CeuEM Revista Española de Educación Médica

UNIVERSIDAD DE MURCIA

A scientometric analysis of the thematic structure and analysis of the convergence mapping of medical education.

Un análisis cienciométrico de la estructura temática y análisis del mapeo de convergencia de la educación médica.

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Received: 5/15/2025; Accepted: 8/5/2025; Published: 8/8/25

Abstract: This study investigates the thematic structure and conceptual dynamics of research in medical education using scientometric and network analysis approaches. Despite the growing volume of literature in this field, few studies have comprehensively mapped its evolving patterns and interdisciplinary connections. To address this gap, a descriptive-analytical method was employed, focusing on two time periods: 2001–2010 and 2016–2025. Articles indexed in the Web of Science (WoS) database formed the statistical population, selected due to WoS's comprehensive and interdisciplinary coverage. A keyword-based search strategy was developed through expert consultation and refined with artificial intelligence tools. Data from over 56,000 articles were collected, cleaned, and standardized using PreMap Ravar software. Core keywords were identified through Bradford's law, and thematic structures were visualized using VOSviewer, Ucinet, and NetDraw software. The study analyzed word co-occurrence patterns, thematic clusters, and centrality indices to uncover key research areas and conceptual shifts over time. Findings reveal a growing interdisciplinary trend in medical education, with increasing integration of fields such as information technology, management, and artificial intelligence. Emerging topics include virtual education, simulation, evidence-based learning, and interprofessional collaboration. The analysis also highlights the expanding global interest in network-based evaluation of scientific fields.This research contributes to a deeper understanding of the intellectual landscape of medical education and provides valuable insights for researchers, policymakers, and educators. It underscores the importance of network analysis in mapping complex research domains and guiding strategic development in academic and institutional contexts.

Keywords: Scientometrics, Medical education, Knowledge Mapping, Network Analysis, Health Information Systems, Artificial Intelligence in Education, Interdisciplinary Research

Resumen: Este estudio investiga la estructura temática y la dinámica conceptual de la investigación en educación médica utilizando enfoques cienciométricos y de análisis de redes. A pesar del creciente volumen de literatura en este campo, pocos estudios han mapeado exhaustivamente sus patrones evolutivos y conexiones interdisciplinarias. Para abordar esta brecha, se empleó un método descriptivo-analítico, centrándose en dos períodos de tiempo: 2001-2010 y 2016-2025. Los artículos indexados en la base de datos Web of Science (WoS) formaron la población estadística, seleccionada debido a la cobertura integral e interdisciplinaria de WoS. Se desarrolló una estrategia de búsqueda basada en palabras clave mediante consulta con expertos y se refinó con herramientas de inteligencia artificial. Los datos de más de 56,000 artículos se recopilaron, depuraron y estandarizaron utilizando el software PreMap Ravar. Las palabras clave principales se identificaron mediante la ley de Bradford, y las estructuras temáticas se visualizaron utilizando el software VOSviewer, Ucinet y NetDraw. El estudio analizó patrones de coocurrencia de palabras, grupos temáticos e índices de centralidad para descubrir áreas de investigación clave y cambios conceptuales a lo largo del tiempo. Los hallazgos revelan una creciente tendencia interdisciplinaria en la educación médica, con una creciente integración de campos como las tecnologías de la información, la administración y la inteligencia artificial. Los temas emergentes incluyen la educación virtual, la simulación, el aprendizaje basado en la evidencia y la colaboración interprofesional. El análisis también destaca el creciente interés global en la evaluación en red de los campos científicos. Esta investigación contribuye a una comprensión más profunda del panorama intelectual de la educación médica y proporciona información valiosa para investigadores, legisladores y educadores. Subraya la importancia del análisis de redes para el mapeo de dominios de investigación complejos y la orientación del desarrollo estratégico en contextos académicos e institucionales.

Palabras clave: Cienciometría, Educación médica, Mapeo del conocimiento, Análisis de redes, Sistemas de información sanitaria, Inteligencia artificial en la educación, Investigación interdisciplinaria

1. Introduction

Numerous scientometric studies have been conducted across various medical and non-medical fields using databases such as Science direct. However, a comprehensive analysis of medical education as a distinct domain is lacking. Medical education encompasses foundational learning theories, general medical training, and residency programs. Previous research in this area has often focused on teaching methods and pedagogical frameworks. This study applies network analysis to uncover thematic patterns, evolving concepts, and hidden relationships within the field. Network analysis enables the identification of trending topics, emerging research themes, and influential concepts shaping the discourse in medical education (1-2). Several studies support the significance of this method.

One study emphasized the impact of medical education on patient care in the U.S (3). Another highlighted the role of scientific mapping in informing policymakers and enhancing research quality (4). A recent analysis of COVID-19 literature identified three main clusters: health, basic science, and clinical research (5). Additional research tracked the growth of type 2 diabetes treatment using tools like Ucinet and NetDraw (6), while another study used word coherence to map the thematic structure of information management and identified nine subject clusters (7). Further studies have explored related areas: One work used data mining to assess trends in electronic mental health research (8), while another conducted a bibliometric analysis of health information management literature over 40 years (9). A citation analysis of health care management journals noted a 76.6% increase in cumulative citations (10). Another investigation examined scientometric trends in COVID-19 research, highlighting key areas and collaborations (11). Other studies emphasized the operational role of health information management systems (12), identified research gaps in infection control (13), and showed increasing publication trends in gamification, game-based learning, and serious games (14).Recent research trends in medical education include studies on virtual assessments that identified trends such as gamification, AI, VR, and AR (15), and simulation-based education as a growing research hotspot (16). One analysis argued that the interdisciplinary nature of health literacy enhances research collaboration (17), while another explored AI's transformative impact on global business and management education (18). High-impact pediatric education research was also reviewed (19), and calls were made for global integration of AI in portfolio-based learning assessments (20). Some emphasized the need for inter-institutional collaboration in integrating e-health into curricula (21), and others identified five dominant areas in the literature: medical education, students, personnel, schools, and undergraduate programs (22).

