained quantitative growth but has also exhibited qualitative advancements in terms of theoretical refinement, methodological diversity, and broader application domains. These trends suggest that the field has gradually entered a mature stage and has become an important area of educational research.

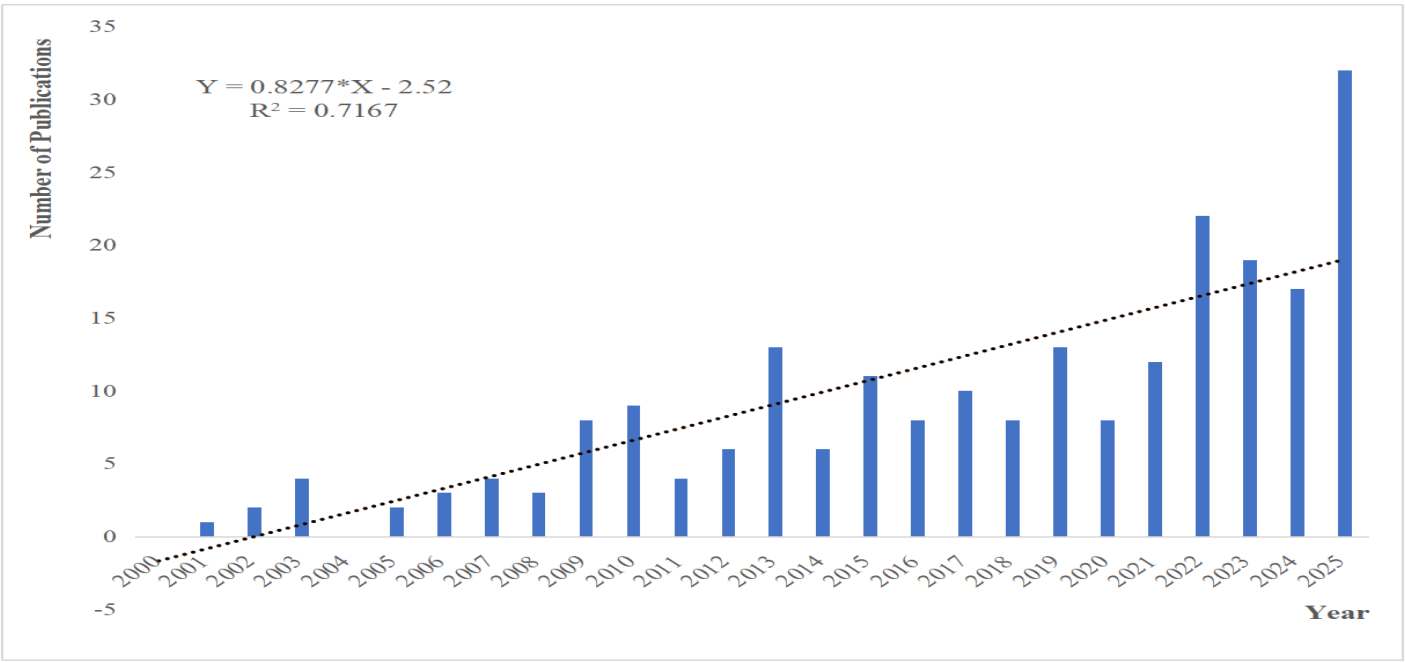

Figure 2: Annual publication trends on critical thinking in problem-based learning within higher education (2000–2025)

2. Author Collaboration Analysis

Author co-authorship analysis provides an intuitive means of revealing prolific authors and their collaborative relationships within a research field, thereby helping to identify key scholarly contributors and to characterize the structure of author collaboration networks (Gao et al., 2023; Wang, Liu, Li, & Xiao, 2022). Through co-authorship mapping, it is possible not only to examine authors' publication frequencies but also to identify core authors and the collaborative patterns of research teams in the field (Pan & Zhang, 2023).

In this study, Price's Law, expressed as (N=0.749(Mmax)1/2), was applied to determine the threshold for identifying prolific authors in the field of PBL and critical thinking in higher education. Here, (Mmax) denotes the publication count of the most productive author, and (N) represents the minimum number of publications required to be classified as a prolific author (Zhang, Hu, Jiao, & Wang, 2022). The bibliometric results indicate that the most productive author published three articles (Mmax=3), yielding a calculated threshold of approximately (N ≈1.30). Following common practice in bibliometric research, this value was rounded up to

two, meaning that authors with at least two publications were identified as prolific authors in this field. The results show that only 18 authors met this criterion, accounting for 2.14% of the total number of authors. This finding suggests that a large-scale and stable core group of scholars has not yet emerged, and that the field remains in a phase of ongoing development.

Based on this threshold, VOSviewer was used to visualize the author collaboration network for studies published between 2000 and 2025 in the field of PBL and critical thinking in higher education (Figure 3). In the co-authorship network, each node represents an author, with node size indicating publication frequency. Different colors denote distinct collaboration clusters, while links between nodes represent co-authorship relationships. The number and density of links reflect the strength and intensity of collaboration among authors (Kemeç & Altınay, 2023; Mao, Chen, Wang, Hou, & Xiang, 2020).

The analysis identified 18 authors who were involved in collaborative relationships, forming several small and relatively dispersed collaboration clusters. Within each cluster, authors tended to maintain relatively close connections, whereas inter-cluster links were sparse. As a result, no highly centralized or large-scale core collaboration network has yet formed in this field.

From a structural perspective, stable dyadic or triadic collaboration patterns were observed among certain authors. For instance, Porter, A., Matsuda, Y., and Falcon, A. constituted a closely connected small collaboration unit, while a clear collaborative relationship was also evident between Marshall, T. A. and Finkelstein, M. W. Similarly, author pairs such as Latif, R. and Mumtaz, S., as well as Tao, J. and Wen, X., formed relatively independent collaboration groups.

