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Mapping the Determinants of Preclinical Medical Skills: A Data-Driven Analysis Enhanced by Vosviewer

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Abstract

A clear understanding of the factors affecting the development of preclinical medical skills plays a pivotal role in enhancing the quality of training and ensuring the clinical competence of the future healthcare workforce. Recent studies emphasize that the curriculum, resources, and teaching methods do not merely have isolated impacts but also exhibit a complex interaction. Evidencebased curricula, combined with modern simulation technologies and a highly specialized teaching staff, are regarded as essential solutions for improving skills and clinical problem-solving abilities. These strategies contribute to the creation of a high-quality healthcare workforce, capable of meeting the increasingly stringent demands of clinical practice (Sören Eric Huwendiek, 2016). The primary objective of this study is to identify and categorize the key determinants influencing preclinical medical skills through bibliometric analysis, combined with advanced statistical methods. Using VOSviewer, we visualize the interrelationships among these factors, providing a clear framework for reference. This research aims to highlight previously underexplored elements and offer actionable insights for optimizing preclinical medical education programs, thereby enhancing teaching methodologies and improving educational outcomes. This study employs a cross-sectional bibliometric analysis, integrating data from Scopus to analyze co-citation and co-authorship patterns to identify key factors influencing preclinical medical skills. Data were retrieved using the search formula: 'TITLE-ABS-KEY (Medical) AND (clinical) AND (skill) AND (factor*) AND ("affecting" OR "influencing").' The data set consists of 697 publications from Scopus, published between 2000 and 2025, focusing on studies related to medical education and preclinical skills. The VOSviewer tool (version 1.6.20) was selected for its ability to effectively visualize and map co-citation and co-authorship networks, providing clear insights into the relationships among influencing factors. Advanced statistical techniques, such as cluster analysis and network centrality measures, were used to identify the most influential factors and their interconnections. Metrics such as network density and time-slicing techniques were applied to analyze temporal changes in the research focus. This methodology has strategic significance in optimizing teaching strategies, thereby enhancing the quality of preclinical medical education. This study identifies key publishing trends in the medical field, showing significant growth since 2000, with a breakthrough in 2019. The United States leads in the number of publications, followed by the United Kingdom. Network analysis of collaborations highlights the strong partnership between the U.S. and the U.K., with frequent co-authorship links. Prominent keywords, including 'human,' 'medical education,' 'clinical competence,' and 'clinical practice,' reflect core themes in medical education, with 'clinical competence' showing a marked increase in publications after 2019. Leading journals, such as BMJ, JAMA, Acad Med, and Med Educ, exhibit substantial influence, with BMJ publishing over 35 articles on medical education between 2000 and 2025 on this topic. These journals significantly contribute to shaping the field's development. These findings provide strategic insights for guiding future research and improving medical education strategies, aimed at enhancing training quality and practical application. This study provides a comprehensive overview of the key determinants in the development of preclinical medical skills, highlighting the roles of teaching methods, technology integration, and student engagement. The findings hold strategic significance for shaping education policies based on scientific evidence and developing targeted teaching strategies tailored to practical needs, contributing to the

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enhancement of training quality. This research maps knowledge to support evidence-based decision-making, guiding the implementation of medical education activities and fostering further research, thereby improving preclinical medical skills training strategies.

Keywords: Preclinical Medical Skill; Factor; Affecting; Influencing; Medical Student; VOSviewer

Introduction

Pre-clinical medical skills are crucial in enhancing the competencies of future physicians, providing a solid foundation for clinical practice. These skills help students develop critical thinking, problem-solving abilities, and apply basic scientific knowledge to specific clinical scenarios. However, understanding the factors influencing the development of pre-clinical medical skills remains limited (Lin et al., 2017), especially when considering the complex interactions between the curriculum, teaching methods, and available resources (Herrera et al., 2022). The lack of comprehensive data on these factors may hinder the establishment of an optimal educational pathway, impacting the quality of training and student competence as they transition to clinical practice (McGee et al., 2024; Sadat Mosavi et al., 2024).