The review underscores a growing global interest in network analysis for mapping scientific domains. Despite the expansion of such analyses in specialized fields, regional and local scientometric evaluations especially in medical education remain limited. This study aims to fill that gap by systematically analyzing the thematic structure and conceptual dynamics of medical education, contributing to a deeper understanding of its evolution and guiding future research and policy decisions. Four primary research questions guide the study:

- Question 1: What is the trend of scientific productions in medical education in the 2016-2025 and what factors have caused its growth or decline?
- Question 2: What is the degree of convergence and frequency between frequently occurring concepts in medical education in the periods 2001–2010 and 2016–2025?
- Question 3: What changes have the structure of the medical education Thematic network undergone over time and what process of becoming more specialized has it undergone?

- Question 4: What role do centrality indices (Closeness, Betweenness, Eigenvector, Degree) play in identifying key and central terms in medical education?

These questions are examined through the following hypotheses:

- H1: From 2016 to 2025, medical education has experienced significant growth in scientific production, driven by advancements in educational technology, interdisciplinary collaboration, and an increased focus on virtual and clinical training.
- H2: The degree of semantic convergence has increased in the 2016–2025 period compared to 2001–2010, with more specialized and frequently co-occurring vocabulary.
- H3: The network structure has evolved from a decentralized, fragmented form in the 2000s to a more clustered and specialized configuration in the 2020s.
- H4: Centrality indices particularly Betweenness and Eigenvector effectively identify strategic terms and core concepts in the semantic network of medical education.

2. Methods

This descriptive-analytical study employed word co-occurrence analysis, topic modeling, and semantic concept search using a semantic exploration tool to generate knowledge maps in the field of medical education. The research population included all articles indexed in the Web of Science (WoS), Thomson, and Clarivate databases during two time periods: 2001–2010 and 2016–2025. These intervals were selected due to the high volume and complexity of research outputs in this domain, which required temporal delimitation for more effective analysis.The WoS database was chosen for its comprehensive, multidisciplinary coverage and its strength in scientometric analysis, particularly in tracking citation networks and research trends. Unlike specialized medical databases such as PubMed, WoS includes broader interdisciplinary content—essential for analyzing medical education's overlap with fields such as management, computer science, and information technology.

Data collection was based on a keyword-driven search strategy. Keywords were identified through expert consultation and refined using AI tools. The final search formula for the recent decade was as follows (replicated for the earlier decade with adjusted dates):

TI=("Medical Education" OR "Medical Informatics" OR "health professions education" OR "Informatics Health" OR " Educational Equity in Medicine" OR "E-Learning in Medicine" OR "Inter professional Education" OR "Educational Feedback" OR "AI in Medical Education" OR "VR/AR in Medical Training" OR "Evidence-Based Medical Education" OR "Health Information Technology" OR "Patient Education" OR "Health Literacy" OR "Curriculum Evaluation" OR "educational management" OR "Internet" OR "interdisciplinary education") AND PY=(2016-2025)

A total of 44,627 articles (2016–2025) and 11,878 articles (2001–2010) were retrieved. Records were exported as plain text files and merged using TXT Collector. Keywords were standardized using PreMap Ravar software, expert input, and subject headings. This process involved removing stop words, country names, statistical terms, numbers, and uninformative words, as well as converting plural terms to singular. Key concepts were identified based on Bradford's law. For visualization and analysis, VOSviewer and Ucinet were used to map topic structures and thematic clusters. Centrality measures and network structures were analyzed and visualized using NetDraw. In total, 57 cleaned and formatted files were created, and thematic maps were generated to identify conceptual trends in the field. Final analysis and hypothesis testing were conducted using appropriate scientometric and social network analysis tools.

In this study, all articles related to medical education published during the selected years constituted the statistical population. Thematic concepts were used as measurement indicators to explore relationships between disciplines—an approach well-established in information science research. Notably, the target population was directly observed without any transformation or subjective interpretation. To ensure validity (measuring what was intended) and reliability (achieving consistent results), the following measures were taken: A precise search strategy was developed by researcher. Data were sourced exclusively from the Web of Science, a trusted and validated database. Post-collection, data were carefully filtered and monitored to eliminate inaccuracies and ensure quality.

The table 1 presents a summary of the methodology for testing each research hypothesis in the scientometric analysis of the medical education domain. It includes the analytical tools, type of method, and suggested software for each hypothesis.

Hypothesis No.	Content of Hypothesis	Analytical Tool	Type of Method	Suggested Software
Hypothesis 1	Growth in scientific production during 2016–2025	Trend and correlation analysis	Quantitative – Statistical	SPSS, Excel
Hypothesis 2	Increase in semantic convergence of terms	Co-occurrence and clustering analysis	Network-based – Semantic	VOSviewer,
Hypothesis 3	Increased specialization of the term network structure	Network structure and cluster comparison	Descriptive – Graph-based	Pajek,
Hypothesis 4	Role of centrality indices in identifying key terms	Calculation of centrality measures	Network-based – Mathematical	Pajek

3. Results

Here we show a comprehensive analysis of the collected data to answer the research questions and uncover conceptual and thematic patterns within the field of medical education. By applying scientometric and network analysis techniques, the chapter explores keyword co-occurrence, centrality measures, and thematic clustering based on records extracted from the Web of Science database. The data have been processed and visualized using specialized software tools such as VOSviewer, Ucinet, and NetDraw to reveal the structural and relational dynamics among key concepts.To ensure clarity and facilitate interpretation, the findings are accompanied by clear tables, charts, and network maps that illustrate the connections between topics, trends over time, and interdisciplinary linkages. Each section systematically addresses a specific research question, offering both quantitative and visual insights into the evolving landscape of medical education research.This analytical phase not only validates the methodological choices made in earlier stages but also provides the foundation for discussing the implications of the findings in the following chapters.

Question 1: What is the trend of scientific productions in medical education in the 2016-2025 and what factors have caused its growth or decline?