Overall, author collaboration in this field is characterized by small-scale, low-density, and multi-cluster structures, rather than a highly integrated network centered on a group of core authors. This pattern indicates that research activities are still predominantly conducted by individuals or small teams, and that cross-team and cross-institutional collaboration remains limited. Consequently, there is considerable potential for future development through strengthened international collaboration and enhanced coordination among research teams.

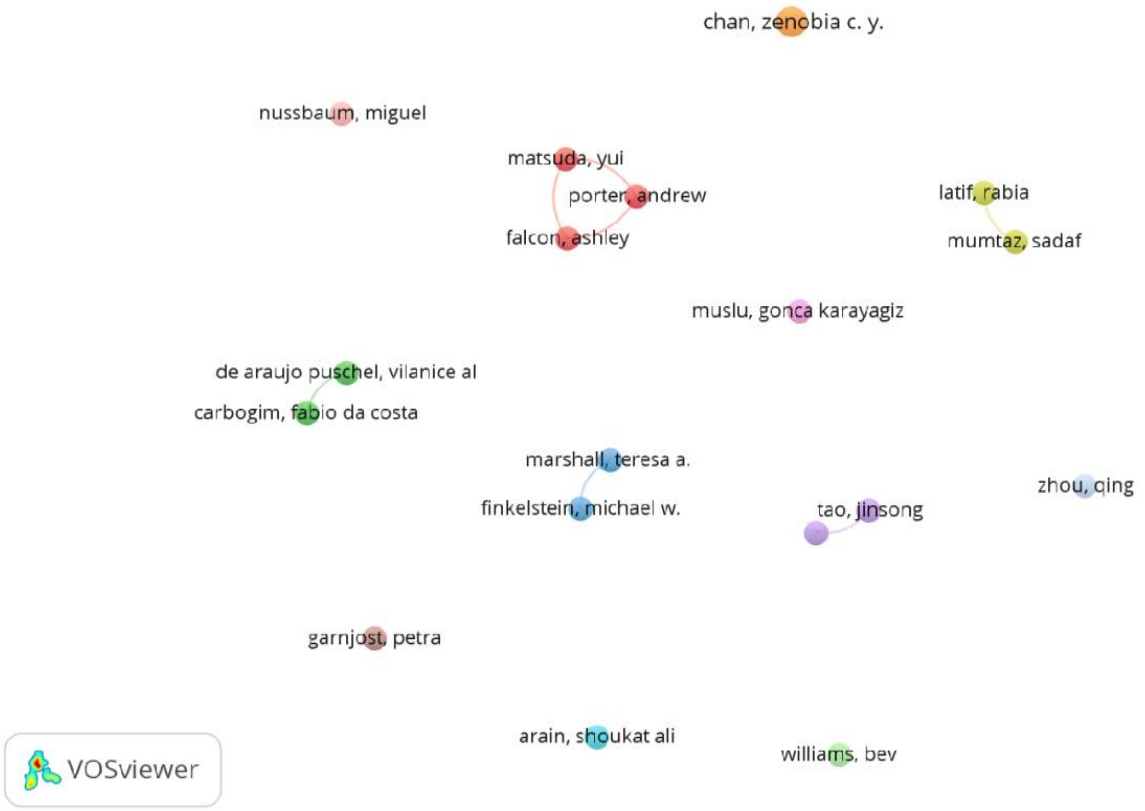

Figure 3: Collaboration Network of Authors

3. Spatial Distribution of Publications and Institutional Collaboration Analysis

To objectively depict the global distribution of publications, a spatial visualization analysis was conducted on the included WoS literature (Figure 4). The top five countries in terms of publication volume were China (52 publications, 23.1%), the United States (45 publications, 20%), Canada (18 publications, 8%), the United Kingdom (15 publications, 6.7%), and Spain (13 publications, 10.1%).

In terms of international collaboration, a research network centered on China and the United States emerged. However, collaboration among countries remains relatively limited, indicating that further strengthening of cross-national partnerships is needed to enhance the global research network in the field of PBL and critical thinking.