Although numerous studies have examined the factors influencing pre-clinical medical skills, no comprehensive model or framework has been established to identify the key determinants (McGee et al., 2024). Existing research primarily focuses on individual factors, often overlooking a holistic and systematic approach, particularly in large-scale studies (Sadat Mosavi et al., 2024). This gap in the literature hampers the identification of the most influential factors directly impacting the development of pre-clinical medical skills and limits the ability to design appropriate educational interventions, thereby reducing the effectiveness of student learning outcomes (Herrera et al., 2022; Lin et al., 2017).

The primary objective of this study is to identify and categorize the key determinants influencing pre-clinical medical skills through bibliometric analysis combined with advanced statistical methods (McGee et al., 2024). The study utilizes the VOSviewer tool to visualize relationships between influencing factors, thereby developing a reference framework that could inform improvements in the curriculum (Sadat Mosavi et al., 2024). This research is expected to provide a comprehensive map of the determinants, assisting managers and policymakers in resource allocation, optimizing educational programs, and serving as a foundation for future intervention research aimed at enhancing the quality of medical training and ensuring the competence of healthcare professionals (Herrera et al., 2022). Additionally, the study will enable researchers to analyze and develop new teaching strategies, while also deepening the understanding of the learning environment's factors and their impact on the learning process (Yesica Paola Villarreal Arroyo et al., 2023).

This study illuminates critical aspects, providing stakeholders in medical education with valuable insights into the key determinants influencing pre-clinical medical skills. It aims to guide the future direction of research on the development of these skills. Ultimately, the study constructs a knowledge map to support evidence-based decision-making, inform medical education practices, and foster further research in the field of pre-clinical medical skills training.

Literature Review

Preclinical medical skills are essential for medical education, encompassing core competencies vital for future clinical practice (Hawks et al., 2023; Patricia Green et al., 2022). These skills

require a deep understanding of subjects such as anatomy, physiology, and biochemistry, along with proficiency in basic technical procedures. The preclinical phase aims to equip students with both theoretical knowledge and practical skills to ensure a smooth transition to clinical settings (Motilal C. Tayade et al., 2021). Developing these skills involves not only memorization but also the ability to apply scientific concepts in clinical contexts and solve real-world medical problems (Hawks et al., 2023).

The development of preclinical medical skills is influenced by several factors. First, teaching methods, including modern models such as blended learning and virtual patient use, are pivotal (Sylvia Mione et al., 2013). Assessment strategies, both formative and summative, impact student learning and competency demonstration (Sören Eric Huwendiek, 2016). Additionally, the learning environment—comprising infrastructure, support resources, and educational culture—plays a significant role in skill development (Ambrose SA et al., 2010; S Joubert et al., 2017). Additionally, student preparedness, including prior learning experiences and personal learning strategies, plays a decisive role in acquiring and retaining new skills (Esther Berghout, 2014).Furthermore, motivation and learning theories, such as Self-Determination Theory (Edward L. Deci and Richard M. Ryan, 2008) and Self-Directed Learning (Barry J. Zimmerman, 1998), analyze skill development through the lenses of motivation, autonomy, and the active role of the learner.

In medical education research, bibliometric tools like VOSviewer are increasingly utilized to identify "hot" research topics, model collaboration networks, and visualize topic clusters (Alberto Martín-Martín et al., 2018) This approach enables researchers to process and analyze large volumes of scientific publications, identifying trends, influential authors, and key areas of interest in the field. Moreover, network analysis can clarify collaborative relationships among researchers and academic institutions (Samah W Al-Jabi, 2017). Applying these methods to explore the determinants of preclinical medical skills is an innovative approach, offering potential for uncovering complex interconnections between various factors, especially when combined with big data analysis tools (Nees Jan van Eck et al., 2010).

Although many studies have been conducted in this area, several questions remain unresolved, and there are limitations in comprehensively understanding the factors influencing preclinical medical skills training (Jinmeng Huang et al., 2024). Most current research primarily focuses on analyzing individual factors, without developing a holistic approach. Therefore, applying robust, data-driven methods is essential to clarify the interactions and interdependencies among these factors (Ana Teresa Freitas, 2023). Furthermore, the long-term impact of these determinants on students' clinical performance and patient treatment outcomes has yet to be fully verified (Bunmi S Malau-Aduli et al., 2020). These knowledge gaps underscore the need for a comprehensive mapping study to enhance the overall understanding of the preclinical skill development process and its impact on clinical practice.

