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ARTIFICIAL INTELLIGENCE IN NURSING LEADERSHIP AND CLINICAL PRACTICE: A BIBLIOMETRIC ANALYSIS

Mohanam Ramalingam¹, Intan Idiana Hassan², Aldrin Abdullah³, Wan Muhamad Amir Wan Ahmad⁴, Edinur Hisham Atan⁵

¹Faculty of Nursing Science, School of Health Sciences, Universiti Sains Malaysia (USM), Health Campus, Kubang Kerian, Kelantan, Malaysia

 mohanam.ramalingam@student.usm.my

 <https://orcid.org/0009-0008-4542-468X>

² Faculty of Nursing Science, School of Health Sciences, Universiti Sains Malaysia (USM), Health Campus, Kubang Kerian, Kelantan, Malaysia

 intanidiana@usm.my

 <https://orcid.org/0000-0001-6907-8920>

³ School of Housing, Building and Planning, Universiti Sains Malaysia (USM), Main Campus, Penang, Malaysia

 aldrin@usm.my

 <https://orcid.org/0000-0003-3169-8141>

⁴ School of Dental Sciences, Universiti Sains Malaysia (USM), Health Campus, Kubang Kerian, Kelantan, Malaysia

 wmamir@usm.my

 <https://orcid.org/0000-0003-2366-3918>

⁵ School of Health Sciences, Universiti Sains Malaysia (USM), Health Campus, Kubang Kerian, Kelantan, Malaysia

 edinur@usm.my

 <https://orcid.org/0000-0002-3379-6063>

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Abstract:

Artificial intelligence (AI) is increasingly shaping healthcare systems, with growing implications for nursing leadership and clinical practice through enhanced decision-making, workforce management, education, and patient care delivery. Despite the rapid growth of AI-related research in nursing, the overall intellectual structure, research trends,

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and global collaboration patterns within this field remain insufficiently understood. This study aimed to systematically map and analyze the scientific landscape of artificial intelligence research related to nursing leadership and clinical practice using a bibliometric approach. A bibliometric analysis was conducted using data retrieved from Elsevier's Scopus database. Peer-reviewed journal articles published in English between 2006 and 2025 were included. A total of 932 records met the inclusion criteria. Descriptive publication trends and citation indicators were analyzed using Scopus Analyzer, while bibliographic data were cleaned and standardized using OpenRefine. Keyword co-occurrence and international co-authorship networks were visualized using VOSviewer to identify dominant research themes and collaboration patterns. The findings reveal a sustained and accelerated growth in publications, particularly after 2018, indicating increasing scholarly attention to AI applications in nursing contexts. The United States emerged as the leading contributor in terms of publication output and collaborative strength, followed by the United Kingdom, Australia, and several European and Asian countries. Keyword analysis identified core research themes centered on clinical practice, nursing education, competence development, patient safety, and evidence-based practice, with artificial intelligence increasingly integrated within these domains rather than positioned as a standalone focus. In conclusion, this bibliometric analysis provides a comprehensive overview of research trends, thematic priorities, and global collaboration patterns related to artificial intelligence in nursing leadership and clinical practice. The findings offer valuable insights to guide future research, policy development, and strategic leadership initiatives, while highlighting the need for broader international collaboration and deeper empirical evaluation of AI implementation in nursing practice.

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Keyword:

Artificial Intelligence, Bibliometric Analysis, Clinical Nursing Practice, Nursing Leadership



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Introduction

Artificial Intelligence (AI) has rapidly emerged as a transformative force in nursing leadership and clinical practice, reshaping the landscape of modern healthcare. The integration of AI technologies into nursing is redefining decision-making processes, streamlining clinical workflows, and enhancing resource management. Nurse leaders and practitioners are increasingly leveraging AI-driven tools such as predictive analytics, clinical decision support systems, and automated documentation to improve patient care outcomes and operational efficiency. These advancements are not only optimizing routine tasks but also enabling more precise risk assessments and personalized care strategies, positioning AI as a catalyst for innovation in both leadership and bedside practice. However, the adoption of AI also brings

forth complex challenges, particularly in maintaining the humanistic values central to nursing, such as empathy, patient autonomy, and ethical responsibility.