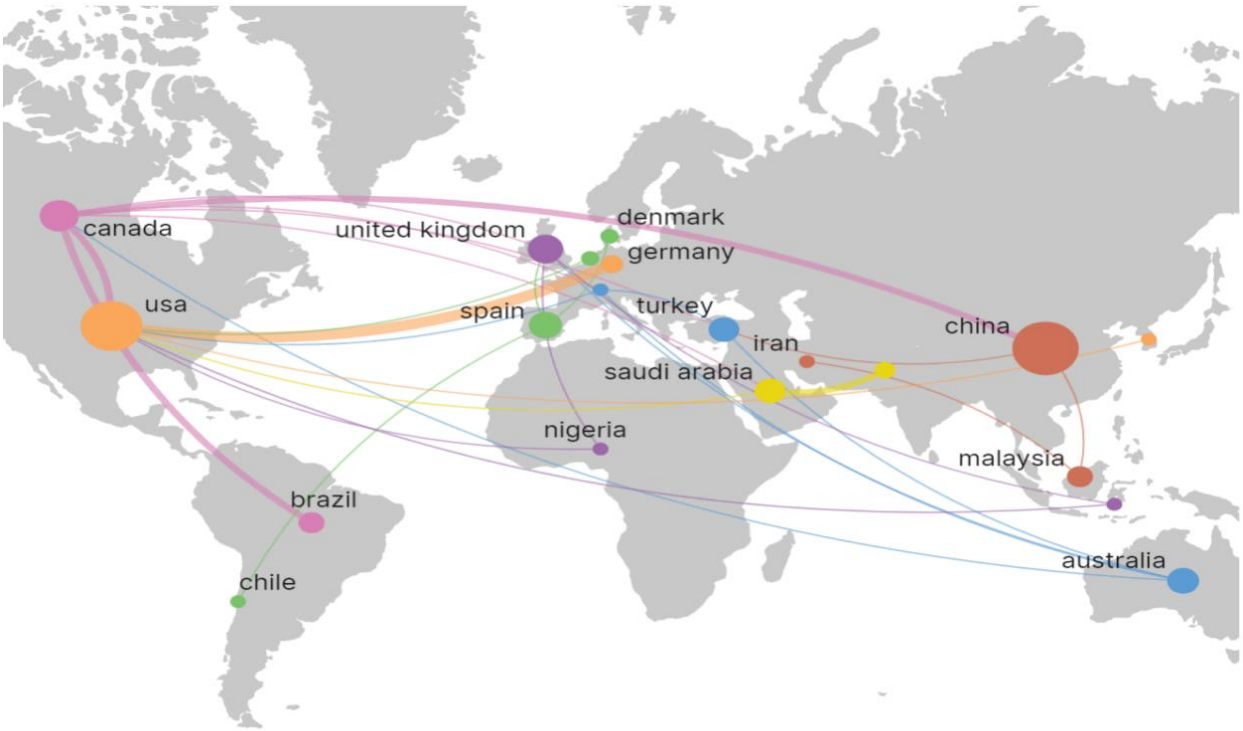

Figure 4: Geographical Distribution of Publications

Note: Nodes represent countries, the size of each node indicates the number of publications, and the links between nodes represent interregional collaboration.

Among research institutions, Hong Kong Polytechnic University ranked highest in publication output with 6 articles, followed by The University of Hong Kong (4 publications), Shanghai Jiao Tong University (4 publications), Jilin University (3 publications), and Aalborg University (3 publications). Notably, four of the top five institutions are based in China, indicating the growing research capacity and attention devoted to studies on PBL and critical thinking within Chinese higher education.

A co-occurrence cluster map of institutions with at least two publications was generated using VOSviewer, with time overlay visualization (Figure 5). The results show that a small number of institutions maintain relatively close collaborations, whereas the majority of institutions exhibit limited cooperative links. In addition, domestic collaborations tend to display regional characteristics, reflecting geographic proximity effects.

From the temporal overlay (Figure 5), it can be observed that Hong Kong Polytechnic University and The University of Hong Kong focused on PBL and critical thinking research in higher education around 2010. In contrast, institutions such as Shanghai Jiao Tong University and Jilin University showed increased attention to this research area around 2020, suggesting that Chinese universities are progressively placing greater emphasis on the development of PBL and critical thinking studies in higher education.

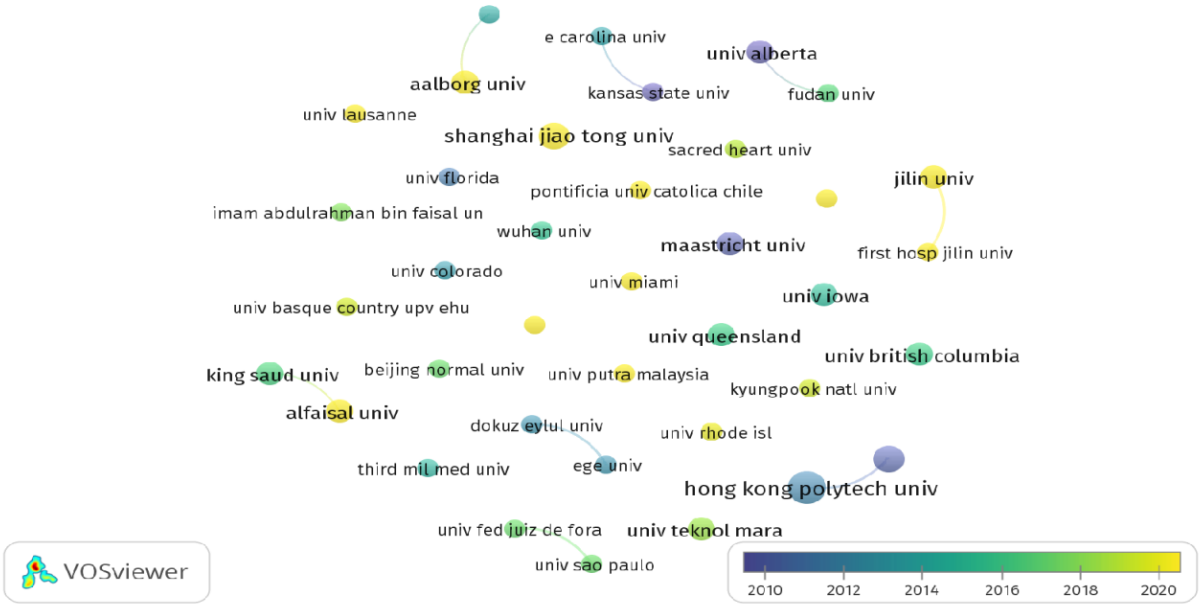

Figure 5: Co-occurrence Cluster Map of Research Institutions (Time Overlay)

4. Co-Citation Analysis

A co-citation network of the 225 included publications was generated using VOSviewer (Figure 6), comprising 36 items across 9 clusters with 65 links. To enhance the readability of the network, only publications cited at least 30 times were visualized. In this network, node size represents citation frequency, while links indicate co-citation relationships among publications.

The co-citation analysis identified several foundational studies that have strongly influenced research on PBL and critical thinking in higher education. Srinivasan, Wilkes, Stevenson, Nguyen and Slavin (2007, 325 citations) compared traditional problem-based learning (PBL, open inquiry) and case-based learning (CBL, guided inquiry) in medical education, finding that both students and faculty at two major academic medical centers favored CBL due to its efficiency in dense curricula, highlighting CBL as a viable alternative to conventional PBL group instruction. Tiwari, Lai, So and Yuen (2006, 215 citations, 13 links) examined the effects of PBL versus lecture-based teaching on students' critical thinking development, demonstrating that PBL significantly enhances critical thinking skills and occupies a structurally central position in the co-citation network. Şendağ and Odabaşı (2009, 200 citations) investigated online PBL in undergraduate courses, revealing that while it did not significantly improve domain knowledge, it produced a notable positive effect on students' critical thinking skills. Similarly, Choi, Lindquist, and Song (2014, 116 citations) explored PBL in nursing education, reporting positive trends in critical thinking, problem-solving, and self-directed learning, although statistical significance was limited due to small sample size and low statistical power. Kamin, O'Sullivan, Deterding and Younger (2003, 93 citations) examined different case presentation formats in PBL group discussions and found that digital video cases effectively enhanced students' critical thinking in both face-to-face and virtual settings.

