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Understanding the Research Evolution, Knowledge Structure, and Trends of Augmented Reality–Supported Problem-Based Learning: A Bibliometric Perspective

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Abstract

This study systematically maps the intellectual structure, developmental trajectory, and emerging directions of Augmented Reality–Supported Problem-Based Learning (AR–PBL) research. Guided by five research questions, it examines publication growth patterns, identifies influential authors, institutions, and journals, uncovers major thematic clusters, analyzes keyword interconnections, and detects emerging research fronts. A bibliometric and network analysis was conducted on Scopus-indexed publications from 2015 to 2025, integrating PRISMA-based screening with Biblioshiny and VOSviewer visualization techniques. The results indicate a steady increase in AR–PBL publications over the past decade, reflecting expanding scholarly attention. Influential contributions are concentrated among a limited group of authors and institutions, while several core journals serve as primary outlets. Co-citation and conceptual structure analyses reveal dominant thematic clusters centered on pedagogical design, augmented reality applications, learner engagement, and system implementation. Keyword co-occurrence patterns demonstrate strong interconnections between AR technology and PBL pedagogy, yet limited integration with advanced computational approaches. Emerging theme analysis shows that areas such as learning analytics, artificial intelligence, and adaptive instructional systems remain underexplored. Overall, AR–PBL has evolved into a multi-clustered but unevenly integrated research domain, highlighting the need for stronger theoretical coherence, system-level integration, and pedagogical innovation in future studies.

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INTRODUCTION

The rapid adoption of immersive digital technologies in formal education has highlighted a persistent gap between technological innovation and the establishment of strong pedagogical and theoretical frameworks (Bizami et al., 2023; Mamanazarov et al., 2025; Wang et al., 2024; Zou et al., 2025). Although schools and universities increasingly implement sophisticated digital tools, the ways in which these technologies effectively enhance learning processes remain underexplored (Alenezi, 2023; Matthew et al., 2018; Mhlongo et al., 2023; Timotheou et al., 2023). Augmented reality (AR), for instance, has emerged as a prominent interactive technology that overlays virtual content onto real-world

environments, supporting contextualized and experiential learning (Coştu, 2025; Nair et al., 2024; Rehman et al., 2024; Scavarelli et al., 2021). Nevertheless, research in the learning sciences consistently indicates that technology itself does not guarantee improved learning outcomes. Evidence from Smith et al. (2021) and Zenios (2020) emphasizes that instructional design, guidance, and cognitive scaffolding are the primary drivers of learning effectiveness in technology-enhanced settings. This gap between technological deployment and pedagogical insight presents a major challenge for the development and assessment of effective educational technology systems.

Building on this challenge, problem-based learning (PBL) has been widely acknowledged as a pedagogical approach that naturally complements AR-enhanced learning environments (Arici & Yilmaz, 2023). Grounded in constructivist and situated learning theories, PBL engages learners with authentic, complex, and ill-structured problems, fostering collaborative inquiry and iterative construction of knowledge (Wu et al., 2025). Research by Bae et al. (2021) and Hendrayana & Mutaqin (2025) further demonstrates that PBL can enhance deep conceptual understanding and transferable problem-solving skills when learners are provided with sufficient cognitive and social scaffolding. Within this framework, AR–PBL can be conceptualized as a technology-mediated learning system, where augmented reality functions as a digital interface that organizes information, supports visualization, and facilitates interaction throughout the PBL process (Kanbur & Arcagök, 2024). By integrating AR into the PBL framework, educational technology can more effectively align with pedagogical objectives, bridging the gap between technological innovation and meaningful learning outcomes.

Despite its strong theoretical compatibility, empirical research on AR–PBL demonstrates differentiated patterns of emphasis, both in reported learning outcomes and in how AR is conceptually positioned within the PBL framework. For example, Arici & Yilmaz (2023) highlight the positive influence of AR-enhanced PBL on learners' affective dimensions, particularly motivation and engagement. In contrast, Gibran & Setyasto (2025) observe that AR is frequently framed as a general technological enhancement, with limited differentiation of how specific affordances correspond to distinct phases of the PBL process, such as problem representation, hypothesis generation, or solution evaluation.

Collectively, these strands of research suggest that the AR–PBL literature encompasses diverse focal points, ranging from outcome-oriented investigations to system-level and design-oriented discussions. However, the absence of a clearly articulated integrative perspective makes it difficult to discern how these thematic orientations relate to one another within a coherent knowledge structure. From an information systems standpoint, this limited functional differentiation constrains a deeper understanding of how AR–PBL research has developed and how its conceptual foundations have evolved over time.

In the broader field of educational technology, research generally follows a discernible developmental path. According to bibliometric evidence from Jing et al., (2024), initial studies often focus on system feasibility and technological potential, while later investigations increasingly emphasize pedagogical alignment and theoretical grounding. It remains uncertain whether AR–PBL research has moved beyond these exploratory and implementation-focused stages. Existing reviews are mostly narrative in nature or limited in scope, providing only partial insight into the evolution of research themes, system-level considerations, and theoretical orientations over time.

This gap becomes especially evident when compared with broader trends in PBL research. Recent work by Ouyang et al. (2023) highlights that advanced digital approaches, such as learning analytics, artificial intelligence, and adaptive scaffolding, are beginning to influence contemporary PBL scholarship. However, these computationally oriented perspectives have yet to be fully incorporated into AR–PBL studies. Without a systematic,

data-driven analysis of publication patterns, thematic developments, and intellectual connections, it is difficult to assess whether AR–PBL is advancing toward greater theoretical and technological sophistication or remaining largely descriptive.

To address these gaps, the present study situates AR–PBL within a pedagogically informed and system-oriented framework rather than treating it as a purely technology-driven phenomenon. Using systematic bibliometric and network analysis, this research maps AR–PBL publications from 2015 to 2025, illustrating the relationships between technological systems, pedagogical models, and research themes. The findings contribute to a deeper conceptual understanding of AR–PBL as an educational technology system and provide empirical guidance for future investigations, particularly regarding system design, instructional alignment, and the integration of advanced digital tools.