The growing reliance on AI in healthcare settings signals a paradigm shift where technology augments, rather than replaces, the expertise of nursing professionals. Innovative AI applications are being deployed to predict patient deterioration, automate administrative functions, and optimize staffing, thereby transforming traditional models of care delivery. Despite these promising developments, significant concerns persist regarding data privacy, algorithmic bias, and resistance to technological change among nursing staff. These challenges underscore the necessity for robust governance frameworks, interdisciplinary training programs, and proactive leadership to ensure that technological innovation aligns with the core values of nursing. As the field continues to evolve, integrative approaches that balance technological potential with ethical and practical considerations are essential for bridging the gap between innovation and compassionate, patient-centered care (Lora & Foran, 2024; Aqel et al. 2025; Ruksakulpiwat et al. 2024).

Literature Review

A growing body of research highlights the multifaceted impact of AI on nursing leadership and clinical practice. AI applications have been shown to enhance diagnostic accuracy, facilitate personalized treatment plans, and streamline patient management through advanced clinical decision support systems. These systems, leveraging predictive analytics, significantly reduce error rates and improve patient outcomes by providing evidence-based insights into care delivery. The integration of AI into nursing workflows also reduces administrative burdens and optimizes resource allocation, allowing nurses to dedicate more time to direct patient care. Notably, simulation-based AI training programs have demonstrated their effectiveness in translating theoretical knowledge into practical skills, thereby boosting nurses' confidence and clinical competencies. Such training not only prepares nurses for AI-driven decision-making but also supports safer and more efficient patient care (Lora & Foran, 2024; Benfatah et al. 2025).

Leadership dimensions play a critical role in the successful integration of AI within nursing. Transformational leadership characterized by intellectual stimulation, supportive relationships, and a vision for innovation has been identified as a key factor influencing nurses' readiness and intention to adopt AI technologies. Nurse leaders who actively engage in digital transformation and foster an innovation-supportive culture are more likely to implement AI tools effectively. Organizational support, including continuous education, interdisciplinary collaboration, and digital fluency, further enhances nurse leaders' confidence and preparedness for AI adoption. These factors collectively help overcome resistance to change and address ethical concerns such as data security and patient consent. The literature underscores the importance of tailored leadership initiatives that not only promote technical skill acquisition but also encourage ethical vigilance and professional development (Benfatah et al. 2025; Kotp et al. 2025; Dharman, 2025).

Ethical considerations are a recurring theme in studies examining AI in nursing leadership and clinical practice. Concerns related to algorithmic bias, data privacy, transparency, and accountability are pervasive, with scholars emphasizing the need for nursing-specific ethical guidelines and robust governance frameworks. The risk of dehumanization and erosion of patient autonomy is particularly salient, prompting calls for transparent oversight structures

that integrate ethical and practical monitoring of AI outcomes. These frameworks are essential for maintaining trust in AI-driven healthcare solutions and ensuring that technological advancements enhance, rather than compromise, the quality of patient care. Furthermore, nurse leaders are increasingly recognized as pivotal in navigating ethical dilemmas, advocating for patient-centered approaches, and embedding nursing values into AI governance (Badawy et al. 2025; George & Peirce, 2025; Arcadi, 2025).

Despite the promising advancements, significant research gaps remain. There is a clear need for more rigorous empirical studies, including randomized controlled trials and longitudinal assessments, to evaluate the long-term outcomes of AI integration in diverse clinical settings. Future research should also explore the intersection of AI education and ethical training within nursing curricula to foster preparedness across healthcare systems. Additionally, the development of comprehensive policy and regulatory frameworks tailored to nursing is necessary to address emerging challenges and support sustainable, ethical AI adoption. Addressing these gaps through interdisciplinary collaboration and targeted policy interventions will be crucial for realizing the full potential of AI in nursing leadership and clinical practice (Arcadi, 2025).

Research Question

RQ1. What are the publication trends and growth patterns of research on artificial intelligence in nursing leadership and clinical practice over time?