Together, these co-cited publications form the foundational literature in the field, providing empirical evidence on instructional design, learning modalities, and the cultivation of higher-order thinking skills. They reflect the evolution of PBL research in higher education and underscore the importance of pedagogical strategies that actively engage students in critical thinking development.

The five most productive journals in this field were Nurse Education Today (13 publications), BMC Medical Education (11 publications), Sustainability (10 publications), International Journal of Engineering Education (9 publications), and Journal of Chemical Education (9 publications). In terms of disciplinary coverage, these high-output journals primarily represent medical education, nursing education, engineering education, and chemistry education. Collectively, the highly cited publications in these journals have examined the role of problem-based learning (PBL) in fostering critical thinking among higher education students across diverse disciplinary and

instructional contexts. These studies consistently highlight the positive impact of PBL on the development of higher-order thinking skills. At the same time, they indicate that the effectiveness of PBL can be influenced by factors such as course design quality, the nature of problems or cases, and the learning environment. These findings provide important theoretical and empirical foundations for further research on the relationship between PBL and critical thinking in higher education.

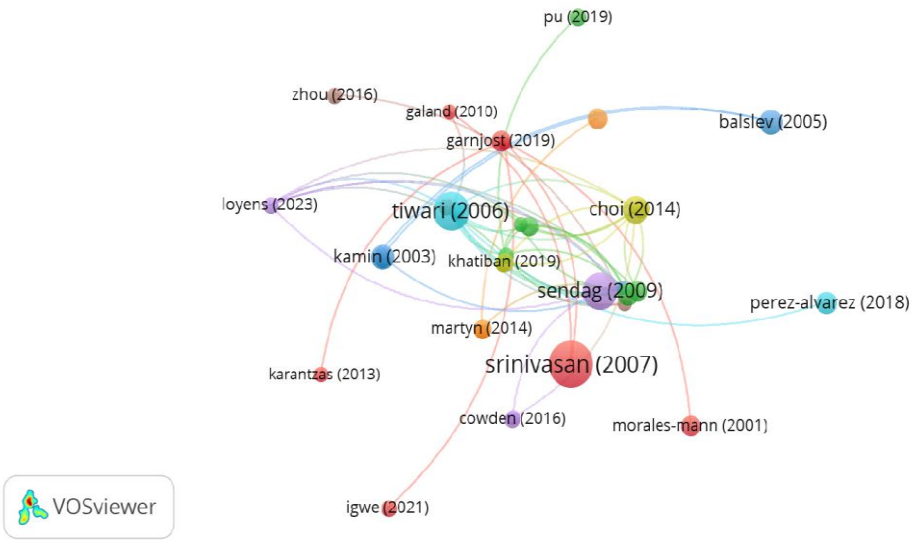

Figure 6: Co-citation Network of References

Research Hotspots and Evolution Trends

Research hotspots refer to topics or clusters of interrelated publications that receive substantial attention over a certain period (Gao, Yang, & Ye, 2022). Keyword co-occurrence and clustering analyses can be used to investigate current research hotspots (Xin et al., 2024).

1. Keyword Co-Occurrence Analysis

Keywords are concise representations of the core content of publications, and systematic analysis of keywords in a research field can help reveal research hotspots and knowledge structures (Fei, Kang, Sun, & Hu, 2023). However, during keyword selection, variations in authors' expressions of concepts related to problem-based learning may lead to multiple terms representing the same concept, which can affect the accuracy and interpretability of co-occurrence analysis results. To minimize the interference of synonyms and variant expressions and to enhance the scientific validity and stability of the keyword co-occurrence network, keywords were standardized prior to formal analysis. Specifically, in CiteSpace's alias file, all keywords from the included publications were consolidated, merging different expressions with the same meaning into standardized terms. For example, "problem based learning," "problem-based learning (PBL)," and "PBL" were all unified under "problem-based learning." This preprocessing effectively reduced keyword redundancy and improved the accuracy and reliability of the co-occurrence analysis.

After standardization, CiteSpace was used for keyword analysis. The resulting co-occurrence network (Figure 7) consisted of 425 nodes and 1,046 links, with a network density of 0.0116. Larger nodes indicate higher occurrence frequency (Narong & Hallinger, 2023). The top five keywords by frequency were problem-based learning (105 occurrences), critical thinking (78), higher education (65), students (55), and skills (23). In addition, keywords with high betweenness centrality are typically considered turning points or key nodes in a field (Xu, Yang, Wang, Guo, & Li, 2023); the top three keywords by centrality were higher education (0.37), followed by critical thinking (0.34) and competence (0.29). Furthermore, keywords such as active learning, performance, and skills showed relatively high frequency but lower centrality, indicating that they may serve as important entry points for future research on critical thinking development through problem-based learning in higher education.