This study aims to systematically examine the development, thematic organization, and intellectual structure of research on AR–PBL. By employing bibliometric and network analysis, the research seeks to identify publication patterns, leading contributors, prominent and emerging themes, and temporal changes in research emphasis. The study is guided by the following research questions:

RQ1. How have publication patterns in AR–PBL research changed over time?
RQ2. Who are the most influential authors, institutions, and journals shaping AR–PBL scholarship?
RQ3. What major thematic clusters emerge from the co-citation and conceptual structure of AR–PBL research?
RQ4. How do keyword co-occurrence patterns reveal the interconnections among core research topics?
RQ5. What emerging and underexplored themes indicate potential directions for pedagogical innovation and instructional design in AR–PBL?

METHODS

Research Design

This study adopted a bibliometric research approach with a science mapping orientation to examine the intellectual structure, thematic development, and geographic distribution of AR–PBL scholarship. The research framework integrates performance analysis and conceptual structure analysis, enabling a detailed understanding of both quantitative publication patterns and the organization of knowledge within the field. Performance analysis focused on general publication characteristics, such as annual research output and distribution of contributions across authors, institutions, journals, and countries, as well as broader trends in scholarly production.

In parallel, the conceptual structure of the field was investigated using science mapping techniques, with particular attention to keyword co-occurrence networks. This method analyzes how specific keywords appear together across multiple publications, providing insight into the thematic relationships and intellectual linkages among research topics. By mapping co-occurring keywords, the study identifies clusters of related concepts, highlighting dominant research areas, emerging themes, and underexplored topics. Keywords that frequently appear together are considered conceptually connected, reflecting shared focus, methodological approaches, or theoretical frameworks. The resulting co-occurrence networks offer a visual and quantitative representation of the field's thematic structure, showing how ideas are interconnected and how research priorities have evolved over time. This approach allows the detection of both core topics and peripheral or interdisciplinary themes, providing a systematic basis for understanding the intellectual landscape of AR–PBL research.

To implement this design, complementary bibliometric tools were employed to support both performance-based and conceptual analyses. Together, these complementary tools provided a coherent framework for capturing the structural characteristics, thematic organization, and developmental trends of AR–PBL research, without conflating the research design with data collection or dataset construction.

Data Sources and Search Strategy

The bibliographic records for this study were retrieved exclusively from the Scopus database, chosen for its comprehensive coverage of peer-reviewed journals, multidisciplinary scope, and compatibility with bibliometric and systematic literature mapping. The search focused on publications issued between 2016 and 2024 to capture the contemporary development of AR–PBL research. A structured search strategy was applied using Boolean operators and field-specific constraints, limited to the TITLE-ABS-KEY fields to ensure that only studies explicitly addressing augmented reality within problem-based learning were included. The exact search query was TITLE-ABS-KEY (augmented AND reality AND problem AND based AND learning) AND PUBYEAR > 2015 AND PUBYEAR < 2025 AND (LIMIT-TO(SUBJAREA,"SOCI")) AND (LIMIT-TO(DOCTYPE,"ar")) AND (LIMIT-TO(LANGUAGE, “English")). To ensure a focused and high-quality dataset, the study included only peer-reviewed journal articles in English that directly examined augmented reality applications in problem-based learning, including both empirical and conceptual studies relevant to AR–PBL. Studies were excluded if they were conference proceedings, book chapters, review articles, editorials, letters, or other non-article document types; if they did not focus specifically on augmented reality or problem-based learning; if they fell outside the social sciences domain; or if they lacked sufficient methodological detail to establish relevance.

Study Selection Process and Data Analysis

To maintain clarity and ensure methodological rigor in constructing the bibliographic dataset, the study employed a systematic, multi-step screening process in accordance with the PRISMA framework. This procedure involved sequential stages of identifying potential records, screening for relevance, assessing eligibility, and determining final inclusion, with the overall workflow illustrated in the PRISMA flow diagram shown in Figure 1.

The initial search conducted in the Scopus database yielded 1,610 records. As shown in Figure 1, duplicate entries and clearly irrelevant publications were removed during the preliminary screening stage. The remaining records were then subjected to title and abstract screening to assess their relevance to the scope of AR–PBL. Subsequently, full-text assessments were performed to verify the conceptual alignment of the studies with the objectives of this review. Following this stepwise filtering process, 134 articles were retained as the final dataset for bibliometric analysis, as indicated in Figure 1. This systematic procedure ensured that only studies explicitly addressing the integration of augmented reality within problem-based learning contexts were included, thereby strengthening the focus and validity of the dataset.

After the final dataset was established, all bibliographic metadata were exported in BibTeX and RIS formats for further analysis. Two bibliometric tools with distinct functions were employed: VOSviewer (version 1.6.20) was used exclusively for science mapping, including the visualization of international collaboration networks and the conceptual structure of the field through keyword co-occurrence analysis, while Biblioshiny (version 4.1) was applied for performance-based and descriptive analyses, covering publication trends, contributions across countries, institutions, authors, and journals, as well as thematic development patterns. The data were retrieved on January 3, 2026, and the minimum

keyword occurrence threshold was set at 5. The combined use of these tools enabled a comprehensive, systematic mapping of the AR–PBL research landscape, knowledge structure, and developmental trends.

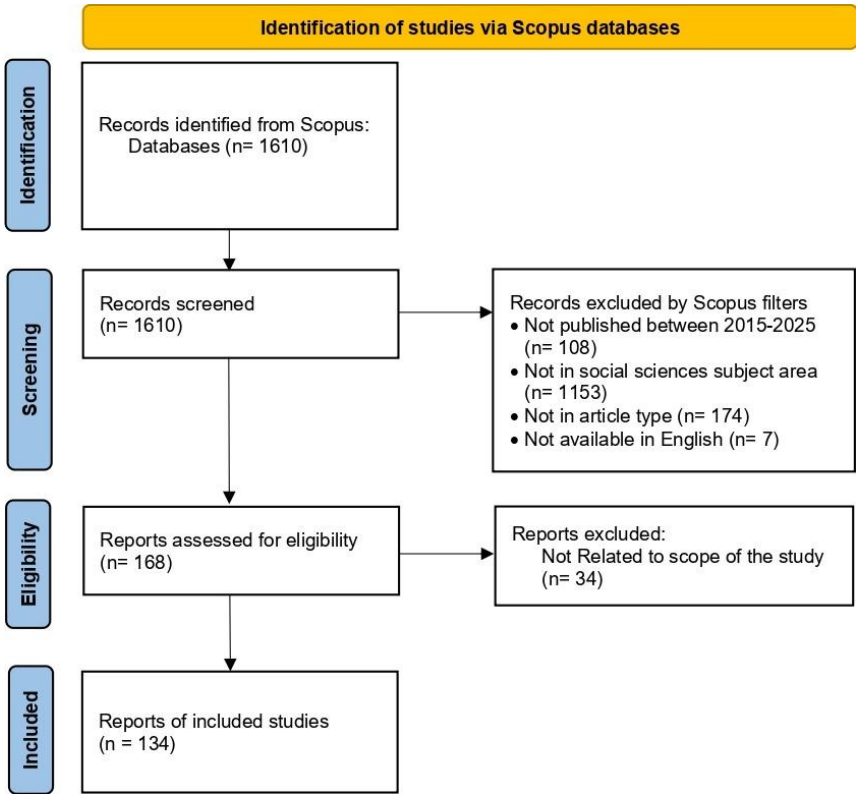

Figure 1 Prisma flow diagram

RESULTS AND DISCUSSION

Overview of the Included Studies (2015–2025)