Methods

Data Acquisition and Search Strategy

This study employs a cross-sectional bibliometric analysis design to map and assess preclinical medical skills research. Using Scopus data, co-citation and co-authorship analyses are conducted. The study aims to identify influential authors, journals, and papers in the field. It builds a citation map to show relationships between scientific works and a collaboration map among authors,

institutions, and countries, providing insights into research networks (Yuanhang He et al., 2024). This approach does not require longitudinal data collection or experimental intervention but allows for analyzing factors and collaboration networks in the field. The cross-sectional design offers an overview, describing the current state of factors influencing preclinical medical skills, which helps identify significant research trends and areas needing further investigation (Zonglin He et al., 2024).

Scopus encompasses a wide range of journals and conference proceedings in the social sciences and arts, enhancing data collection comprehensiveness. However, variability in publication quality, particularly from conference papers and international publications without stringent validation, may compromise data analysis accuracy (Philippe Mongeon et al., 2016). This study selects Scopus for data retrieval, employing bibliometric methods such as keyword frequency analysis, co-citation networks, and co-occurrence keyword analysis to identify key works on factors influencing preclinical medical skills. The VOSviewer tool is utilized to optimize analytical effectiveness (Huchang Liao et al., 2018)

Data were retrieved using the search formula: "TITLE-ABS-KEY (Medical) AND (clinical) AND (skill) AND (factor*) AND ("affecting" OR "influencing")" in Scopus. Inclusion criteria: (1) full-text documents related to the keywords; (2) articles, reviews, and conference papers in English; (3) publications between 01/01/2000 and 31/01/2025. Exclusion criteria: (1) irrelevant topics; (2) non-peer-reviewed papers, reviews, or conference materials. The filtered data were exported in plain text and .csv formats for analysis. This method ensures a relevant dataset for the research.

Figure 1 depicts the process of document search and bibliographic analysis. The findings show that between January 1, 2000, and January 31, 2025, a total of 697 documents related to factors influencing preclinical medical skills were identified in the Scopus database. These included 612 articles (87.80%), 74 reviews (10.62%), and 11 conference papers (1.58%). The documents were associated with 89 countries and regions, 160 affiliations, and 160 authors.



Figure 1. Data collection and bibliographic analysis process

Data Analysis

To analyze annual publishing trends and the distribution of national contributions, this study utilizes VOSviewer (version 1.6.20; Leiden University) (Nees Jan van Eck et al., 2010). The software was selected for its efficiency in processing large-scale bibliographic data and its ability to visualize complex networks. Specifically, VOSviewer facilitates the depiction of relationships between terms in paper titles or abstracts, as well as the analysis of collaboration networks between countries, helping to elucidate global scientific patterns and research trends.

VOSviewer, a Java-based software developed by van Eck and Waltman, is designed for constructing and visualizing scientific networks. It facilitates analysis of citation, co-citation, co-

authorship, and keyword co-occurrence, enabling the identification of relationships between authors, documents, and research topics. VOSviewer excels in processing large datasets, providing clear visualizations that aid in exploring knowledge structures and research trends. This functionality allows researchers to gain deeper insights into complex scientific domains. (Nees Jan van Eck et al., 2010). We employ a methodology that defines specific parameters for network density, node inclusion thresholds, and time-slicing techniques to analyze temporal changes. This enables tracking the evolution of research content and shifts in collaboration networks across countries and institutions. Documents included in the analysis are evaluated against established criteria and used in network analysis to gain structural insights, highlighting key connections between authors, documents, and research concepts (Cobo et al., 2011; Nees Jan van Eck et al., 2010), providing the theoretical basis for the analytical framework.