The total number of articles related to the field of medical education indexed in the WOS citation index from 2016 to 2025 was 44627 articles, the frequency of which during this time period is shown in figure 1. The analysis of productions by year of final publication is as follows. The year 2022 has the highest number of productions with 6,834 records (equivalent to 15.314% of the total data). After that, the year 2024 is in second place with 6,271 records (14.052%). The year 2016 has the lowest number of productions with 2,053 records (equivalent to 4.600% of the total data). The year 2017 is slightly higher than 2016 with 2,345 records (5.255%). Productions have increased steadily and significantly from 2016 (2,053) to 2022 (6,834). This is a growth of almost 330% over a 7-year period. Peak in 2022: Production peaks in 2022. After 2022, production declines in 2023 (5,749) and 2021 (5,981), and especially 2024 (6,271) and 2025 (3,276). The decline in 2024 and 2025 may be due in part to incomplete data for these years, as 2025 is still ongoing and 2024 data may not yet have been fully recorded. This is a common limitation in analyzing current and prior year data in mid-2025. However, even with this limitation, the current data show a decline compared to the peak years (2022 and 2021). The decrease in 2023 (5,749 compared to 6,834 in 2022) is also significant and indicates a change in trend after the peak. Trend: A continuous and strong growth is observed from 2016 to 2022, reaching a peak in 2022. After that, a downward trend begins in 2023, 2024 and 2025. Given that 2025 is still ongoing, the data for this year and to some extent for 2024 may not be complete yet and this decrease needs to be interpreted with caution. However, the decrease in 2023 compared to 2022 is real and significant.

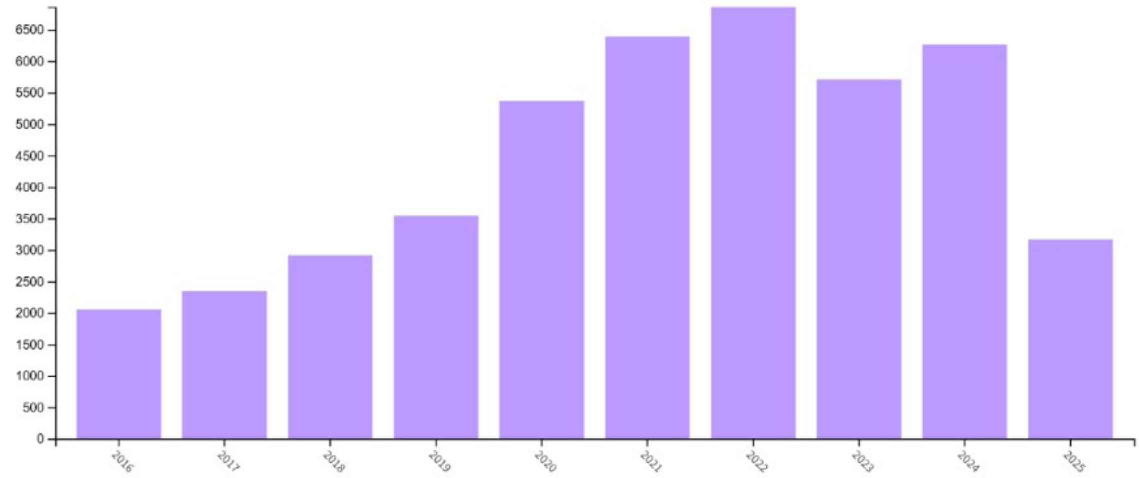

Figure 1. Trend of scientific productions in medical education.

Question 2: What is the degree of convergence and frequency between frequently occurring concepts in medical education in the periods 2001–2010 and 2016–2025?

The total number of articles related to the field of medical education indexed in the WOS citation index from 2001 to 2010 was 11878 articles, the frequency of which during this time period is shown in figure 2. The year 2010 has the highest number of productions with 1,448 records (12.191% of the total data). This is followed by the year 2001 with 1,174 records (9.884%). The year 2007 has the lowest number of productions with 1,107 records (9.320% of the total data). The years 2004 (1,094 records) and 2002 (1,099 records) are also close to the minimum.The data does not fluctuate significantly, with productions fluctuating between 1,100 and 1,450 records.The difference between the maximum (2010: 1,448) and the minimum (2007: 1,107) is only 341 records, indicating relative stability over this decade. After a slight decrease in 2007–2008, production increased significantly from 2009 to 2010 (from 1,291 to 1,448 records). The years 2001–2006 fluctuated around an average of ≈1,140 records without significant changes. Relative stability in most years with a maximum fluctuation of ±170 records around the average. The significant increase in production in 2009 and 2010 indicates a positive trend at the end of the period. This period, unlike the previous data (2016–2025), which had a more dynamic upward trend, indicates stability and sustainability in production.Comparing the two periods, the increase in production in the last decade is confirmed. Figure 1 shows the publications from 2016 to 2025, with 2022 having the highest output (6,834 records). Figure 2 covers the years 2001 to 2010, where 2010 reached its peak of 1,448 records. Comparing these, the numbers in the last decade are significantly higher - for example, the output in 2022 is about 4.7 times that of 2010. So there is a clear upward trend.

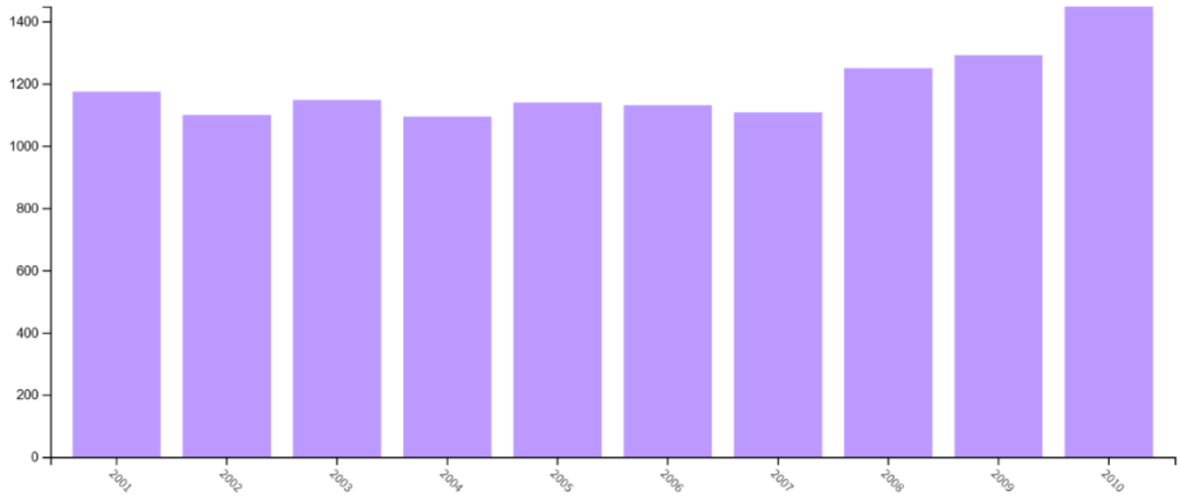

Figure 2. Trend of scientific productions in medical education in the 2001-2010.