To provide a clear overview of the scope and development of research on augmented reality–supported problem-based learning (AR–PBL), this section summarizes publication trends and key descriptive statistics of the final dataset, addressing RQ1 by showing how scholarly output has evolved over time. This overview aims to highlight both the temporal progression of publications and the structural characteristics of the AR–PBL literature produced between 2015 and 2025. Figure 2 depicts the annual number of publications over the past decade, providing a visual representation of the field's development. This illustration facilitates the identification of shifts in research attention, the emergence of growth phases, and evolving patterns of scholarly interest within AR–PBL.

As shown in Figure 2, scholarly research on AR–PBL was relatively limited in the early years from 2015 to 2018, with fewer than five publications per year, reflecting the initial exploratory stage of integrating augmented reality within problem-based learning. Beginning in 2019, a gradual increase in output was observed, which accelerated sharply from 2020 onwards, with the number of publications more than doubling compared to the preceding period. The most substantial growth occurred between 2022 and 2024, with annual outputs reaching 19, 25, and 22 articles, respectively, and this heightened level of research activity continued into 2025. This surge in publications can be interpreted as part of a broader trend in educational research, driven not only by technological advancements

but also by the post-pandemic shift toward digital transformation in education, which has amplified the demand for innovative, immersive, and flexible learning environments. The increased adoption of remote, hybrid, and technology-mediated instruction during and after the COVID-19 pandemic likely stimulated scholarly interest in exploring how AR can enhance student engagement, contextual learning, and problem-solving skills in PBL settings (Butarbutar, 2025; Garmpis et al., 2026; Zhou, 2025).

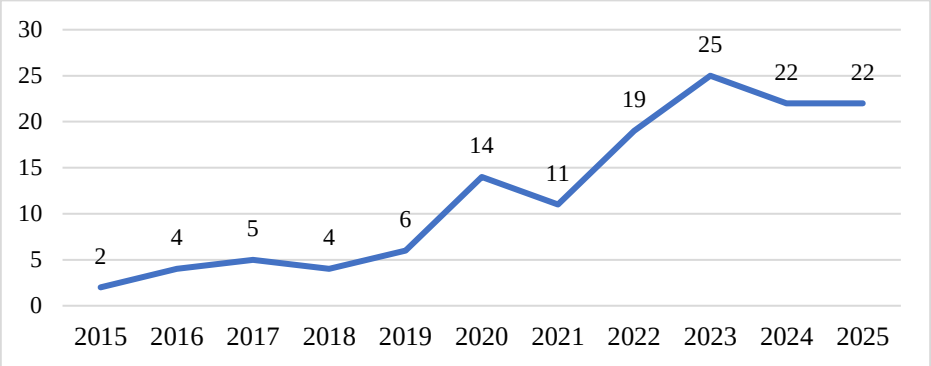

Figure 2 Number of relevant publications per year

Beyond analyzing temporal trends, it is equally important to examine the structural characteristics of the dataset, including the scale, patterns of collaboration among authors and institutions, and the distribution of research outputs across countries, to gain a comprehensive understanding of the current AR–PBL research landscape. To this end, Table 1 summarizes the key descriptive features of the included publications, providing a foundation for interpreting both the growth trajectory and collaborative dynamics of the field.

Table 1 Main information of publications

Description	Results
Timespan	2015:2025
Sources	84
Documents	134
Annual Growth Rate %	3.75
Document Average Age	3.99
Average citations per doc	28.33
References	1155
Keywords Plus (ID)	354
Author's Keywords (DE)	412
Authors	455
Authors of single-authored docs	16
Single-authored docs	16
Co-Authors per Doc	3.67
International co-authorships %	21.64

Regarding authorship and collaboration patterns, the dataset includes 455 contributors, with only 16 papers authored by a single researcher, yielding an average of 3.67 authors per publication. This indicates that AR–PBL research is largely collaborative, frequently involving interdisciplinary teams that integrate expertise from educational theory, digital technologies, and relevant subject-matter areas. The share of publications featuring international co-authorships, at 21.64%, points to a moderate but growing level of cross-border collaboration, suggesting increasing global engagement with the field. Collectively,

these patterns demonstrate that AR–PBL has evolved into a collaborative and visible research domain, characterized by multi-author, multi-institutional efforts that reinforce its academic credibility and the interdisciplinary nature of its scholarship.

Most Prolific Contributors

To explore the global landscape of AR–PBL research, this subsection analyzes the geographic distribution of publications and patterns of international contribution. Examining the most productive countries in terms of publication volume, citation influence, and collaborative activity helps to identify the leading centers of research and the structure of knowledge production worldwide. These findings address RQ2 by highlighting which countries play a central role in advancing AR–PBL scholarship. Table 2 presents the top ten countries ranked by total publication output, alongside metrics of collaboration, including single-country publications (SCP), multi-country publications (MCP), and citation impact indicators.