RQ2. Which articles have had the greatest scholarly impact in this field, as reflected by citation counts, and what thematic focus do they represent?

RQ3. Which countries are the most influential contributors to the literature on artificial intelligence in nursing leadership and clinical practice in terms of publication output and citation impact?

RQ4. What are the most frequently occurring and highly connected keywords that define the intellectual structure and core research themes of artificial intelligence in nursing leadership and clinical practice?

RQ5. How do international co-authorship networks reflect collaboration patterns among countries in research on artificial intelligence in nursing leadership and clinical practice?

Methodology

Bibliometric analysis involves the systematic collection, organization, and examination of bibliographic data derived from scientific publications (Alves et al. 2021). Beyond descriptive indicators such as publication years, source journals, and prolific authors (Wu & Wu, 2017), bibliometrics incorporates advanced analytical techniques, including document co-citation analysis, to reveal intellectual structures and research relationships within a field. Conducting a rigorous bibliometric review requires an iterative and methodical process of keyword refinement, literature retrieval, and comprehensive data analysis to ensure the development of a reliable and representative bibliographic dataset (Fahimnia et al., 2015).

Accordingly, this study focused on high-impact publications, as these sources provide critical insights into the theoretical foundations shaping the research domain. To enhance data reliability and consistency, Scopus was selected as the primary database for data extraction (Al-Khoury et al., 2022) (di Stefano et al., 2010) (Khiste & Paithankar, 2017). Only peer-reviewed journal articles were included to maintain scholarly rigor, while books and lecture notes were

intentionally excluded Gu et al.(2019) . Using Elsevier’s Scopus database, which offers extensive multidisciplinary coverage, publications published between 1967 to 2025 were retrieved for subsequent analysis.

Data Search Strategy

A comprehensive data search strategy was implemented using the Scopus database to capture scholarly literature related to artificial intelligence within nursing leadership and clinical practice. An advanced search string was applied, focusing on the article title field to ensure high relevance, with the core term “clinical nursing practice” used as the primary search anchor. To enhance disciplinary relevance while maintaining interdisciplinary breadth, the search was limited to subject areas most pertinent to the study scope, including Nursing (NURS), Health Professions (HEAL), and Social Sciences (SOC). These subject categories were selected to encompass both clinical nursing applications and leadership, organizational, and managerial dimensions relevant to artificial intelligence adoption in healthcare settings. Additionally, only English-language publications were included to ensure consistency in interpretation and analysis.

To capture the longitudinal development and evolution of research in this field, the search was restricted to publications published between 2006 and 2025. This extended timeframe allowed for the identification of early conceptual work as well as more recent empirical and technologically advanced studies reflecting the rapid growth of artificial intelligence in healthcare. The use of year-by-year publication limits ensured comprehensive coverage across nearly two decades of scholarship. Following the application of all inclusion criteria, a total of 932 records were retrieved. This dataset was deemed sufficiently robust for bibliometric analysis, enabling meaningful examination of publication trends, influential journals and authors, collaboration networks, and thematic evolution within artificial intelligence research related to nursing leadership and clinical practice.

Table 1 The Search String

Scopus	TITLE (Clinical nursing practice) AND (LIMIT-TO (SUBJAREA , "NURS") OR LIMIT-TO (SUBJAREA , "HEAL") OR LIMIT-TO (SUBJAREA , "SOC")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBYEAR , 2006) OR LIMIT-TO (PUBYEAR , 2007) OR LIMIT-TO (PUBYEAR , 2008) OR LIMIT-TO (PUBYEAR , 2009) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2024) OR LIMIT-TO (PUBYEAR , 2025))
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Table 2 The Selection Criterion Is Searching

Criterion	Inclusion	Exclusion
Language	English	Non English
Subject	Nursing, Social Sciences, Health Professions	Others
Timeline	2006-2025	<2006

Data Analysis

VOSviewer is a user-friendly bibliometric software developed by Nees Jan van Eck and Ludo Waltman at Leiden University, the Netherlands (van Eck & Waltman, 2017). It is widely used for the visualization and analysis of scientific literature, particularly for constructing network visualizations, clustering related entities, and generating density maps. The software supports multiple types of bibliometric analyses, including co-authorship, co-citation, and keyword co-occurrence networks, enabling a comprehensive examination of research structures and thematic relationships. Its interactive interface and continuous updates facilitate efficient exploration of large bibliographic datasets, while its capacity to compute metrics and customize visualizations enhances analytical flexibility.