Question 3: What changes have the structure of the medical education thematic network undergone over time and what process of becoming more specialized has it undergone?

Keywords with high frequency in the 2016-2025 thematic network (figure 3) include: health literacy, Internet of Things, medical education, machine learning, mental health literacy, communications. These terms are the main topics in the medical education network and act as the main nodes of interdisciplinary discussions. Betweenness centrality or bridging nodes in this network measures how often a node is on the shortest path between other nodes. High betweenness indicates the influence of cluster connectivity. Influential bridging terms include: health literacy (connects mental health and education), medical education (connects health, communication, and technology clusters), machine learning (connects artificial intelligence and healthcare), and Internet of Things (connects engineering/technology with healthcare).

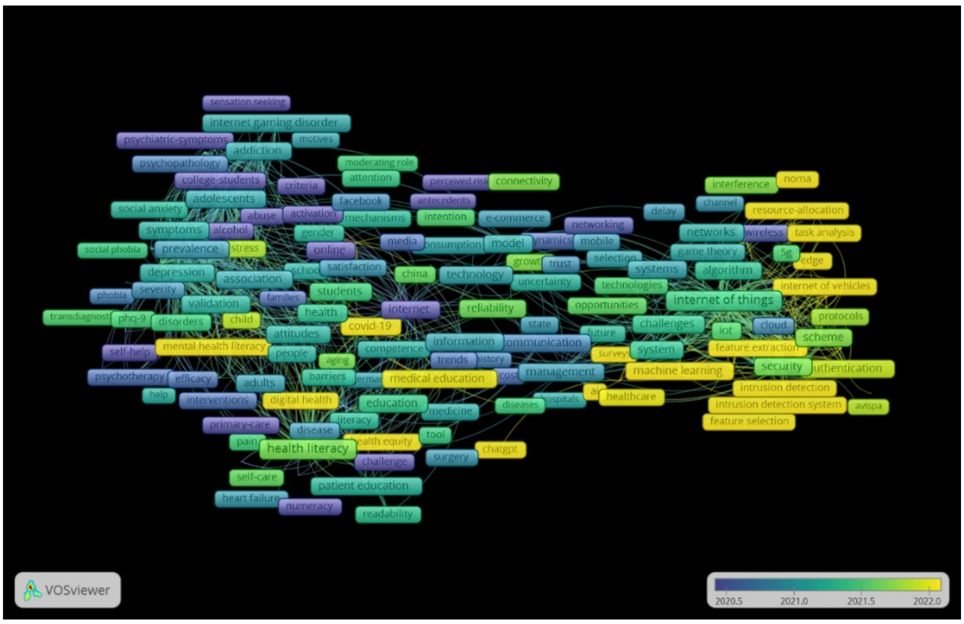

Figure 3. Thematic network of medical education in the Web of Science between 2016 and 2025.

These act as interdisciplinary hubs, showing that concepts such as machine learning and IoT are widely used in medical education. Proximity centrality, or accessibility, measures how easily a term can reach others. Terms with high proximity (central position on the map) include: communications, health, technology, digital health, education. These represent foundational concepts – often used across multiple domains and essential for network integration. The yellow and green colors indicate emerging or currently trending topics such as: IoT, machine learning, security, intrusion detection, authentication, health equity, mental health literacy, ChatGPT. It is notable that "ChatGPT" appears, indicating a recent surge of interest, particularly related to AI-assisted medical education. The convergence of subject terms highlights three main interdisciplinary clusters:

- Technology-enabled medical education (right; keywords: IoT, machine learning, security, 5G, authentication). Convergence through: "Internet of Things", "machine learning" indicates a shift towards intelligent, AI-based medical education systems.
- Focus on mental health and literacy (left, keywords: mental health literacy, addiction, adolescents, depression, Convergence through: "health literacy", "credentialing"). Strong in public health/psychology education; "health literacy" acts as a bridge.
- Core area of medical education (center, keywords: medical education, communication, digital health, management). Convergence through: "medical education", "communication" acts as the backbone of the entire map.