Table 2 Most prolific countries

Rank	Country	Total Publications		SCP		MCP		Total Citations	C/Y
		N	%	N	%	N	%		
1	China	22	16.4	16	72.7	6	27.3	694	31.50
2	Indonesia	19	14.2	18	94.7	1	5.3	125	6.60
3	USA	8	6	7	87.5	1	12.5	179	22.40
4	India	7	5.2	7	100	0	0	322	46.00
5	Malaysia	6	4.5	4	66.7	2	33.3	115	19.20
6	Turkey	6	4.5	6	100	0	0	505	84.20
7	Thailand	5	3.7	3	60	2	40	54	10.80
8	UK	5	3.7	5	100	0	0	197	39.40
9	Germany	4	3	2	50	2	50	65	16.20
10	Spain	4	3	3	75	1	25	286	71.50

As presented in Table 2, China leads in AR–PBL research with 22 publications, representing 16.4% of the total dataset, followed by Indonesia with 19 publications (14.2%) and the United States with 8 publications (6%). Despite China and Indonesia ranking highest in publication volume, their patterns of collaboration differ markedly: Indonesia demonstrates a very high share of single-country publications (94.7%), indicating a predominantly domestic research focus, while China engages in a comparatively higher level of international collaboration (27.3% MCP). In terms of scholarly influence, countries such as Turkey, Spain, and India stand out with notably high average citations per year, particularly Turkey (84.20) and Spain (71.50), suggesting that even countries with fewer publications can produce highly impactful work within the AR–PBL field. Beyond overall productivity, it is also valuable to consider temporal trends in country-level contributions. Figure 3 therefore depicts the publication trajectories of the top contributing countries from 2015 to 2025, highlighting how research activity has evolved over the past decade.

Figure 3 illustrates that China has consistently maintained a leading position in AR–PBL research, with publication output increasing sharply, particularly after 2020, reflecting sustained scholarly activity in this area. Indonesia shows a similarly pronounced growth trend beginning around 2019, emerging as the second-most productive contributor in recent years. The United States demonstrates steady but more moderate growth, while India and Turkey show gradual yet consistent increases over time. These differing growth trajectories suggest that the expansion of AR–PBL scholarship is concentrated among certain countries represented in the Scopus-indexed, English-language social sciences literature, with China and Indonesia showing particularly strong activity. Other countries contribute more selectively but often produce publications with notable citation impact. Overall, this

temporal analysis indicates that the field is expanding globally within the scope of the dataset, with publication patterns shaped by variations in research capacity, national priorities, and disciplinary focus.

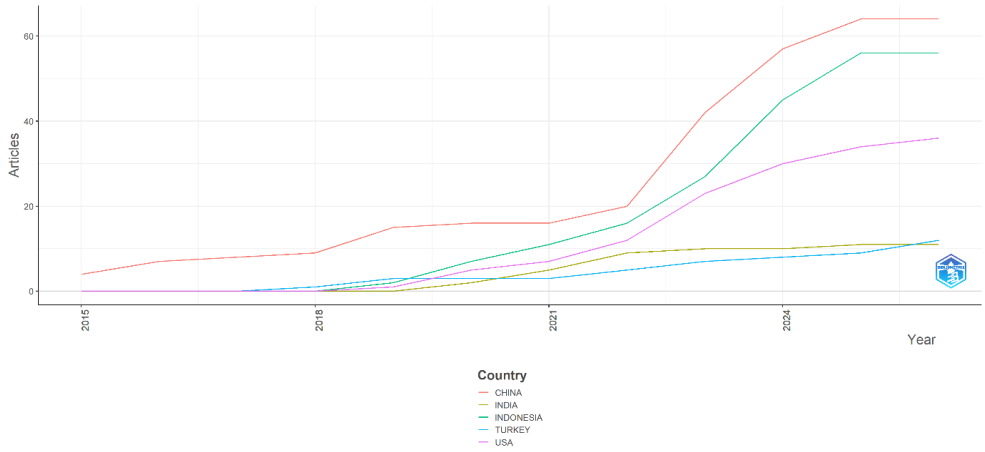

Figure 3 Production growth of the top 10 countries

In addition to national-level output, analyzing patterns of international collaboration offers a clearer view of how AR–PBL knowledge is produced across different countries. To examine these cross-border research connections, a network of transnational cooperation involving 28 countries was constructed and visualized using VOSviewer, as shown in Figure 4.

Figure 4 Transnational cooperation network of 28 partner countries

Figure 4 illustrates a collaboration network organized around several principal hubs, with China, Indonesia, and the United States serving as central nodes connecting multiple regional clusters. China holds a prominent position, maintaining notable collaborative links with countries including Indonesia, Taiwan, Pakistan, and Portugal, highlighting its role as a key international partner in AR–PBL research. Indonesia also demonstrates strong connections, particularly with the United States and Taiwan, reflecting its growing participation in global research networks. European nations such as the United Kingdom, Switzerland, and Germany form a separate, closely connected cluster, suggesting a regionally concentrated but still internationally engaged pattern of collaboration. Overall, the network indicates that while a small number of countries dominate AR–PBL research, cross-national collaboration is gradually increasing, fostering a more interconnected global research community rather than isolated national efforts.

Following the identification of productive countries and their collaboration patterns, the analysis next examines the institutional level to determine which organizations have been most active in contributing to AR–PBL scholarship, with the leading affiliations summarized in Table 3.

Table 3 Most prolific affiliation

Rank	Affiliation	Country	Number of Publications
1	Chitkara University	India	6
2	Universitas Sebelas Maret	Indonesia	5
3	University of Nottingham Ningbo China	China	4
4	Central China Normal University	China	3
5	National Taichung University of Education	Taiwan	3
6	South China Normal University	China	3
7	Universitas Negeri Semarang	Indonesia	3
8	University of East Anglia	UK	3
9	Ajou University	South Korea	2
10	Arizona State University	USA	2

Following the top institutions, Universitas Sebelas Maret (Indonesia) contributed five publications, and the University of Nottingham Ningbo China produced four. Other Chinese universities, including Central China Normal University and South China Normal University, also rank among the leading contributors, highlighting China's robust institutional presence in AR–PBL research. The involvement of universities from various regions, such as the United Kingdom, South Korea, Taiwan, and the United States, demonstrates that AR–PBL scholarship is supported by a geographically diverse network of institutions rather than being concentrated within a single national or academic system. Nevertheless, the relatively modest number of publications per institution suggests that research activity is still broadly distributed, reflecting a field that is developing and expanding rather than being dominated by a few major organizations.

Beyond institutional contributions, identifying the most active individual researchers provides insight into the key intellectual drivers of the field. Table 4 presents the authors with the highest publication counts along with their corresponding citation impact metrics.