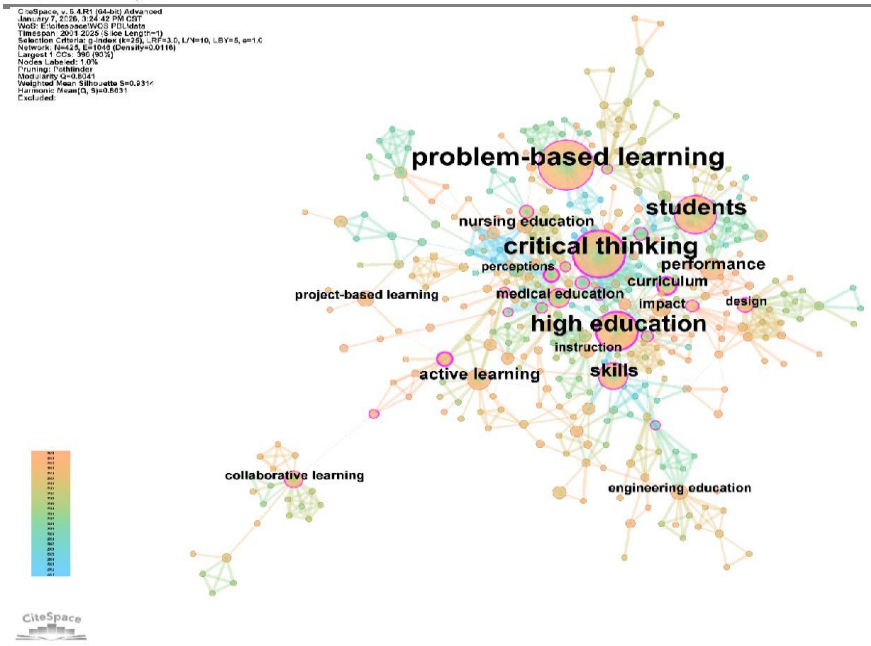

Figure 7: Keyword Co-occurrence Network

2. Keyword Cluster Analysis

The process of keyword clustering involves using prominent words or phrases within a field as clustering objects, which are then integrated and classified into distinct clusters. These clusters reflect the research hotspots within the field (Liu, Che, & Zhu, 2022). In the present study, high-frequency keywords in the research on critical thinking in problem-based learning (PBL) in higher education were clustered to reveal the main research themes. Keyword clustering is an aggregation and classification process, in which CiteSpace identifies similar keywords and groups them into clusters (Sun, Huang, Song, & Feng, 2020). In the co-occurrence network, clusters appear as irregularly shaped regions, each represented by a single label. Cluster indices range from 0 to 11, with larger numbers indicating fewer keywords in the cluster (Ren, Zhong, & Sun, 2023). Clusters composed of closely related keywords represent one of the major thematic directions within the field (Yue, Liu, Long, Chen, & Li, 2020). Using the log-likelihood ratio (LLR), high-frequency keywords were subjected to clustering analysis, resulting in the cluster map shown in Figure 8.

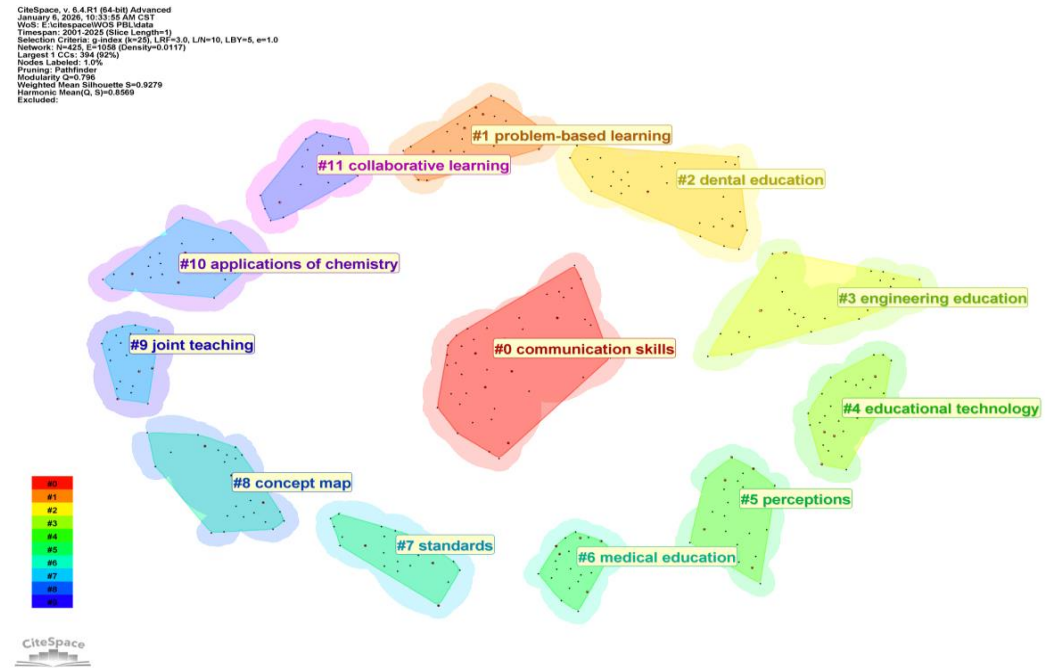

Figure 8: Keyword Cluster Map

The network modularity Q value was 0.796, indicating a significant clustering structure, and the average silhouette score S was 0.9279, suggesting that the clustering was highly reliable and efficient. The identified clusters included: #0 communication skills, #1 problem-based learning, #2 dental education, #3 engineering education, #4 educational technology, #5 perceptions, #6 medical education, #7 experimental courses, #8 concept map, #9 joint teaching, #10 applications of chemistry, and #11 collaborative learning.Current research on critical thinking in PBL within higher education primarily focuses on the following aspects:

(1) PBL Teaching Model and Learning Ability Development

Corresponding clusters: problem-based learning (#1), communication skills (#0), collaborative learning (#11), and concept map (#8). This cluster reflects the main research line investigating how PBL fosters critical thinking and learning ability development in higher education. Relevant studies suggest that critical thinking is a higher-order skill gradually formed through social interaction and cognitive construction, emphasizing collaborative learning, communicative engagement, and the use of cognitive tools such as concept mapping to guide students in analyzing, reasoning, reflecting, and integrating knowledge during problem-solving. Therefore, these studies focus more on the learning process and mechanisms of skill formation rather than merely evaluating teaching outcomes.