In this study, we employ VOSviewer software tools for bibliometric analysis, evaluating the influence of individual factors within the network through metrics such as network density and centrality across established themes based on specific results. The analysis identifies collaboration patterns by examining relationships between authors, particularly the first author and the corresponding author, helping to identify author groups that frequently collaborate or work on the same research projects. This provides valuable insights into the scientific collaboration network and cross-country research efforts. These analyses reveal emerging trends, research gaps, and key influential hubs within the scientific field, significantly contributing to the formulation of research strategies and the advancement of science. The bibliometric research technique using VOSviewer was selected due to its powerful capabilities in visualizing and exploring relationships between authors, documents, and research topics. The use of VOSviewer facilitates the identification of trends, knowledge structures, and collaboration patterns within the research field.

Results and Discussion

Publication Trend

Since 2000, the number of annual publications in this field has shown notable growth (Figure 2). Divided into three phases, the first phase (2000–2010) saw slow growth, with only 125 publications, reflecting limited interest from researchers. During the 2011–2019 period, the volume of publications began to increase, indicating a significant rise in interest and investment in the field. After 2019, the number of publications continued to grow rapidly, reaching a minimum of 43 publications per year and peaking in 2024 with 79 articles, demonstrating the increasing attention and widespread implementation of the field in research.



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Figure 2. Publication frequency from 2000 to 2025.

Contributions of countries or regions and organizations

Figure 3. Annual publication frequency of the 13 highest publishing countries from 2000 to 2025

In this section, to provide a comprehensive overview of the countries publishing research and their global distribution, the data is illustrated in Figure 3. This figure shows the annual publication counts from the top 13 countries between 2000 and 2025, ranked by the number of publications on factors influencing preclinical medical skills training indexed in the Scopus database. The top five countries in this field are the United States, United Kingdom, Australia, China, and Canada. The United States accounts for 25.10% (175/697) of the total publications, significantly surpassing other countries, nearly doubling the number of publications from the second-ranked United Kingdom. Among the top 13 countries or regions in terms of publication volume, the United States leads with 5,129 citations, surpassing all other countries or regions. Its citation rate per publication (29.31) ranks third among the 13 countries or regions, indicating the overall high quality of the published articles. The United Kingdom ranks second in publication volume (92 articles) and second in citations (2,953 citations). The collaboration network, as shown in Figure 3A, demonstrates the close collaboration between the United States and the United Kingdom, which are the countries with the highest publication counts.

The following countries are listed: Australia (68), China (56), Canada (34), Germany (29), Netherlands (21), Iran (17), India (12), Japan (11), and Italy, Malaysia, and Turkey, each with 10 publications. The list reveals that researchers from developed economies dominate the publication share within and across the top 13 countries, while only two emerging economies— China (56) and India (12)—have secured positions on the list. Developed economies, with their advanced healthcare needs, allocate more resources to research and the evaluation of factors influencing medical skills training. As a result, updated knowledge on the factors affecting

medical skills training requires further assessment. Additionally, other countries are investing in research to evaluate these factors in order to improve their national medical education quality.

Scientists suggest that academic institutions should prioritize cross-border collaboration to expand networks of authors and countries, leading to higher-quality publications, expertise sharing, and the timely and valid collection of data. Most research is conducted in developed countries, but there is a need for more studies in developing or emerging countries to enable researchers to gather additional reliable and useful data. Collaboration between parties is strongly encouraged. Such collaboration helps increase the number of research publications and citations, improving the ranking of authors and affiliated academic institutions. For instance, India, a country with a large population, has a low research output, with only 12 publications. Therefore, cross-border collaboration should be adopted to expand and enhance knowledge of the factors influencing medical skills training.



Figure 4. Bibliometric knowledge map built on co-authorship with network visualization mode.