Table 4 Authors with the highest number of publications

Rank	Author	Country	Number of Publications	Total Citations	Cit./Year
1	Mantri, A.	India	5	271	12.1
2	Singh, G.	India	4	213	12.2
3	Wang, Y.	Singapore	4	496	16.2
4	Elford, D.	UK	3	109	8.4
5	Jones, G. A.	UK	3	109	8.4
6	Lancaster, S. J.	UK	3	109	8.4
7	Abildinova, G.	Kazakhstan	2	21	3.8
8	Buchner, J.	Germany	2	93	15.3
9	Cai, S.	China	2	18	6
10	Chen, C.-H.	Taiwan	2	217	13.9

According to Table 4, Mantri from India emerges as the most prolific author with five publications, followed by Singh (India) and Wang (Singapore), each with four contributions. However, publication volume does not necessarily equate to influence: Wang demonstrates a particularly high total citation count (496) and a strong yearly citation rate, highlighting substantial scholarly impact despite having fewer publications than some peers. Several researchers from the United Kingdom also appear with three publications each and similar citation patterns, suggesting collaborative efforts within the same research networks. Collectively, these findings indicate that AR–PBL scholarship is primarily driven by a small core of recurring contributors, while still leaving room for authors with fewer publications to exert significant influence through strategically impactful work.

To further explore the platforms where AR–PBL research is concentrated, the analysis next considers the most productive journals and publication outlets, summarized in Table 5.

Table 5 Sources with the highest number of publications

Rank	Sources	Number of Publications	Total Citations	PY_start
1	International Journal of Information and Education Technology	7	9	2019
2	Computers and Education	5	755	2015
3	Education and Information Technologies	5	178	2020
4	Computer Applications in Engineering Education	4	182	2018
5	Journal of Chemical Education	4	161	2020
6	International Journal of Emerging Technologies in Learning	4	124	2018
7	Education Sciences	4	121	2018
8	Computers and Education: X Reality	4	43	2023
9	Interactive Learning Environments	3	175	2019
10	Frontiers in Education	3	23	2023

Table 5 shows that the International Journal of Information and Education Technology leads in terms of publication count within AR–PBL research, although its overall citation impact is relatively moderate. Conversely, Computers and Education demonstrates a notably high citation total (755 citations) despite publishing fewer articles, highlighting its position as a central, high-impact journal in the field. Other key outlets, including Education and Information Technologies, Computer Applications in Engineering Education, and the Journal of Chemical Education, reflect the interdisciplinary reach of AR–PBL research, bridging educational, technological, and applied science domains. Overall, these patterns indicate that AR–PBL scholarship is disseminated across a combination of specialized educational technology journals and broader, high-impact education journals, underscoring both the field's growing maturity and the ongoing diversification of its publication landscape.

Development and Focus of Research Trends

To investigate the thematic structure and intellectual organization of AR–PBL research, a keyword co-occurrence analysis was performed using VOSviewer. This approach helps uncover both the major thematic clusters and the relationships among core research topics. By examining which keywords frequently co-occur, the analysis addresses RQ3, identifying the principal thematic clusters that define the field, and RQ4, revealing the interconnections and conceptual linkages among these topics. The resulting network map, shown in Figure 5, visualizes the conceptual structure of the field: nodes represent keywords, links indicate co-occurrence relationships, and clusters group related concepts together. Together, these visualizations provide a comprehensive overview of how research themes are organized and interconnected within AR–PBL scholarship.

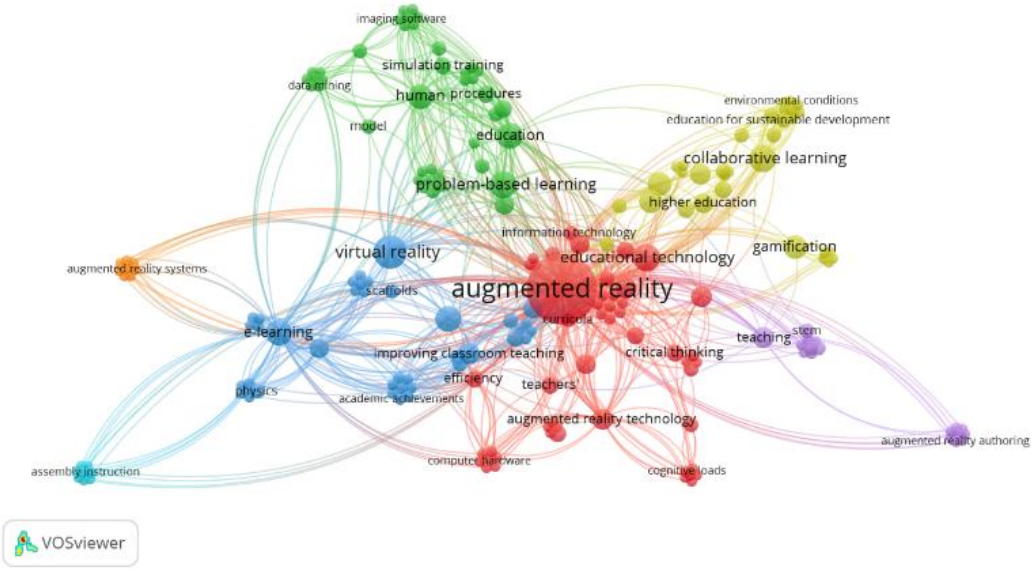

Figure 5 Network visualization for co-occurrence

Figure 5 illustrates that the co-occurrence network revolves around the central concept of augmented reality, which occupies a highly prominent and well-connected position within the field. In addition to this core structure, the visualization reveals several distinct yet interrelated clusters, each reflecting a specific thematic focus within the literature. For a more systematic interpretation of these clusters, Table 6 presents the results, detailing the number of items in each cluster alongside their representative keywords.

Table 6 Research topics on each cluster

Cluster	Number of Item	Representative Keywords
Red	50	augmented reality, educational technology, teaching, curriculum, critical thinking, teachers, cognitive load, learning efficiency
Green	40	problem-based learning, simulation training, human procedures, education, instructional model, data mining, learning process
Blue	39	virtual reality, e-learning, scaffolding, physics, academic achievement, improving classroom teaching, learning performance
Yellow	32	collaborative learning, higher education, gamification, education for sustainable development, environmental conditions
Purple	17	teaching STEM, augmented reality authoring, instructional design, technology integration
Arctic	8	assembly instruction, procedural learning, technical training
Orange	8	augmented reality systems, system development, applied AR technologies

According to Table 6, the red cluster represents the largest thematic grouping, indicating that research on educational technology, instructional strategies, and cognitive aspects of learning with augmented reality dominates the field. This prominence likely reflects the central role of pedagogical effectiveness and technology-mediated learning in AR–PBL scholarship, as researchers prioritize understanding how AR can enhance student engagement and learning outcomes. The green and blue clusters, which also occupy substantial portions of the dataset, highlight a sustained emphasis on problem-based and simulation-based learning, as well as the integration of immersive technologies such as virtual reality and e-learning platforms. This pattern suggests that scholars are increasingly

exploring the synergies between AR and other interactive learning environments to create richer, experiential learning opportunities.