For this study, bibliographic data were retrieved from the Scopus database in PlainText format, including information on publication year, title, authors, source journals, citations, and keywords, covering the period from 2004 to December 2024. The datasets were analyzed using VOSviewer version 1.6.19. VOSviewer employs visualization of similarities (VOS) mapping and clustering techniques to position items in a low-dimensional space, such that the distance between items reflects their degree of relatedness (van Eck & Waltman, 2010). While conceptually similar to multidimensional scaling (MDS) approaches (Appio et al., 2014), VOS differs in its normalization of co-occurrence data. Instead of relying on similarity measures such as cosine or Jaccard indices, VOS applies the association strength normalization, calculated as:

$$AS_{ij} = \frac{C_{ij}}{w_i w_j}$$

where C_{ij} represents the number of co-occurrences between items i and j , and w_i and w_j denote their total occurrences. This measure reflects the ratio between the observed co-occurrence frequency and the expected co-occurrence under the assumption of statistical independence (Van Eck & Waltman, 2007).

Result and Discussion

RQ1. What Are the Publication Trends and Growth Patterns of Research on Artificial Intelligence in Nursing Leadership and Clinical Practice Over Time?

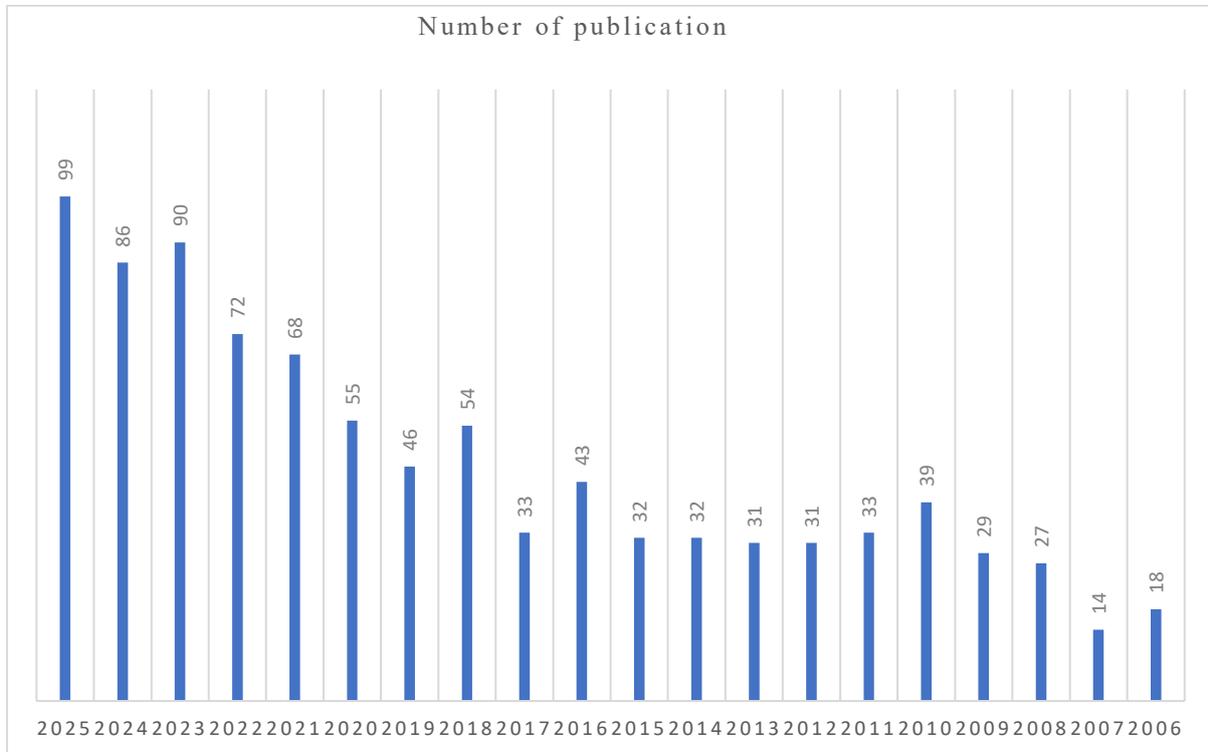


Figure 1: Trend Of Research In Online Learning By Years

The publication trend demonstrates a clear and sustained growth trajectory in research related to artificial intelligence in nursing leadership and clinical practice over the past decade, with particularly notable acceleration after 2018. From 2014 to 2017, the number of publications remained relatively modest and stable, fluctuating between 32 and 33 articles, reflecting an early exploratory phase in which AI applications in nursing were still emerging and largely conceptual. A gradual increase became evident from 2018 (54 publications) and 2019 (46 publications), suggesting growing academic awareness and initial integration of AI-driven tools into clinical nursing workflows and leadership decision-making. This upward movement coincides with broader digital health initiatives, advances in machine learning, and increasing institutional interest in data-driven healthcare management.

A more pronounced expansion is observed from 2020 onward, marking a rapid growth phase in the literature. Publications rose steadily from 55 in 2020 to 68 in 2021 and 72 in 2022, followed by a sharp increase to 90 publications in 2023. This surge likely reflects the accelerated adoption of artificial intelligence during and after the COVID-19 pandemic, when healthcare systems increasingly relied on digital solutions to support clinical decision-making, workforce management, and leadership responsiveness. The consistently high output in recent years indicates that AI has transitioned from a peripheral innovation to a central research focus within nursing leadership and clinical practice. Overall, this trend highlights a maturing research field characterized by expanding scholarly interest, deeper empirical inquiry, and