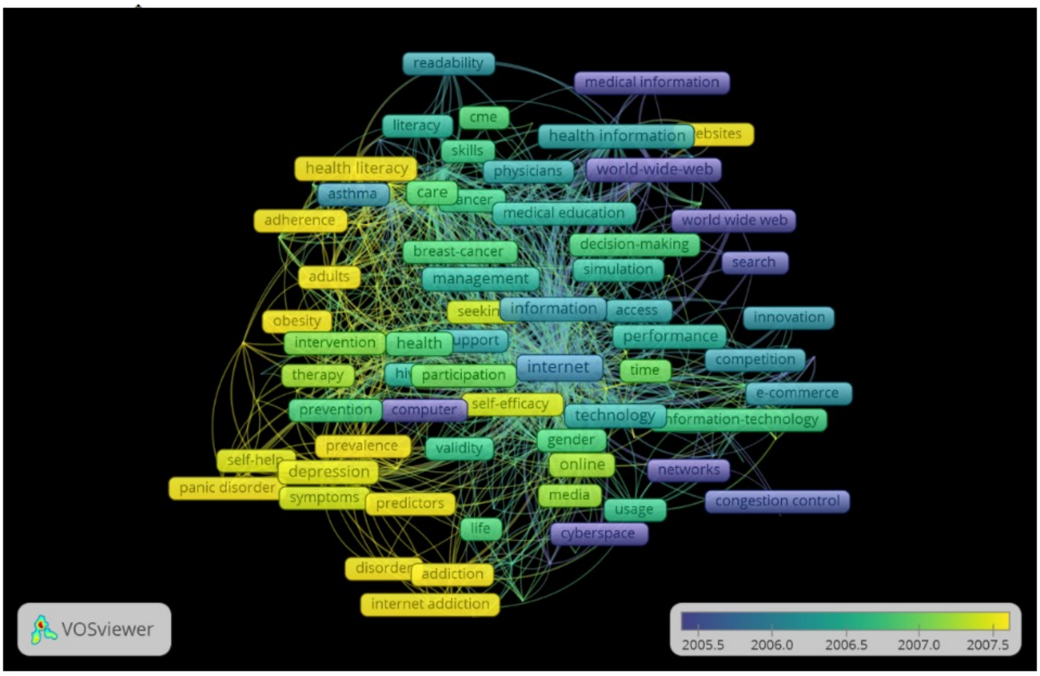

Figure 4. Thematic network of medical education in the Web of Science between 2001 and 2010.

Figure 4 illustrates the thematic structure of medical education research from 2001 to 2010, as analyzed through network science metrics and thematic convergence mapping. During this foundational period, the field was primarily centered on traditional educational priorities such as curriculum design, student learning, assessment strategies, clinical competence, and the broader infrastructure of healthcare education. Technology integration and AI-driven methodologies were not yet prominent. The thematic clusters indicate a strong instructional orientation, with an emphasis on pedagogical models and clinical training practices. In contrast to later years, particularly post-2020, the thematic landscape appears more fragmented, with fewer interdisciplinary linkages and a lower presence of data-intensive or computational approaches. This reflects the early developmental stage of the field before the rise of digital transformation and learning analytics in medical education.

Question 4: What role do centrality indices (Closeness, Betweenness, Eigenvector, Degree) play in identifying key and central terms in medical education?

Closeness centrality highlights the ability of certain concepts to efficiently reach all other parts of the network, acting as rapid connectors that promote interdisciplinary communication (figure 5). In this analysis, functional literacy stands out as the most central node, linking areas such as social vulnerability, health behaviors, maternal and mental health. Its central role shows how essential health understanding is to public health, clinical care, and education. Behavioral intention also emerges as a key connector, bridging topics like digital inequality, mental health, and healthcare policy—indicating its importance in translating educational efforts and technologies into actual behavior change. Similarly, health literacy plays a vital role, positioned at the crossroads of personalized care, digital innovation, and social equity. These central nodes do not always have the most direct links, but they hold strategic positions that allow for efficient flow of information across the network. They enable knowledge integration between clinical practice, educational reform, and social health, supporting the development of modern, collaborative approaches in medical education and healthcare.

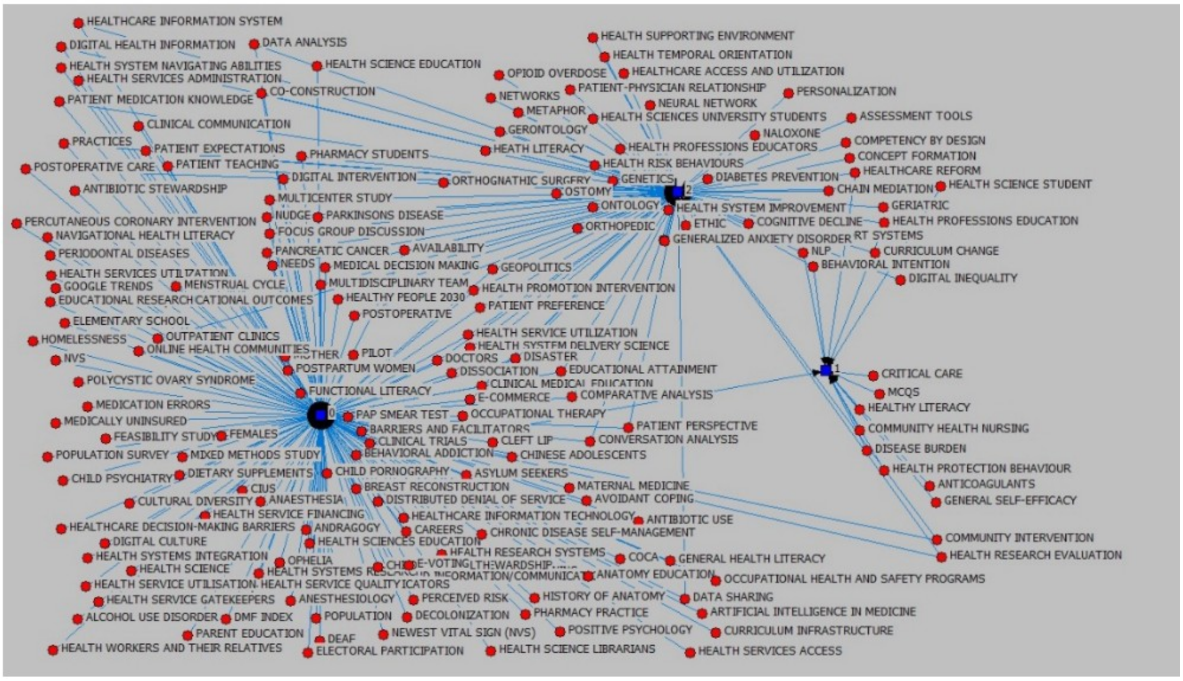

Figure 5. Scientific map of the field of medical education based on the closeness centrality criterion.

The structure and betweenness centrality network of the medical education field is shown in figure 6. The interpretation of betweenness centrality in the semantic network of medical education highlights the importance of certain key concepts that act as bridges between otherwise separate thematic clusters. These intermediary nodes enable the flow of knowledge and ideas across different disciplines, promoting integration and coherence within the network. Concepts with high betweenness values are visually represented by larger red circles, showing their frequent role in linking different areas.