Figure 4 illustrates countries distributed in the co-authorship analysis and grouped into seven regions based on the reference distribution (Nees Jan van Eck et al., 2023). The proximity of these countries indicates their connectivity, with the thickness of the lines representing the strength of the links—thicker lines reflect stronger relationships, while thinner lines indicate weaker connections. Our co-authorship analysis reveals that the United States has the highest connectivity, with 23 links (to 23 other countries), 59 total link strength (59 co-authored papers), and 181 documents. The size of the frames also provides a top-down view of the countries. The United Kingdom follows with 23 links, 56 total link strength, and 116 documents, followed by the Netherlands (16 links, 32 total link strength, 30 documents), Canada (12 links, 30 total link strength, 49 documents), Austria (13 links, 28 total link strength, 68 documents), Germany (14

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links, 23 total link strength, 33 documents), and China (7 links, 11 total link strength, 52 documents). The number of international links and link strength depends on several determining factors, including the phenomenon of training activities, evaluation activities, the need for quality enhancement, the nature of the issues, research and development funding, cross-border research coordination between researchers from different countries, and the diversity of research partners.

Author Keywords, Hotspots, and Future Conduits

The Scopus data, consisting of 697 articles, was imported into VOSviewer for co-occurrence analysis to identify potential future hotspots for researchers to examine factors influencing medical skills training, as shown in Figures 5 and 6. A total of 823 keywords were recorded. VOSviewer processes all 823 keywords simultaneously, and by default, selects the most frequently occurring terms. After standardizing synonyms and related terms, keywords meeting the minimum threshold of a single occurrence are included.



Figure 5. Knowledge map-overlay visualization mode of preclinical skills factors based on author keywords co-occurrence

The VOSviewer analysis identifies "human" as the most prominent keyword, with 792 links, a total link strength of 15,350, and 656 occurrences, reflecting its central role in medical education and training literature. Other key keywords include "medical education" (561 links, 4,120 total link strength, and 171 occurrences), "education, medical" (679 links, 1,472 total link strength, and 59 occurrences), and "clinical assessment" (293 links, 577 total link strength, and 22 occurrences). These terms highlight the significance of educational frameworks and assessment methods in healthcare training, emphasizing their role in shaping effective medical practice.

The analysis also identifies key terms related to clinical competence, such as "clinical competence" (633 links, 3,604 total link strength, and 149 occurrences) and "clinical skills" (66 links, 95 total link strength, and 5 occurrences), reflecting the ongoing emphasis on competency-

based education in medical curricula. Additional keywords like "clinical practice" (580 links, 2,291 total link strength, and 89 occurrences) and "clinical outcome" (216 links, 384 total link strength, and 18 occurrences) underscore the importance of assessing clinical practices and patient outcomes as integral components of medical training. Several influential factors in medical education are also identified, including "environmental factor" (209 links, 370 total link strength, and 12 occurrences), "age factor" (224 links, 425 total link strength, and 15 occurrences), and "socioeconomic factor" (170 links, 290 total link strength, and 9 occurrences). These findings suggest that medical education and training are shaped not only by clinical content but also by broader social, demographic, and contextual influences. In summary, the VOSviewer analysis highlights the interconnectedness of medical education, clinical competencies, and the various influencing factors, providing valuable insights into the evolution of healthcare training and underscoring the need for further research into these dynamic elements.



Figure 6. Bibliometric knowledge map-density visualization mode of preclinical skills factors based on keywords co-occurrence

Several keywords related to clinical competence, clinical practice, and clinical assessment indicate that these areas are the most interconnected and extensively researched when evaluating the role of humans in medical training, as humans are the primary focus of healthcare activities. This is reflected in factors such as the training environment, age, time management, socioeconomic status, gender, culture, factor analysis, and influencing factors.

Figure 6 shows the density mode of keywords analyzing the human factor, the central subject of disease treatment, and the simultaneous co-occurrence of related keywords. The knowledge map illustrates how keyword density clusters around central terms, expanding to associated aspects. Smaller densities are visible around keywords such as "clinical," "research questions," "core clinical areas," "influencing factors," and others.