In terms of the pathways for skill development, Latif, Mumtaz, Mumtaz and Hussain (2018) introduced debate and role-playing strategies into a second-year undergraduate medical PBL course. They found that both strategies were effective in enhancing communication skills, but each had distinct advantages in critical thinking: debates broadened thinking pathways, whereas role-playing facilitated the integration of knowledge and practical experience. The study recommended complementary integration of these strategies according to instructional goals and learning contexts to comprehensively enhance higher-order thinking and communication skills among medical students.

Regarding the use of reflective learning tools, Woldt and Nenad (2021) conducted a systematic review of 13 studies in undergraduate dental education between 2000 and 2019 and found that reflective writing significantly improved students' critical thinking, judgment, and learning abilities. Successful pedagogical practices typically included structured writing guidance, clear assessment criteria, and facilitation of students' management of negative cognitions. The study suggested that reflective writing not only enhances students' reflective capacity and clinical reasoning but also sustainably supports problem-solving and motivation for learning.

At the course level, Karantzas et al. (2013) developed a PBL- and collaborative-learning-centered tutoring program for undergraduate psychology students. Using latent growth curve modeling, they found that students exhibited significant linear growth in critical analysis and problem-solving skills, indicating that sustained course-level design and long-term implementation are crucial for the development of higher-order abilities.

Regarding cognitive scaffolds and technological support, Alt, Weinberger, Heinrichs and Naamati-Schneider (2023) examined the use of digital concept maps in PBL among 129 undergraduate students in Israeli and Austrian universities. The results indicated that concept maps helped students organize argumentation logic and deepen understanding, especially for students with a deep-learning orientation. In contrast, students with a surface-learning orientation perceived limited utility from the tool; therefore, course designs need to specifically guide these students to engage in more challenging learning activities.

(2) Application of PBL in Different Disciplinary Contexts

Corresponding clusters: dental education (#2), engineering education (#3), medical education (#6), and applications of chemistry (#10). This cluster primarily reflects the practical application of problem-based learning (PBL) across different disciplinary contexts and its impact on the development of students' critical thinking. Studies generally suggest that critical thinking is not a simple transfer of generic skills, but a capacity gradually constructed within specific disciplinary problem contexts through the integration of domain knowledge, situational judgment, and practical decision-making. Accordingly, these studies emphasize embedding PBL within highly contextualized and practice-oriented disciplines such as medicine, engineering,

and chemistry, using authentic or simulated professional problems as learning drivers to promote higher-order thinking in complex decision-making and problem-solving.

In dental education, Pardamean (2012) examined the critical thinking abilities of 98 undergraduate dental students at the University of Southern California. The results indicated no significant overall improvement, though inductive reasoning showed modest enhancement. The study noted that factors such as gender, ethnicity, native language, and educational background may influence the effectiveness of PBL, suggesting that curriculum design should account for individual differences to optimize skill development.

In engineering education, Aziz (2011) explored an IT-supported, collaborative PBL module that integrated cooperative learning, PBL, and critical thinking within a virtual collaborative environment. Findings revealed that the interactive module significantly enhanced students' sense of responsibility for self-directed learning and engagement, demonstrating the potential of technology to facilitate higher-order thinking and active learning.

In medical education, Zhou et al. (2023) implemented PBL for 267 third-year medical students at Nantong University and evaluated clinical reasoning abilities. Results indicated that students in the PBL group exhibited significantly higher post-test clinical reasoning scores than the control group, with improvements across all subscales relative to the pre-test. Multiple regression analysis identified literature review frequency, time spent on self-directed PBL learning, and classroom performance as key influencing factors. The study concluded that systematically designed PBL courses can effectively enhance medical students' clinical reasoning, with outcomes dependent on students' engagement in self-directed learning and the quality of course implementation.

In STEM interdisciplinary education, Cowden and Santiago (2016) implemented an interdisciplinary PBL module in an advanced biochemistry course, collaboratively designed with librarians and chemists. Preliminary results demonstrated that the module enhanced students' multidisciplinary integrative thinking, research skills, and critical thinking, suggesting that interdisciplinary PBL is an effective strategy for promoting higher-order thinking and comprehensive competence.

(3) Instructional Implementation, Learner Perceptions, and Technological Support

Corresponding clusters: educational technology (#4), perceptions (#5), standards (#7), and joint teaching (#9). This cluster focuses on the practical implementation of problem-based learning (PBL) in higher education, learner perceptions, and the conditions of technological and organizational support, highlighting the moderating role of instructional context and external support factors in the development of critical thinking. Unlike the first two clusters, which center on instructional models or disciplinary applications, this body of literature emphasizes how PBL can be effectively implemented and how students and instructors understand, adapt to, and sustain engagement with the instructional approach, thereby creating a supportive and sustainable learning environment for higher-order thinking development.

Regarding technological support, Woodham et al. (2015) investigated the use of video resources in virtual patient PBL. The study found that although videos provide rich contextual and visual cues, most students still preferred textual information for clinical reasoning tasks, suggesting that videos could slow learning pace and reduce critical evaluation of information. The authors recommended balancing video and text resources in virtual PBL design to avoid potential interference with critical thinking.

In terms of organizational structure and team collaboration, Carvalho (2016) used structural equation modeling to examine the impact of PBL on transferable skills development in management education. Results indicated that faculty–student interactions, university–industry partnerships, and clearly defined team collaboration rules significantly enhanced problem-solving, critical thinking, and teamwork abilities. Additionally, learning satisfaction was influenced by multiple instructional and organizational factors. This study underscores that well-designed organizational structures and interactive mechanisms are critical for the effective implementation of PBL.

At the level of overall course effectiveness and learner perceptions, Antepohl, Domeij, Forsberg and Ludvigsson (2003) conducted a large-scale survey of medical graduates and found that PBL-centered undergraduate

curricula were highly regarded for promoting physician–patient communication, interprofessional collaboration, critical thinking, and scientific attitudes. Most graduates reported that the curriculum adequately prepared them for subsequent clinical practice, providing longitudinal evidence of PBL's value in cultivating higher-order competencies.