- Among them, Node 0—Health System—emerges as the most central and influential, serving as a bridge between clinical service delivery, digital health, chronic disease management, and population health. This node reflects how healthcare infrastructure, policy, and digital transformation intersect to shape medical practice.
- Node 1—Health Literacy—also plays a vital bridging role, connecting domains like digital inequality, behavioral science, patient communication, and personalized care. It represents

the multifaceted nature of health literacy and its relevance to both equity and innovation in education.

- Node 2—Health Professions Education—connects areas related to curriculum reform, assessment methods, clinical training, and pharmacy education, underscoring the role of education in shaping professional competencies and self-efficacy. Other moderately influential nodes include digital interventions, neural networks, and NLP, which link the realm of emerging technologies with health delivery. Concepts like patient perspective, focus groups, and cultural diversity also help connect public health and patient-centered approaches. Overall, the network reveals several thematic axes such as the integration of mixed methods in research, the empowerment role of education and literacy, the focus on equity and vulnerable populations, the incorporation of advanced technologies into care, and the unification of psychological and behavioral strategies in health promotion. These conceptual bridges ensure that medical education evolves not in isolated silos but as a dynamically connected and interdisciplinary field.

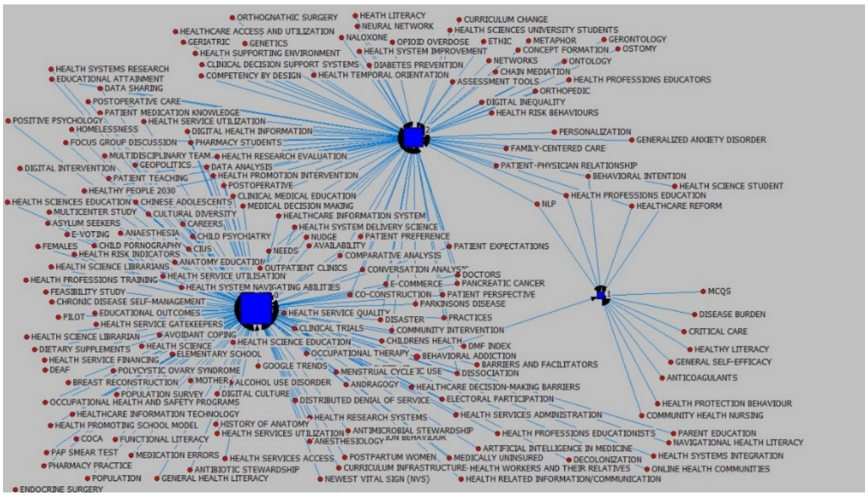

Figure 6. Co-occurrence network of descriptors based on the betweenness centrality measure.

The interpretation of the eigenvector centrality network reveals that influence within the network is not solely determined by the number of connections a node has, but also by the importance of the nodes it connects to (figure 7). Nodes with high eigenvector values, represented by large red circles, play a dominant conceptual role and are deeply embedded in the thematic structure of the field. The dark blue squares on the map, particularly nodes 0, 1, and 2, represent central hubs that shape the conceptual architecture. Node 0, the most influential, is closely linked to key terms such as patient preference, health research evaluation, and health service quality, suggesting a strong integration of medical education with healthcare policy, service delivery, and patient-centered care. Node 1, while slightly less dominant, focuses on concepts like health literacy and health promotion behavior, highlighting the importance of preventive education, public health, and behavioral change. Node 2, with fewer but strategically meaningful connections, bridges themes of digital health, educational reform, and access to care, connecting concepts such as digital inequality, curriculum change, and healthcare utilization. These nodes form thematic clusters that reflect key areas in medical education, such as the integration of digital health and technology to promote equity and informed clinical decisions; the modernization of medical curricula to enhance competency-based education; the role of psychological and behavioral factors in health education; the emphasis on social justice and health policy for equitable access and governance; and the rise of mixed methods and qualitative research approaches that deepen understanding of complex health phenomena. Overall, the structure suggests a well-connected, interdisciplinary, and evolving knowledge network within the field of medical education.

The degree centrality network map illustrates the most frequently co-occurring concepts in medical education and health-related literature, highlighting dominant themes and conceptual hubs (figure 8). Nodes with the highest number of direct connections particularly nodes 0, 1, and 2 stand out as key pillars in the discourse. Node 0, representing the health systems and digital health axis, is the most connected, linking terms such as health service quality, digital information, pharmacy education, and multidisciplinary teams, reflecting a broad theme that integrates policy, digital infrastructure, and socio medical issues. Node 1 emphasizes the intersection of digital health and behavior, connecting clinical education with technologies like NLP and data sharing, showing how innovation supports decision-making and behavior change. Node 2 centers on health equity and educational access, linking digital inequality, curriculum change, and patient expectations highlighting efforts toward inclusive and reform driven healthcare. Overall, the network shows thematic convergence across digital innovation, curriculum development, psychological well-being, equity, and interdisciplinary research, suggesting a dynamic and interconnected research landscape in medical education.