The yellow cluster points to growing interest in collaborative, gamified, and sustainability-focused learning scenarios, likely driven by the increasing demand for educational approaches that promote teamwork, motivation, and real-world problem-solving skills. Meanwhile, the purple cluster underscores technical and discipline-specific concerns, particularly in STEM education and AR content development, reflecting the need for specialized tools and content to support effective implementation. Smaller clusters, such as the Arctic and Orange groups, capture niche, application-oriented, and technical topics, indicating that researchers are beginning to explore less conventional areas and innovative uses of AR–PBL.

Overall, these findings suggest that AR–PBL research has evolved into a thematically diverse and multifaceted domain. Well-established streams in pedagogy, technology integration, and learning outcomes continue to anchor the field, while the emergence of specialized, application-focused clusters signals ongoing diversification and experimentation. To further understand these dynamics, an overlay visualization of keyword co-occurrence was created (Figure 6), showing the average publication year for each keyword. This temporal perspective reveals not only the foundational topics that have shaped the field but also emerging areas gaining attention, reflecting shifts in research priorities and the evolving challenges and opportunities in AR–PBL scholarship.

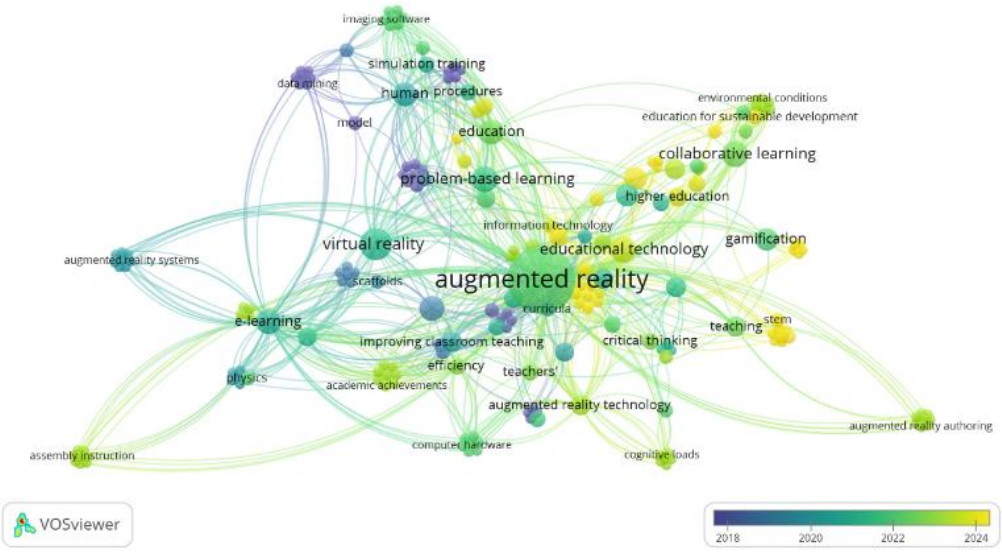

Figure 6 Overlay visualization for co-occurrence

Figure 6 illustrates the temporal evolution of research focus in AR–PBL. Keywords appearing in darker blue and green tones represent earlier studies, which predominantly addressed foundational technological and instructional aspects, such as virtual reality, e-learning, physics education, scaffolding strategies, and basic measures of instructional effectiveness. In contrast, more recent keywords, indicated by lighter green to yellow shades, highlight emerging pedagogical and cognitive concerns, including collaborative learning, higher education, gamification, STEM teaching, critical thinking, cognitive load management, and education for sustainable development. This progression reflects a shift in the field from primarily technology-centered investigations toward a greater emphasis on instructional design, learning processes, and educational outcomes. Augmented reality

consistently maintains a central position throughout the timeline, reinforcing its role as the conceptual anchor of the field. Collectively, the temporal analysis in Figure 6 demonstrates that AR–PBL research has matured, moving from exploratory technological studies toward a more pedagogically informed and instruction-focused agenda.

To complement this temporal perspective and better distinguish central from peripheral research themes, a density visualization was produced, as presented in Figure 7. This map depicts the intensity of keyword co-occurrence, with brighter and warmer regions signaling topics that have received the greatest attention and represent the most concentrated areas of scholarly investigation within AR–PBL.