growing recognition of AI's strategic role in shaping contemporary nursing leadership and clinical care delivery.

RQ2. Which Articles Have Had the Greatest Scholarly Impact in This Field, As Reflected by Citation Counts, And What Thematic Focus Do They Represent?

The analysis of the top 10 most cited publications highlights that the intellectual foundation of this research domain is strongly anchored in clinical practice effectiveness, workforce roles, and nursing education, rather than purely technical artificial intelligence concepts. The most cited article by et al. (2017), published in Human Resources for Health (306 citations), emphasizes the impact of advanced practice nursing roles on quality of care, clinical outcomes, patient satisfaction, and cost. Its prominence underscores the centrality of leadership, role optimization, and outcome-driven practice in nursing scholarship key domains in which AI-enabled decision support and workforce analytics are increasingly applied. Similarly, highly cited works by Immonen et al., particularly systematic reviews published in Journal of Clinical Nursing and International Journal of Nursing Studies, reflect sustained scholarly interest in translating evidence into clinical practice and assessing competence, reinforcing the importance of knowledge integration, evaluation, and leadership-driven practice improvement.

A closer examination of the remaining highly cited studies reveals a strong thematic concentration on nursing students' competence, stress, coping strategies, and readiness for practice, largely published in leading education-focused journals such as Nurse Education Today and Nurse Education in Practice. These studies address challenges related to clinical learning environments, professional socialization, and performance assessment areas where artificial intelligence tools, such as simulation technologies, predictive analytics, and competency assessment systems, have gained increasing relevance. Although many of these influential articles predate the widespread adoption of AI in nursing, their high citation impact indicates that they provide the conceptual and empirical groundwork upon which AI-enabled leadership, education, and clinical support systems are being developed. Collectively, the citation pattern suggests that research on artificial intelligence in nursing leadership and clinical practice is evolving from established concerns about workforce capability, education, and care quality toward more technologically integrated and data-driven approaches, guided by longstanding priorities in nursing leadership and practice.