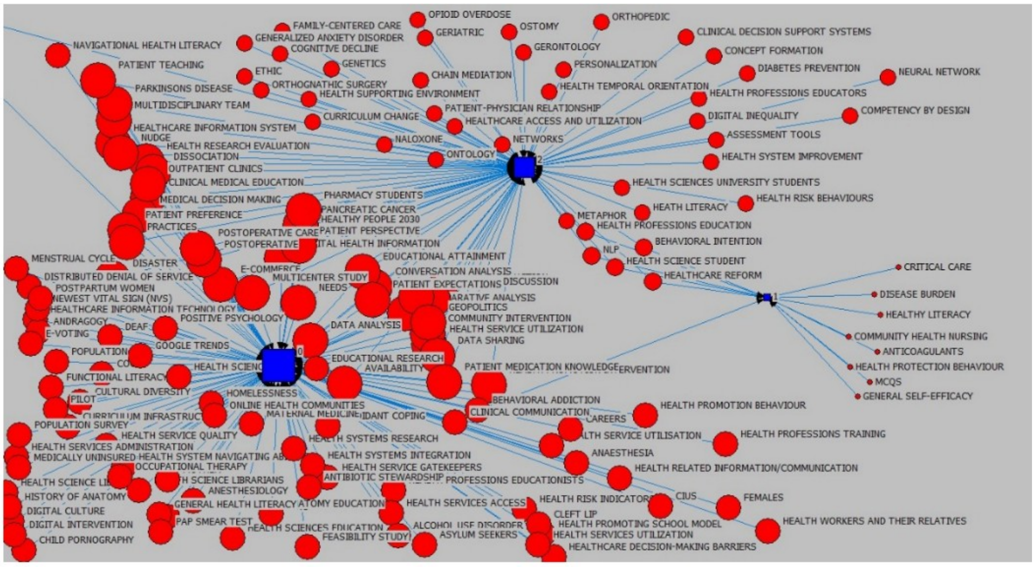

Figure 7. Medical Education Research Domain Based on Eigenvector Index.

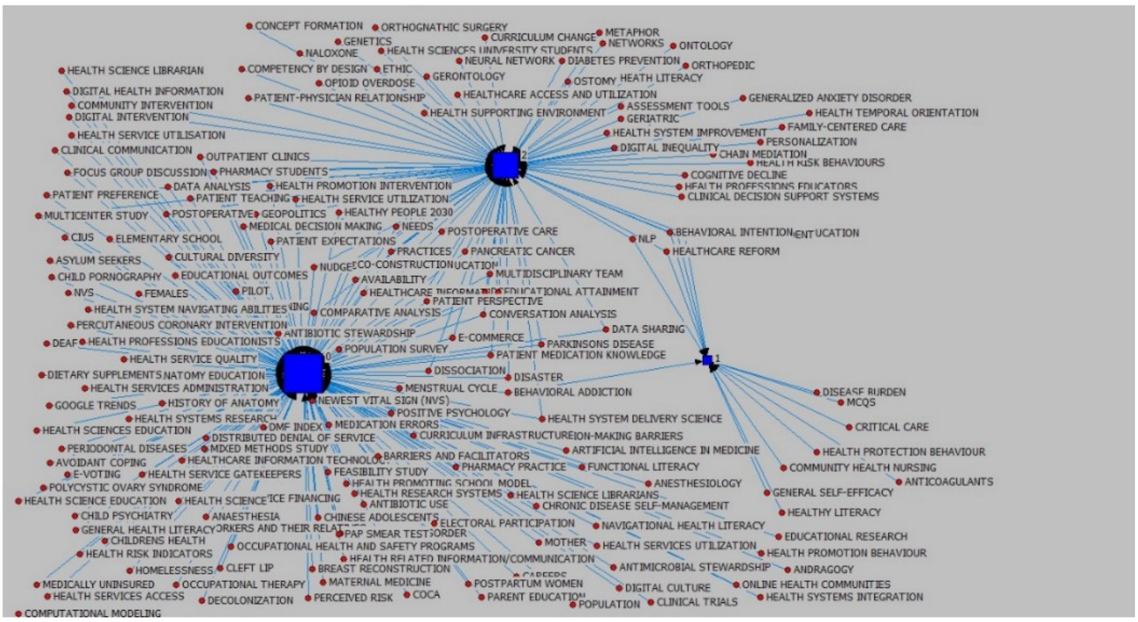

Figure 8. Medical Education Research Domain Based on degree centrality.

4. Discussion

Technological Transformation in Medical Education and Digital Health Integration and Studies highlight the shift toward digital health competencies (e-health, AI, VR) in curricula.The integration of digital health competencies into medical education has transformed training models worldwide. As highlighted by Timakum et al. (2022), the incorporation of telehealth, wearables, and data analytics has become crucial for modern curricula. New technologies like simulation-based learning and generative AI (e.g., ChatGPT) are being recognized as emerging trends in medical education (8). Their successful integration demands institutional support and cross-sector collaboration to ensure effectiveness in teaching and assessment. Scientometric findings reinforce that despite technological progress, the thematic structure of medical education research remains fragmented. For instance, the co-occurrence and network analysis of publications from 2001–2010 and 2016–2025 reveal a progression from generalized clusters to more specialized terminologies and structures(16). Khademi et al. (7) mapped nine clusters in health information management, and Maskerpour et al. (5) outlined three core COVID-19 clusters: public health, clinical practice, and basic science. However, compared to fields such as diabetes or HIM, comprehensive scientometric evaluations of medical education are limited (5-7).

Data-driven analysis of the thematic networks demonstrates semantic convergence in medical education, especially in recent years (2016–2025). The increased closeness and eigenvector centrality values for terms like "simulation," "telemedicine," and "competency-based education" suggest growing importance and interconnection of these terms within the broader domain. Meanwhile, betweenness centrality highlights key bridging terms such as "assessment" and "curriculum," indicating their critical role in linking specialized subdomains. Scientometric data further reveal disparities in global collaboration.(6-9). Guo (13) identifies a lack of North-South partnership, with developed nations like the U.S., China, and European countries dominating publication output, especially during the COVID-19 era. Burtis and Shekhar (10-11) also reports fragmented collaboration networks in healthcare management. These imbalances can hinder equitable knowledge distribution and innovation. Network metrics such as degree and betweenness centrality were instrumental in identifying influential topics and authors, as evidenced in scientometric studies by Maleki et al. and Timakum et al. Such metrics help locate strategic nodes that bridge different thematic areas. For example, in the 2016–2025 term map, "digital learning" and "virtual simulation" had high eigenvector and degree values, indicating their centrality and influence across clusters.The integration of scientometric techniques, including co-occurrence mapping and centrality analysis, provides robust insights into the evolution, convergence, and fragmentation of medical education research. The emergence of specialized clusters and semantic coherence in recent years points to a maturing field, although interdisciplinary gaps and global inequities remain challenges to be addressed. Future research must leverage these analytical tools to support curriculum innovation, policy-making, and inclusive academic collaboration. Another critical aspect of the thematic structure is the increasing modularity and density observed in recent network maps, especially between 2016 and 2025. Compared to the earlier period (2001–2010), the newer networks demonstrate a more interconnected web of key terms, with noticeable subdomains forming around "digital assessment," "inter professional education," and "adaptive learning." These modules not only reflect the diversification of educational themes but also indicate the stronger interdependence between technological and pedagogical innovations. The density of these clusters measured by higher degree centrality and their strategic positions captured by betweenness and closeness values highlight the emergence of new disciplinary junctions and the shifting core of medical education knowledge production.