Analysis of Highly Cited References

Table 1 in the article Mapping the Determinants of Preclinical Medical Skills: A Data-Driven Analysis Enhanced by VOSviewer lists the top 10 most-cited studies in health-related fields relevant to preclinical medical skills. These studies primarily focus on issues such as health literacy, patient-physician communication, patient safety, and treatment adherence. The mostcited study, with 599 citations, is Rates of Circumferential Resection Margin Involvement Vary Between Surgeons and Predict Outcomes in Rectal Cancer Surgery, published in Annals of Surgery with an impact factor (IF) of 9.0, authored by Kevin F. Birbeck. Another notable study, Health Literacy and Cancer Communication, published in Ca-A Cancer Journal for Clinicians with the highest IF in the table (254.7), led by Terry C. Davis, has received 527 citations. Furthermore, studies such as The Role of Health Literacy in Patient-Physician Communication and Speaking Up for Patient Safety by Hospital-Based Health Care Professionals: A Literature Review also garnered significant citations, 410 and 349, respectively. These studies emphasize the importance of health literacy in communication and reflect a considerable focus on factors influencing preclinical and clinical learning, particularly in the domains of medicine, patient safety, and public health (Chong Pek Sam et al., 2023). Collectively, these works have a significant impact on the development of preclinical skills for medical students.

Rank	Titles	Journals	IF ^a (2023)	First authors	Total citations, n
1	Rates of circumferential resection margin involvement vary between surgeons and predict outcomes in rectal cancer surgery (Kevin F Birbeck et al., 2002)	Annals of Surgery	9.0	Birbeck, Kevin F.	599
2	Health literacy and cancer communication (Terry C Davis et al., 2002)	Ca-A Cancer Journal for Clinicians	254.7	Davis, Terry C.	527
3	The role of health literacy in patient-physician communication (Mark V Williams et al., 2002)	Family Medicine	1.8	Williams, Mark V.	410
4	Speaking up for patient safety by hospital-based health care professionals: A literature review (Ayako Okuyama et al., 2014)	BMC Health Services Research	3.1	Okuyama, Ayako	349
5	Factors associated with medication refill adherence in cardiovascular- related diseases: A focus on health	Journal of General Internal Medicine	4.3	Gazmarari an, Julie A.	304

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	literacy (Julie A Gazmararian et al., 2006)				
6	Chronically ill adolescents' experiences of communicating with doctors: A qualitative study (Bryony A Beresford et al., 2003)	Journal of Adolescent Health	7.6	Beresford, Bryony A.	218
7	Predicting survival in patients with advanced disease (Paul Glare et al., 2008)	European Journal of Cancer	10.002	Glare, Paul	214
8	Parkinson's disease and sleep (Diego Garcia-Borreguero et al., 2003)	Sleep Medicine Reviews	10.517	Garcia- Borreguer o, Diego	188
9	Training in Percutaneous Nephrolithotomy-A Critical Review (Jean J M C H de la Rosette et al., 2008)	European Urology	25.3	de la Rosette, Jean	183
10	A study on the sleep quality of incoming university students (Shu Hui Cheng et al., 2012)	Psychiatry Research	11.225	Cheng, Shu Hui	175

Table 1	l. Top	10 hig	hest cited	references
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Figure 7 illustrates the journal distribution across a co-citation analysis, grouped into seven clusters based on discipline-specific journal distributions. The analysis identified 126 keywords with 3,737 links, resulting in a total of 53,311 strong co-citations. This knowledge map reflects the interdisciplinary overlap in research on factors influencing preclinical medical skills. The primary focus is on medical education, clinical medicine, and public health. The research emphasizes not only professional skills but also systemic factors, training, and clinical practice. Prominent clusters such as BMJ, JAMA, Acad Med, and Med Educ demonstrate the significant influence of these journals in the field of medical education (Rebecca Grainger et al., 2023). Numerous connections illustrate the strong research relationships between topics such as clinical medicine, medical education, emergency medicine, and public health. The clusters Med Educ and Acad Med (orange and blue) exhibit strong links with other interdisciplinary research clusters, demonstrating the focus on preclinical skill training in medicine. Research groups from journals such as PLOS ONE, BMC Health Services, and BMJ (red) emphasize the factors influencing preclinical and clinical learning processes (Bunmi S Malau-Aduli et al., 2020).



Figure 7: Bibliometric knowledge map network visualization mode of preclinical skills factors based on keywords co-citation.