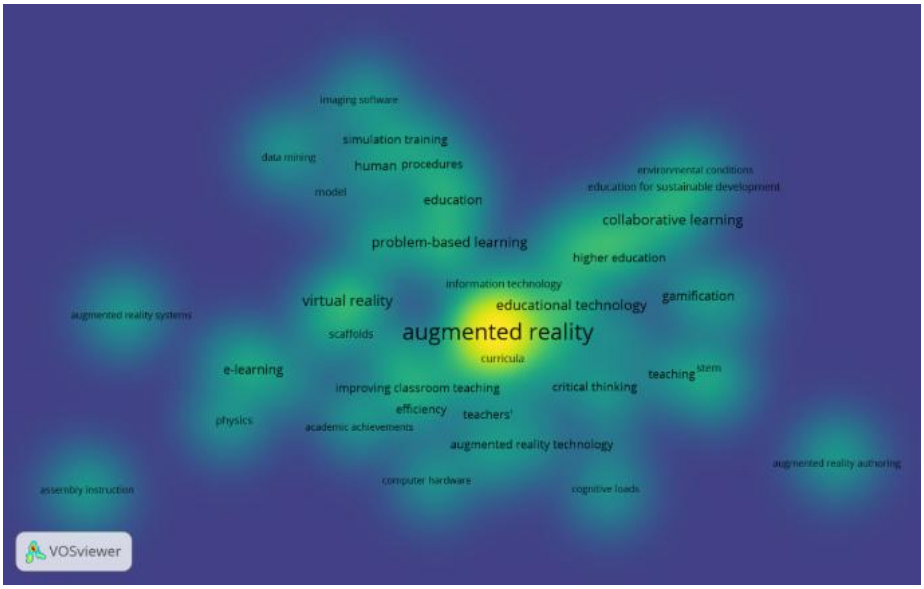

Figure 7 Density visualization for co-occurrence

Figure 7 illustrates that augmented reality occupies the most central and highest-density position within the keyword co-occurrence map, highlighting its role as the dominant and most frequently addressed concept in AR–PBL research. Surrounding this central node are other densely clustered topics, including educational technology, problem-based learning, virtual reality, e-learning, curriculum design, teaching practices, and critical thinking, which together form the main intellectual core of the field. In contrast, keywords related to more specialized or emerging areas such as augmented reality authoring tools, assembly instruction, computer hardware, and cognitive load are positioned in lower-density, peripheral regions, suggesting these themes are currently less explored or represent niche strands of research. Collectively, the density visualization demonstrates that AR–PBL scholarship is anchored around a strong core of pedagogical and technological themes while simultaneously expanding into more focused, application-oriented, and specialized topics.

To complement the structural and density-based analyses, it is also crucial to investigate how individual research themes have shifted and gained prominence over time. Accordingly, a trend topic analysis was performed using authors' keywords to capture the longitudinal evolution of thematic emphases within the AR–PBL literature. The findings of this analysis are presented in Figure 8, which visualizes the temporal trajectories and relative frequency of key topics, offering insight into the dynamic development of research priorities across the study period.

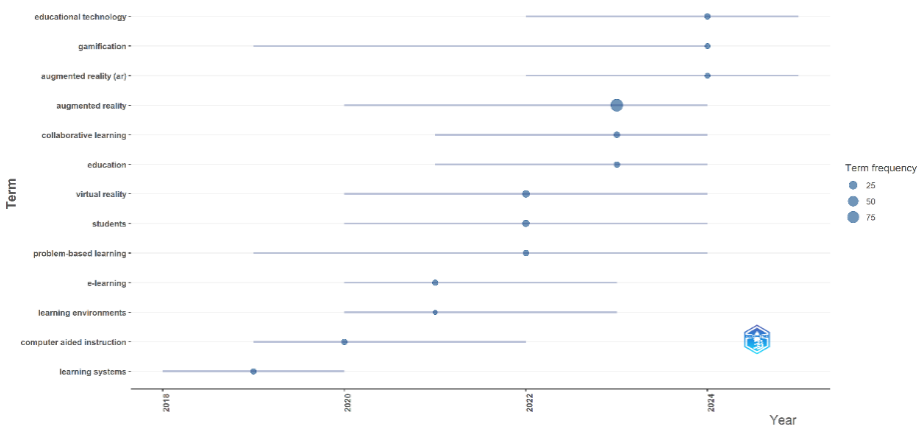

Figure 8 The trend topics of the publication collection on authors' keywords

Figure 8 highlights a clear evolution of research themes in AR–PBL over time. In the early phase (2018–2020), studies primarily concentrated on technological and system-oriented aspects, including learning management systems, computer-assisted instruction, and educational learning environments. This pattern suggests an initial focus on testing the feasibility and infrastructure of augmented reality applications in educational settings. During the middle phase (2020–2022), the focus shifted toward integrating AR into pedagogical practices, with increased attention to e-learning, problem-based learning, student engagement, and virtual reality. This change reflects efforts to align AR technologies with established instructional models and learner-centered teaching approaches. In the most recent period (2022–2024), research trends emphasize pedagogical depth and learning outcomes, with keywords such as collaborative learning, gamification, educational technology, critical thinking, and augmented reality gaining prominence. This indicates that the field is maturing toward enhancing instructional design, promoting cognitive engagement, and supporting meaningful learning experiences. Overall, the trend analysis demonstrates a clear longitudinal progression from early technology-centered studies to a more instructional and educationally focused research agenda, reinforcing the multi-dimensional development of AR–PBL identified in previous analyses.

To further examine the positioning of research themes in terms of their conceptual significance and developmental maturity, a thematic map analysis was performed. This approach categorizes themes based on centrality, reflecting their importance within the field, and density, indicating the degree of thematic development. Through this classification, the analysis identifies motor themes, basic themes, niche areas, and emerging or declining topics. The resulting thematic structure is illustrated in Figure 9, providing insight into the strategic and developmental landscape of AR–PBL research.

Figure 9 illustrates that the motor themes quadrant is primarily occupied by topics such as problem-based learning, virtual reality, and education, indicating that these areas are both highly developed and central to the AR–PBL research landscape. Closely associated concepts, including students, e-learning, and learning systems, also hold prominent positions, highlighting their ongoing significance in guiding research directions and informing instructional practices. In contrast, the basic themes quadrant encompasses augmented reality, educational technology, teaching, and interactive learning. These topics are foundational and highly relevant, yet they are still evolving and mainly serve as supportive elements for more specialized research streams rather than forming dense, core thematic clusters themselves.

Figure 9 Thematic map

The niche themes quadrant features subjects such as computer-based learning, collaborative or cooperative learning, and first-year undergraduate education. These topics are well-developed but relatively specialized and occupy less central positions within the broader research network. Meanwhile, emerging or potentially declining themes, including surveys and primary education, are located in the lower centrality and lower density region, suggesting limited integration with the dominant research streams or a potential decrease in scholarly focus over time. Overall, the thematic map demonstrates that AR–PBL research is structured around strong pedagogical and technological core themes, underpinned by foundational concepts and supplemented by specialized niches. This arrangement reflects both the consolidation of key research areas and the presence of peripheral topics that could either grow into future research priorities or gradually lose prominence.

Agenda for Future Research Directions

Drawing from the identified thematic patterns, temporal developments, and the positioning of topics within AR–PBL research, it becomes essential to translate these insights into a systematic agenda for future inquiry, directly addressing RQ5. The integration of findings from network, overlay, density, and thematic map analyses highlights variations in thematic maturity, spanning well-established pedagogical cores to emerging, less-explored areas. Based on this, prospective research directions are organized into distinct streams that correspond to dominant, foundational, and peripheral themes observed in the literature. Each stream is further specified through focused research topics and translated into corresponding research questions, reflecting differences in conceptual significance and research priority. This structured framework, summarized in Table 7, provides a strategic roadmap for guiding future theoretical development, pedagogical innovation, and empirical investigation in AR–PBL studies.