Regarding instructional innovation and joint teaching, Qu et al. (2024) implemented a hybrid PBL (hPBL) approach in medical laboratory courses and demonstrated that integrating PBL with lecture-based instruction enhanced students' theoretical understanding, experimental skills, self-directed learning, and communication abilities. Further, Qiu, Lin, Pan, Wang and Ma (2025) combined case-based learning (CBL), PBL, standardized patients, and evidence-based medicine in clinical medical teaching, showing that multimodal joint instruction significantly outperformed traditional lecture-based methods in clinical performance, critical thinking, and teaching satisfaction, highlighting its systematic advantages and scalability.

Overall, research on PBL has evolved from examining its singular teaching effectiveness to systematically investigating the mechanisms underlying critical thinking development and associated learning support. Its application has been centered in medical and engineering disciplines, gradually extending to other STEM and applied fields. The focus has shifted from assessing "whether it works" to exploring "how high-order thinking can be continuously promoted through the design of communication, collaborative structures, and cognitive scaffolds." Evidence suggests that the enhancement of critical thinking through PBL is not determined solely by the instructional model itself, but is influenced by multiple factors, including the selection of technological tools, organizational design, and learners' perceptions. Current research hotspots have moved beyond a sole focus on teaching formats and tools, emphasizing the optimization of implementation strategies and learning experiences to construct a learning ecosystem that supports sustained development of high-order thinking. These findings offer significant insights for the theoretical advancement and practical refinement of PBL in interdisciplinary and digital learning contexts.

3. Evolutionary Trends: Burst Detection of Keywords

Keyword burst coefficients are used to measure sudden changes in the frequency of a keyword within a specific period (Fu et al., 2024). Specifically, when the frequency of a keyword increases or decreases sharply over a short time, its burst coefficient rises, reflecting the frontier dynamics and directional shifts in a research field (Jin, Jian, & Liu, 2024; Lu & Li, 2025). The higher the burst strength, the more significant the change in attention to the keyword during a particular period.

In this study, the burst detection function of keyword co-occurrence in CiteSpace v.6.4.R1 was employed to rapidly identify keywords exhibiting sharp frequency changes over specific periods. By analyzing the number and strength of burst nodes, the research activity within the field can be assessed, and emerging topics and potential development trends can be further revealed (Jian, Jin, & Wu, 2023). Burst detection is thus widely applied in studies of disciplinary evolution to explore research topics at different periods and capture the dynamic changes at the frontier of a field (Sun, Zhang, & Jin, 2025). Overall, this method not only reflects the evolution of research hotspots but also provides a reference for predicting future research directions.

By selecting "Keyword" as the node type in CiteSpace, 20 keywords with burst occurrences were identified, along with their burst periods and intensities (Figure 9). By combining these keywords with relevant high-burst publications, the study further analyzed the frontier issues and evolutionary trends in critical thinking research within problem-based learning (PBL) in higher education.

From a chronological perspective, 2001–2008 can be considered the early stage of PBL and related skills research in higher education. During this stage, research focused primarily on foundational skill development, such as problem solving and self-directed learning, as well as preliminary explorations of perceptions and outcomes. These studies laid the theoretical foundation for the subsequent practice and promotion of PBL in higher education.

The period 2009–2019 represents the mid-stage research frontier. Research during this stage concentrated on specific instructional strategies and curriculum designs, including critical thinking skills, dental education,

communication, concept maps, and inquiry-based/discovery learning. This trend indicates that PBL implementation in various disciplines and courses gradually matured, with researchers increasingly focusing on the practical effects of teaching methods on student skill development.

From 2020 to 2025, research represents the latest frontier. Hot topics during this period include project-based learning, skills, teachers, instruction, achievement, case-based learning, and technology, demonstrating a shift in PBL research in higher education from single-skill development to comprehensive curriculum design, teacher development, and integration of technology, with greater attention to improving students' critical thinking and academic achievement.

Regarding burst intensity, dental education exhibited the highest burst strength (2.91), followed by skills (2.58), teachers (2.47), project-based learning (2.71), and perceptions (2.38). These keywords further confirm that in the past decade, the core focus of PBL research in higher education has concentrated on practical instruction, student skill development, and teacher support.

Considering the duration of research attention, problem solving (2001–2009) and self-directed learning (2001–2008) were themes of sustained early interest; concept maps (2012–2016) and inquiry-based/discovery learning (2016–2019) were mid-stage focal points; while project-based learning (2022–2025), skills (2023–2025), and teachers (2023–2025) represent the most recent research frontier. This pattern indicates a relatively high turnover of research hotspots in higher education PBL studies, with a gradual shift from foundational skill development toward more integrated and application-oriented instructional practices.