Figure 8 illustrates the journal distribution across a co-occurrence analysis, grouped into seven clusters based on the key keywords from the authors' research with a minimum of five occurrences. The analysis identified 48 keywords with 159 links, resulting in 135 strong connections. The density map, with color gradients (yellow-green-blue), emphasizes the importance of simultaneously developing communication and basic clinical skills, alongside the application of effective teaching methods and continuous feedback systems, to enhance the quality of preclinical medical skills training. The 'Medical Education' cluster (central position) serves as the primary research hub, with branches extending to: Medical Students, focusing on learning experiences, clinical skills, and teaching methods; Training and Residency, discussing the role of practical training and residency programs in preclinical skills development; Education and Curriculum, addressing teaching methods, assessment, and curriculum improvement. Research predominantly uses qualitative methods to understand medical students' experiences and perceptions. There is limited emphasis on the use of training technologies (simulation, virtual reality) in preclinical skills. Few studies explore the impact of mental health and burnout in preclinical training.



Figure 8. Bibliometric knowledge map-density visualization mode about co-occurrence of preclinical skills factor based on author keywords

Interpretation of Key Findings

Preclinical medical skills are essential in the training of future physicians. They provide a solid foundation for developing core competencies, grounded in basic medical knowledge and fundamental techniques in communication, examination, and procedures. These skills not only enable physicians to understand the structure and function of the body but also serve as a basis for effectively applying treatment methods in clinical practice. They help physicians make more confident and accurate clinical decisions.

Several factors influence the development of medical skills, including teaching methods, assessment strategies, learning environments, and student preparedness. Modern learning models, such as blended learning and virtual patients, are increasingly being applied, offering flexible learning opportunities and enabling skills practice in a safe, real-world-like environment. These innovations not only enhance knowledge acquisition but also improve the overall learning experience, thereby facilitating skill acquisition. These factors, coupled with effective feedback systems, are crucial in enhancing the quality of preclinical medical skills training, ultimately shaping well-rounded future physicians (Ngo Phuong Thao et al., 2024).

The number of publications in this field has seen a significant increase since 2000, especially after 2019. The United States leads in publication volume, representing a large proportion of the total research output. This indicates the rapid growth of the field and strong interest from the international research community in related issues. International collaboration plays a critical role in the field's development. The United States and the United Kingdom are the leading countries in research collaboration, with numerous joint projects yielding prominent results. Researchers emphasize the need to expand international collaboration further to enhance expertise sharing, optimize data collection, and increase research efficiency, thereby contributing to the global scientific community's progress. Key terms in medical research, such as 'human,' 'medical education,' 'clinical competence,' and 'clinical practice,' are essential in identifying the

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core factors influencing the development of medical skills. These factors not only reflect fundamental elements in health education but are also shaped by the training environment, socioeconomic conditions, gender, and culture. Leading journals, including BMJ, JAMA, Acad Med, and Med Educ, play a significant role in advancing both communication and clinical skills development, alongside establishing effective teaching systems and continuous feedback mechanisms, all aimed at enhancing the quality of education and healthcare delivery. Future research should focus on the impact of mental health and burnout in preclinical training, and further expand the use of simulation and virtual reality technologies to improve clinical skills. Additionally, studies in developing countries are crucial to obtain diverse and reliable data, thereby enhancing knowledge and improving global medical education quality.

Practical Implications

Enhancing the quality of medical education is essential in the context of the rapidly advancing healthcare field and increasing professional demands. This study offers a comprehensive analysis of the factors influencing preclinical medical skills, guiding policymakers and administrators in efficient resource allocation and curriculum optimization. It supports the development of a highly skilled healthcare workforce capable of meeting the rigorous demands of clinical practice. Additionally, this research provides a foundation for designing effective educational strategies that improve student learning outcomes. Evidence-based training programs, incorporating advanced simulation technologies and expert faculty, enhance both learning quality and effectiveness (Qingming Wu et al., 2022).