Table 7 Future research questions

Research Stream	Focus	Future Research Questions
Deepening Pedagogical Use of AR–PBL	Alignment between AR affordances and PBL phases	• How can specific AR features be systematically aligned with distinct stages of problem-based learning? • At which stages of PBL does AR contribute most meaningfully to conceptual change?
	Pedagogical decision-making by instructors	How do teachers adapt pedagogical strategies when implementing AR–PBL in real classroom contexts?
Learning Processes and Cognitive Mechanisms	Cognitive load and knowledge construction	• How does cognitive load fluctuate during AR–PBL activities, and how does it relate to problem-solving performance? • What learning processes mediate the relationship between AR interaction and conceptual understanding?
Collaborative Dynamics in AR–PBL	Social interaction patterns	How does AR reshape collaboration patterns and peer interaction during problem-solving tasks?
	Role distribution in group problem solving	How do learner roles emerge and evolve in AR-supported collaborative problem-based learning?

To meaningfully interpret the current state of AR–PBL scholarship, it is essential to examine how the field has evolved over time and how its structural characteristics reflect broader patterns of educational technology development. In response to RQ1, the consistent rise in AR–PBL publications between 2015 and 2025 indicates growing academic interest and suggests that the field has moved beyond small-scale experimental efforts. The publication trend also points to a change in research focus. Early studies primarily explored how the technology functioned and how it could be applied in educational settings, whereas more recent research gives greater attention to instructional strategies and students' learning experiences within AR–PBL contexts. This development mirrors broader trends in educational technology research identified by Lawless & Pellegrino (2007), which show that new technologies are typically examined for technical feasibility before attention shifts to their instructional value. Similar patterns reported by Djeki et al. (2022) in e-learning research further support this interpretation. Taken together, these findings suggest that AR–PBL research is undergoing a gradual shift from technology validation toward pedagogically informed inquiry.

With respect to RQ2, the identification of influential authors, institutions, and journals reveals a relatively concentrated intellectual network. Such concentration contributes to theoretical consolidation and cumulative development, as recurring contributors help stabilize conceptual foundations. At the same time, limited dispersion across institutions and regions may constrain interdisciplinary expansion and theoretical diversity. The formation of identifiable scholarly hubs indicates that AR–PBL is becoming academically structured, yet it also highlights the importance of broader collaboration to enrich perspectives and methodological approaches.

In relation to RQ3, the co-citation and conceptual structure analyses show that AR–PBL scholarship is organized around dominant clusters centered on pedagogical design, learner engagement, augmented reality applications, and system implementation. This configuration supports the argument advanced by Hagos & Lemma (2026), who emphasize that the success of problem-based learning depends more on instructional design and cognitive scaffolding than on technological tools alone. The clustering pattern suggests that augmented reality is increasingly conceptualized as an instructional medium embedded

within PBL frameworks. This shift reflects a response to longstanding critiques of educational technology research that privilege tool adoption over meaningful learning processes.

The findings related to RQ4 provide further insight into the conceptual orientation of AR–PBL research. Keyword co-occurrence analysis shows strong connections between augmented reality and core PBL concepts such as collaboration, critical thinking, and problem solving. In contrast, links with more advanced computational themes, including learning analytics and artificial intelligence, are relatively weak, suggesting limited integration of these areas within the AR–PBL literature. When viewed alongside broader bibliometric analyses of problem-based learning, such as Hallinger (2023), which highlight increasing diversification and integration of PBL with related learning approaches, AR–PBL appears to remain more concentrated on reinforcing pedagogical alignment within its established framework. This pattern indicates that the field is currently focused on consolidating its instructional foundations rather than expanding into wider interdisciplinary or technologically advanced domains.

Finally, addressing RQ5, the identification of underexplored themes, including learning analytics, artificial intelligence, and adaptive instructional systems, highlights significant opportunities for future research. Akintayo et al., (2024) argued that educational technologies generate meaningful impact only when aligned with established learning theory. Consistent with this view, the limited presence of advanced computational themes in AR–PBL indicates that deeper theoretical grounding and system-level integration remain necessary. Future investigations should therefore incorporate longitudinal designs, contextual sensitivity, and integrative system frameworks to bridge pedagogical coherence with intelligent digital infrastructures.

Overall, these findings position AR–PBL as a maturing yet unevenly integrated domain situated at the intersection of educational technology and learning theory. Its primary contribution lies in clarifying how structured integration between augmented reality and problem-based learning can support authentic and contextually grounded learning experiences across diverse educational settings.

CONCLUSION

This study addressed the lack of a systematic understanding of the evolution, intellectual structure, and thematic development of AR–PBL research by conducting a comprehensive bibliometric and network analysis. In response to the research questions, the findings demonstrate a consistent increase in publication output over the past decade, indicating sustained growth and rising academic interest. The analysis also identifies a concentrated yet expanding network of influential authors, institutions, and journals that shape the direction of AR–PBL scholarship. Conceptual and co-citation mapping reveal several dominant thematic clusters centered on pedagogical design, learner engagement, augmented reality applications, and instructional implementation. Keyword co-occurrence analysis further confirms strong connections between AR and core PBL principles, while highlighting comparatively limited integration with advanced computational domains such as learning analytics and artificial intelligence.

Taken together, these findings suggest that although AR–PBL has evolved into a structured and multi-cluster research domain, its development remains uneven across thematic areas. The field has shifted from technology validation toward pedagogically informed inquiry, yet opportunities remain for deeper theoretical integration and system-level innovation. By clarifying publication trends, intellectual influences, conceptual clusters, and emerging themes, this study provides a coherent overview of the knowledge structure of AR–PBL and offers evidence-based directions for future research. For scholars,

this includes the need for theory-driven and longitudinal investigations; for instructional designers and practitioners, more deliberate alignment between AR affordances and PBL frameworks; and for institutions and policymakers, strategic support for collaborative and interdisciplinary research that advances both pedagogical coherence and technological sophistication.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, LAK and SN; methodology, LAK and SN; formal analysis, LAK; data curation, LAK; visualization, LAK; writing—original draft preparation, LAK; writing—review and editing, LAK and SN. All authors contributed to and approved the final manuscript.

AI DISCLOSURE STATEMENT

The author used QuillBot during the preparation of this work for grammar checking and language improvement purposes only. After using the tool/service, the author carefully reviewed and edited the content as needed and takes full responsibility for the final content of the publication.

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