Table 3 Most Cited Author

No	Authors	Title	Year	Source title	Cited by
1	Woo et al. 2017	The impact of the advanced practice nursing role on quality of care, clinical outcomes, patient satisfaction, and cost in the emergency and critical care settings: A systematic review	2017	Human Resources for Health	306
2	Curtis et al., 2017	Translating research findings to clinical nursing practice	2017	Journal of Clinical Nursing	242

3	Immonen et al., 2019	Assessment of nursing students' competence in clinical practice: A systematic review of reviews	2019	International Journal of Nursing Studies	164
4	Chan et al., 2009	Hong Kong Baccalaureate Nursing Students' Stress and Their Coping Strategies in Clinical Practice	2009	Journal of Professional Nursing	144
5	Admi et al., 2018	Nursing students' stress and satisfaction in clinical practice along different stages: A cross-sectional study	2018	Nurse Education Today	132
6	Zhao et al., 2015	The study of perceived stress, coping strategy and self-efficacy of Chinese undergraduate nursing students in clinical practice	2015	International Journal of Nursing Practice	132
7	Andrews et al., 2006	Professional roles and communications in clinical placements: A qualitative study of nursing students' perceptions and some models for practice	2006	International Journal of Nursing Studies	126
8	Günay & Kılınç, 2018	The transfer of theoretical knowledge to clinical practice by nursing students and the difficulties they experience: A qualitative study	2018	Nurse Education Today	124
9	Levett-Jones et al., 2011	Implementing a clinical competency assessment model that promotes critical reflection and ensures nursing graduates' readiness for professional practice	2011	Nurse Education in Practice	116
10	Khalaila, 2014	Simulation in nursing education: An evaluation of students' outcomes at their first clinical practice combined with simulations	2014	Nurse Education Today	107

RQ3. Which Countries Are the Most Influential Contributors to The Literature on Artificial Intelligence in Nursing Leadership and Clinical Practice in Terms of Publication Output and Citation Impact?

The country-level distribution of publications reveals a clear dominance of high-income, research-intensive nations in shaping the scholarly landscape of artificial intelligence in nursing leadership and clinical practice. The United States leads decisively with 216 publications, reflecting its strong investment in digital health innovation, advanced nursing roles, and interdisciplinary research integrating informatics, leadership, and clinical care. The United

Kingdom (78) and Australia (76) follow closely, highlighting the active role of English-speaking healthcare systems with well-established nursing leadership frameworks and national strategies supporting health informatics and workforce modernization. The substantial contributions from Canada (59) further underscore the importance of policy-driven nursing leadership research and the integration of AI into healthcare management and clinical decision-making.

Beyond Western countries, notable research contributions from South Korea (59) and China (53) indicate the growing influence of Asian healthcare systems in this domain. These countries have made significant advances in digital health infrastructure, smart hospitals, and technology-enabled nursing practice, contributing to the global discourse on AI-supported leadership and clinical care. European countries such as Spain (52), Turkey (49), Norway (40), and Sweden (33) also demonstrate consistent scholarly engagement, reflecting regional priorities in healthcare quality, workforce development, and technology adoption. Overall, the geographical distribution highlights a concentration of research in technologically advanced and policy-supportive environments, while also suggesting opportunities for broader international collaboration and increased representation from low- and middle-income countries in future research on artificial intelligence in nursing leadership and clinical practice.