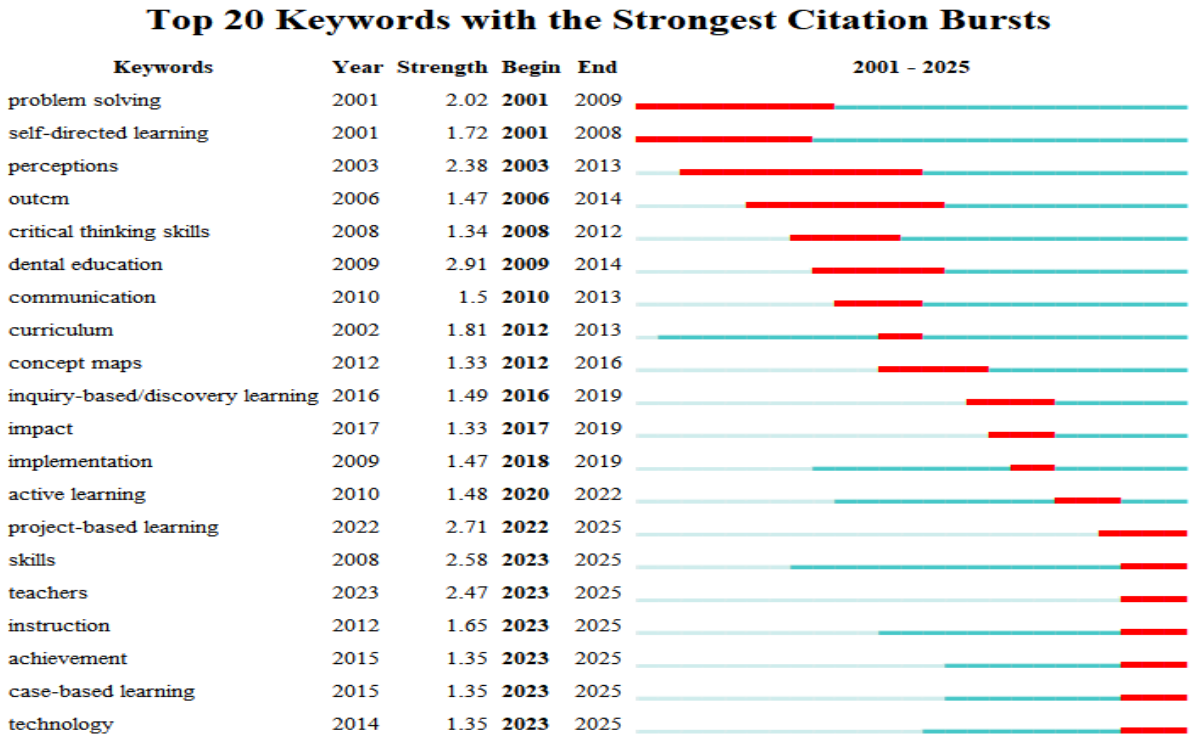

Figure 9: Keyword Burst Map

DISCUSSION

In summary, research on problem-based learning (PBL) and critical thinking in higher education demonstrates a clear trajectory of rapid growth and increasing academic influence. While China and several Asian countries show strong publication output and emerging leadership in this field, this pattern reflects not only regional research capacity but also the growing prioritization of student-centered pedagogies within these educational systems. From a theoretical perspective, this regional concentration suggests that PBL is being actively contextualized within diverse cultural and institutional settings, contributing to the localization and adaptation of constructivist learning theories in non-Western contexts.

However, the fragmented nature of author collaboration networks reveals a critical structural limitation in current research development. The lack of strong inter-institutional and interdisciplinary collaboration may hinder the integration of diverse theoretical perspectives and methodological approaches. From the standpoint of knowledge production, this fragmentation constrains cumulative research progress and limits the potential for large-scale, high-impact studies. Therefore, strengthening collaborative mechanisms—particularly international and cross-disciplinary partnerships—will be essential for advancing both theoretical refinement and empirical robustness in this field.

Another important implication lies in the disciplinary distribution of existing studies. The dominance of PBL research in medicine, nursing, and education reflects its established effectiveness in practice-oriented disciplines. However, this concentration also indicates a gap in the application of PBL in other academic domains, such as engineering, social sciences, and interdisciplinary programs. Expanding PBL into these areas would not only test its generalizability but also enrich its theoretical foundations by integrating discipline-specific epistemologies and problem contexts.

The identification of three major research hotspots—(1) instructional models and skill development, (2) disciplinary context applications, and (3) teaching implementation supported by technology—further reflects an important shift in the field. Specifically, research has evolved from a primary focus on measuring instructional effectiveness to a deeper exploration of underlying mechanisms. This transition aligns with broader developments in educational theory, particularly the move toward understanding how learning environments, cognitive scaffolding, and social interaction jointly contribute to higher-order thinking. The increasing emphasis on collaborative learning and technological integration highlights the convergence of PBL with digital pedagogy and blended learning environments, suggesting a more systemic and design-oriented approach to teaching.

Moreover, the temporal evolution revealed through keyword burst analysis provides additional insight into the developmental stages of this research area. Early studies primarily emphasized foundational skills, while subsequent research focused on instructional strategies and methods. More recent work has shifted toward practical implementation and the holistic development of critical thinking. This progression indicates a maturation of the field, moving from exploratory inquiry toward evidence-based optimization of teaching practices. Importantly, the growing attention to the role of instructors and technological tools underscores the need for pedagogical adaptability and instructional design competence in higher education.

From a practical perspective, these findings suggest that educators and institutions should move beyond isolated implementation of PBL and adopt a more integrated approach that combines collaborative learning structures, discipline-specific problem design, and technological support. Teacher training programs should also emphasize not only the use of PBL but also the underlying principles of cognitive scaffolding and student engagement. Additionally, institutional policies should encourage cross-departmental collaboration to facilitate interdisciplinary applications of PBL.

Despite these contributions, this study has several limitations that should be acknowledged. First, the analysis is based on a single database, which may introduce database selection bias and limit the comprehensiveness of the findings. Although the selected database provides high-quality and widely recognized publications, it may not fully capture relevant studies indexed in other databases. Future research is therefore encouraged to replicate this study using databases such as Scopus or to adopt a multi-database approach (e.g., combining Scopus and Google Scholar) to enhance data coverage and improve the reliability and generalizability of the results. Second, bibliometric analysis, while effective in identifying trends and patterns, cannot fully capture the depth of pedagogical practices or contextual nuances of PBL implementation. Future studies could integrate qualitative or mixed-method approaches to provide a more comprehensive understanding of how PBL influences critical thinking in different educational settings.

Looking ahead, with the continued advancement of digital technologies and the widespread adoption of blended learning, research on PBL is expected to further expand in scope and depth. Future studies should prioritize interdisciplinary integration, innovative instructional design, and stronger collaborative networks. By doing so, the field can move toward a more holistic framework that not only advances theoretical understanding but also supports effective and scalable educational practices for fostering critical thinking in higher education.

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Ethical Approval

Not applicable.

Conflict Of Interest

The authors declare that there is no conflict of interest.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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