Analysis and Evaluation of Research Hypotheses in Medical Education.

- Hypothesis 1: Growth in Scientific Output in Medical Education Between 2016 and 2025, scientific production in medical education has experienced significant growth. This rise is largely attributed to the advancement of educational technologies, the expansion of virtual and interdisciplinary learning, and the global impact of the COVID-19 pandemic. Peak publication years are observed in 2021 and 2022, with a slight decline afterward. Key terms such as digital health, machine learning, and telemedicine appear at the center of co-occurrence networks, indicating strong semantic convergence and thematic focus. Conclusion: Hypothesis confirmed. Supported by scientometric trend data and thematic network analysis.

- Hypothesis 2: Increased Semantic Convergence of Core Concepts. Comparative analysis of the semantic networks from 2001–2010 and 2016–2025 reveals a clear increase in conceptual convergence. In the later period, concepts cluster more tightly around specialized terms such as competency-based education, simulation, and digital tools. These clusters reflect the growing thematic maturity and lexical consistency of the field. Conclusion: Hypothesis confirmed. The dense clustering of terms in the recent period indicates a more coherent and specialized knowledge structure.
- Hypothesis 3: Structural Evolution of the Conceptual Network. The structure of the medical education conceptual network has evolved from a fragmented, decentralized form (2000s) to a centralized and modular architecture in the 2020s. Core terms such as curriculum, simulation, communication, and assessment now dominate thematic clusters. The post-COVID era also introduced strong links to technological and mental health-related terms, marking an era of structural consolidation. Conclusion: Hypothesis confirmed. The current network shows increased modularity, cohesion, and centrality of high-impact concepts.
- Hypothesis 4: Effectiveness of Centrality Indices in Concept Identification. Centrality measures especially Betweenness and Eigenvector are proven to be effective tools for identifying influential and strategic concepts within the semantic network. Terms like health literacy, assessment, and technology consistently show high centrality values, positioning them as conceptual bridges and thematic anchors across clusters. Conclusion: Hypothesis confirmed. Centrality metrics reliably highlight key nodes within the knowledge structure and guide research focus areas.

Final Summary of Hypotheses

Hypothesis	Result	Supporting Evidence
Scientific output growth	Confirmed	Time-series graphs (2016–2025)
Semantic convergence	Confirmed	Co-occurrence and clustering analysis
Network structure evolution	Confirmed	Conceptual cohesion and centralization
Role of centrality metrics	Confirmed	Identification of key and strategic terms

5. Conclusions

- The scientometric investigation of medical education between 2001 and 2025 reveals a profound transformation in the structure, vocabulary, and dynamics of the field. Over two decades, medical education has evolved from a traditionally curriculum centered, assessment driven domain into a complex, interdisciplinary landscape strongly influenced by digital transformation, virtual pedagogy, and health informatics. Comparative analysis of co-occurrence networks and centrality indices clearly demonstrates:
- A significant increase in scientific production during 2016–2025, closely tied to the rise of e-learning, simulation based education, and the global disruption of COVID-19. An increase in semantic convergence, particularly around core themes such as competency-based education, digital health, telemedicine, and health literacy, reflecting growing conceptual coherence and maturity.
- A structural evolution from scattered and loosely connected conceptual clusters in 2001–2010 to tightly clustered, specialized subnetworks in 2016–2025 evident in higher modularity, clustering coefficients, and proximity indices.

- The strategic role of centrality measures especially betweenness and eigenvector in identifying key bridging concepts and thought-leading nodes such as health literacy, simulation, and assessment, which integrate technical, behavioral, and educational dimensions.
- Furthermore, the data reveal persistent geopolitical imbalances in global scientific collaboration, with developed countries dominating scholarly output, while contributions from the Global South remain limited. Addressing this imbalance requires proactive policy, cross-border collaboration, and equitable access to digital infrastructure and research platforms. From a methodological standpoint, this study affirms the effectiveness of scientometric and network analysis tools (e.g., VOSviewer, Pajek, NetDraw) in uncovering latent patterns, guiding curriculum design, and informing strategic research planning.
- Medical education is no longer an isolated academic discipline but a convergent, multi-domain system linking healthcare, behavioral science, technology, and pedagogy. High-centrality concepts serve as levers for research prioritization and innovation especially in digital education, AI applications, and patient centered care. Scientometric mapping is not only descriptive but predictive, offering actionable insights for future educational strategies, especially in post-pandemic contexts.
- Looking ahead, the future of medical education must be guided by policies that promote adaptive learning ecosystems, digital equity, and interdisciplinary curriculum integration. To bridge identified gaps, educational institutions and policymakers should invest in scalable digital infrastructures, strengthen faculty digital literacy, and promote inclusive access to e-learning platforms especially in underserved regions. Greater emphasis must be placed on integrating AI-driven decision support, virtual simulation, and competency based assessment models within formal curricula. Additionally, fostering global academic partnerships, supporting open access research repositories, and aligning curricula with evolving healthcare challenges such as mental health and health disparities will be essential for cultivating a responsive, equitable, and forward looking medical education system.

Acknowledgments. Ethics approval and consent to participate and Consent to publication is applicable and Data and materials are fully available and made available to the publisher. Also The would like to give special thanks to editorial team, and anonymous reviewers for the helpful suggestions.

Authors' contributions. Design of the study & Data preparation, collection and analysis were performed by MB Negahban. The first draft of the manuscript was written by MB Negahban and the author read and approved the final version.

Funding. This study did not receive any specific funding.

Availability of data and materials. The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Competing interests. Authors states that there are no competing interests.

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