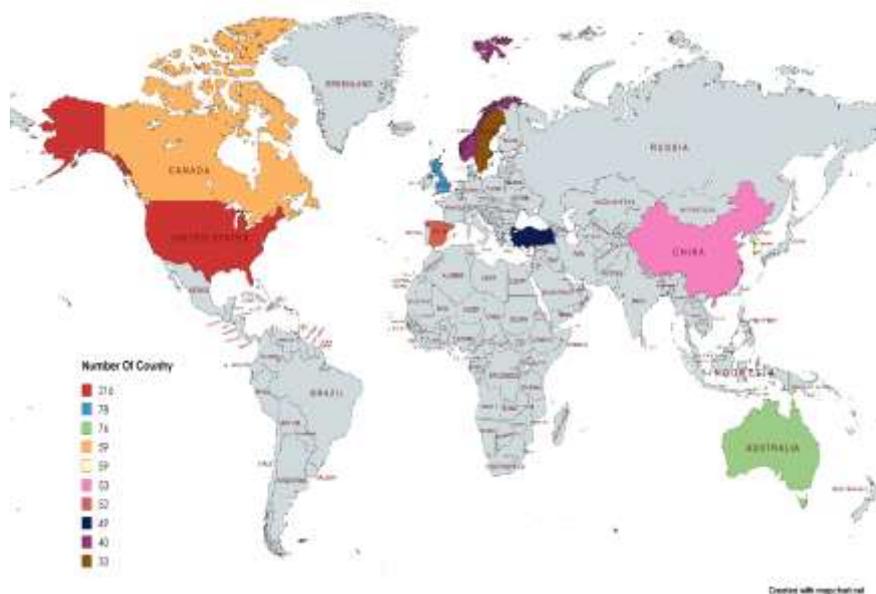


Figure 3: Countries Are The Leading Contributors Intermes Of Publication

Contribution Of the Findings to The Body of Knowledge

The results show that keywords such as “nursing students,” “clinical practice,” “nursing,” “nursing education,” and “evidence-based practice” have the highest occurrences and total link strengths, indicating that the literature is strongly anchored in education–practice integration and competency development. The prominence of terms like clinical competence, simulation, assessment, self-efficacy, stress, patient safety, and learning suggests a strong focus on preparing the nursing workforce for complex clinical environments—areas where artificial intelligence tools are increasingly applied for training, decision support, and performance evaluation. Although “artificial intelligence” appears with a lower occurrence and link strength, its presence alongside keywords such as nursing informatics, decision making, virtual reality, leadership, quality improvement, and patient safety indicates that AI is an emerging but rapidly integrating theme. Overall, the co-occurrence network demonstrates that current knowledge development is driven by traditional nursing education and clinical practice priorities, with artificial intelligence progressively embedded as an enabling technology supporting leadership, competence development, and safe, evidence-based nursing practice.

RQ5. How Do International Co-Authorship Networks Reflect Collaboration Patterns Among Countries in Research on Artificial Intelligence in Nursing Leadership and Clinical Practice?

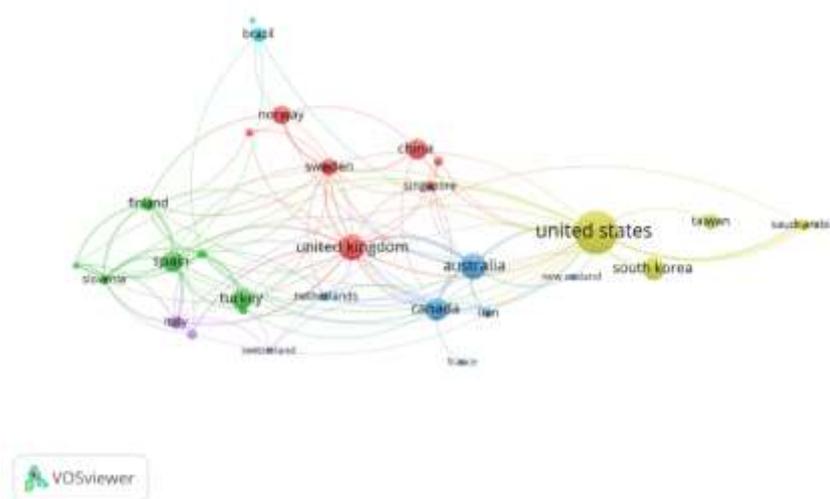


Figure 5: Network Visualization Map Of Citation And Countries Collaboration

Concept Of Country-Level Co-Authorship Collaboration in Vosviewer

Country-based co-authorship analysis in VOSviewer examines collaborative relationships between countries by identifying publications jointly authored by researchers affiliated with different nations. In the network visualization, each country is represented as a node, while links between nodes indicate international research collaborations. The strength of each link reflects the frequency of co-authored publications between two countries, and the total link strength represents the cumulative intensity of a country’s collaborative relationships with all other countries in the network. This approach provides insight into global knowledge flows, partnership patterns, and the degree of international integration within research on artificial intelligence in nursing leadership and clinical practice.