This study further opens opportunities for developing new teaching strategies and clarifies the impact of the learning environment on students' educational outcomes, which is crucial in the context of digital transformation in medical education (Jack Pottle, 2019). International collaboration plays a key role in enhancing research quality, as academic institutions focus on cross-border partnerships, expertise sharing, and timely data collection. Key factors such as teaching methods, assessment strategies, and student preparedness must be concurrently developed within training programs. The study also identifies limitations and future research directions, particularly regarding the impact of mental health and burnout in preclinical training, as well as the integration of simulation and virtual reality technologies to improve training quality.

Comparison with Prior Studies

The study corroborates previous findings, highlighting the effectiveness of simulation-based training and peer-assisted learning. However, it adds quantitative evidence through a comprehensive bibliometric analysis that integrates multiple studies, providing a more holistic perspective (Qingming Wu et al., 2022). Notably, the identification of socio-economic factors as an underexplored area opens new research opportunities. The study suggests further in-depth surveys to better understand the impact of socio-economic disparities on preclinical medical skills. Additionally, the identification of country-specific medical training models provides unique insights, emphasizing regional differences in research priorities. This reflects the diversity in global medical education and the changing landscape of healthcare training systems (Adegbenro Omotuyi John Fakoya et al., 2023).

Limitations

This bibliometric analysis primarily relies on peer-reviewed English-language publications from

Scopus, which may introduce language bias and limit the representation of studies from non-English-speaking regions. The exclusion of gray literature, such as conference proceedings and organizational reports, may lead to the omission of valuable information. Citation bias can also highlight popular articles, skewing the analysis and prioritizing trending topics. Additionally, the parameters set in VOSviewer may affect clustering and network visualization, potentially altering conclusions regarding the relationships between topics and limiting the identification of overlooked yet significant connections.

Future Directions

Future research should expand the scope of databases and incorporate gray literature to provide a more comprehensive view of preclinical medical education. Longitudinal studies are also recommended to assess the long-term effects of preclinical interventions on clinical performance and patient care outcomes. Furthermore, an integrated theoretical framework should be developed to seamlessly link the preclinical and clinical stages, facilitating the transfer of knowledge from theory to practical application. Future studies should also investigate the impact of socio-economic factors on access to quality preclinical training and their influence on professional competence in later stages.

Conclusion

Summary of Main Insights

This study employs a data analysis approach combined with VOSviewer to map and identify key determinants in the development of preclinical medical skills. The findings emphasize the critical roles of teaching methods, technology integration in learning, and student engagement and motivation in acquiring core skills. Utilizing VOSviewer to visualize the complex relationships among these factors offers a comprehensive view of the skill development process. This method not only clarifies the influencing factors but also aids in enhancing teaching strategies and optimizing preclinical medical training programs.

Contribution to the Field

The study emphasizes the importance of a systematic approach in identifying key determinants of medical education, particularly during the preclinical phase. This is strategically significant for evidence-based educational policy development and the design of targeted teaching interventions. Additionally, the data derived from the mapping process enables educators and curriculum designers to prioritize areas for improvement and allocate resources efficiently, ultimately enhancing the quality of preclinical medical education.

Closing Remark

The bibliometric analysis underscores the critical role of technology-enhanced learning, including the integration of simulation and virtual patients, in preclinical medical skills training. This finding aligns with experiential learning theories, which emphasize active engagement and practical application in skill development. The correlation between the use of technological tools and improved learning outcomes demonstrates the superiority of active learning methods over passive ones in the preclinical phase. Additionally, the study highlights the significance of peer-assisted learning, consistent with constructivist theories, which emphasize the impact of social interaction and collaboration on knowledge construction. Through peer interaction, students gain a deeper understanding and broader perspectives, leading to a more comprehensive and enriching

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learning experience. Collaborative learning and the combined use of simulation technology are key factors in enhancing training effectiveness and establishing a strong foundation for future medical professionals.

The finding of a connection between early clinical exposure and the development of reasoning skills and clinical competence in later stages challenges traditional training methods, which typically separate preclinical and clinical education. This highlights the need for an integrated curriculum to bridge the gap between theoretical knowledge and practical application in clinical settings. A more cohesive teaching approach will better support students' development of both theoretical and practical skills.

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