Settings Used to Generate the Collaboration Map

The co-authorship network was generated using the full counting method, whereby each country listed in a multi-country publication receives full credit for that document. This method emphasizes the visibility and participation of all collaborating countries rather than weighting contributions proportionally. A minimum threshold of five documents per country was applied to ensure analytical robustness and to focus on countries with sustained research output. Of the 73 countries identified in the dataset, 36 met the threshold and were included in the final visualization. This filtering process reduced fragmentation in the network and allowed for clearer identification of core collaborating countries and regional research hubs.

Contribution Of the Findings to The Body of Knowledge

The findings indicate that the United States occupies a central and influential position in the global collaboration network, with the highest number of publications (216), citations (2,622), and total link strength (50), highlighting its leadership role and extensive international partnerships. European countries such as Spain, the United Kingdom, Belgium, Finland, Italy, and Sweden demonstrate strong collaborative ties and high citation impact, reflecting well-established cross-border research networks in nursing education, leadership, and health informatics. Australia and Canada also show substantial citation counts and link strengths, underscoring their role as key collaborators in English-speaking research ecosystems. In contrast, several Asian, Middle Eastern, and Global South countries—while contributing a meaningful number of publications exhibit lower total link strength, suggesting more limited international collaboration. Overall, the co-authorship network reveals that knowledge production in artificial intelligence in nursing leadership and clinical practice is concentrated within a core group of highly connected countries, while also highlighting opportunities to strengthen global collaboration, diversify perspectives, and expand capacity building across underrepresented regions.

Conclusion

This bibliometric analysis was conducted to systematically examine the research landscape of artificial intelligence in nursing leadership and clinical practice. The study addressed key questions related to publication trends, influential articles, leading contributing countries, dominant research themes, and international collaboration patterns. By mapping the evolution and structure of this body of literature, the analysis aimed to clarify how artificial intelligence has been explored within nursing leadership and clinical contexts over time.

The findings indicate a clear and sustained growth in publications, particularly in recent years, reflecting increasing academic attention to artificial intelligence applications in nursing. Highly cited articles were largely concentrated on clinical practice effectiveness, nursing education, workforce competence, and leadership-related roles, suggesting that foundational nursing concerns continue to shape the direction of AI-related research. Country-level analysis revealed that research output and collaboration are predominantly driven by high-income countries, with a limited but gradually expanding contribution from other regions. Keyword co-occurrence analysis highlighted strong thematic clusters around clinical practice, nursing education, competence development, patient safety, and learning, while artificial intelligence emerged as an integrating concept rather than a standalone focus.

This study contributes to the field by providing a comprehensive overview of the intellectual structure and global research patterns related to artificial intelligence in nursing leadership and clinical practice. The results offer valuable insights for researchers, educators, and nursing leaders by identifying dominant themes, collaboration gaps, and emerging areas of interest. These insights may support strategic research planning, inform leadership development initiatives, and guide the integration of artificial intelligence into nursing education and practice environments.

Several limitations should be acknowledged. The analysis was restricted to English-language publications indexed in a single database, which may have excluded relevant studies from other sources or regions. Additionally, bibliometric methods focus on quantitative patterns and do not assess the quality or practical effectiveness of artificial intelligence applications. Future research could incorporate multiple databases, qualitative synthesis, or longitudinal evaluations to deepen understanding of real-world implementation and outcomes.

In conclusion, this bibliometric analysis demonstrates the growing importance of artificial intelligence within nursing leadership and clinical practice research. By clarifying research trends, thematic priorities, and collaboration structures, the study underscores the value of bibliometric approaches in informing future scholarship and supporting evidence-informed advancement in nursing leadership and practice.

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Bin Abdullah contributed to the study design, analytical framework, and critically revised the manuscript for important intellectual content. Associate Professor Ts. Dr. Wan Muhamad Amir Bin Wan Ahmad supported the methodological refinement, validation of analysis, and manuscript review. Associate Professor Dr. Edinur Hisham Bin Atan contributed to the interpretation of results, domain expertise input, and critical revision of the manuscript. All authors read and approved the final version of the manuscript prior to submission.

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