REVIEW ARTICLE

Trends and Insights on the Importance of Anatomy Education in Undergraduate Nursing Program: Bibliometric analysis

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ABSTRACT

This study performs a bibliometric analysis of anatomy education in nursing programs from 2004 to 2024 and identifies key trends and insights to enhance educational strategies and clinical competence. The study analysed 105 publications in the Scopus database, revealing an increasing trend in research activity, with significant contributions from the United States and Australia. The integration of advanced technologies such as simulation and virtual reality to enhance clinical competence is on the rise. Interdisciplinary approaches that integrate anatomy education within broader medical training are also being emphasized. The study acknowledged potential biases from database selection and language focus and suggested that future research should include broader and non-English sources for a comprehensive understanding. Overall, the analysis highlights the growing integration of advanced technologies and interdisciplinary approaches in anatomy education, providing valuable insights for educators and policymakers to improve nursing education.

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INTRODUCTION

Nursing is a vital profession dedicated to providing care to individuals and communities, guided by a commitment to enhance health and quality of life as outlined in the Nursing Professionals Code of Ethics (1). To deliver high-quality care, nursing professionals must continuously develop their expertise, adhering to National Curricular Guidelines that emphasize scientific rigour and ethical principles. Human anatomy is a crucial component of the undergraduate nursing curriculum, equipping nurses with essential knowledge for clinical practice (2). Understanding human anatomy is fundamental for nursing students, ensuring their competence in clinical assessments and procedures. While a basic grasp of anatomy is essential for all nurses, those aspiring to advanced roles require deeper expertise. However, anatomy remains one of the most challenging subjects for nursing students (3,4). Previous studies on anatomy education in nursing have primarily utilised content analysis methods such as scoping literature reviews and systematic reviews and meta-analyses (5,6).

This study employs bibliometric analysis to evaluate the development of the field, focusing on publications from 2004 to June 2024 in the Scopus database. The study aims to highlight current research trends and notable contributing authors in anatomy education in nursing. Bibliometric analysis provides a comprehensive view of the historical development of the field, identifying key variables, prolific authors, and the growth of the discipline (7). Additionally, the study will identify the most cited articles, productive countries, and affiliations in the field, helping researchers find reliable articles and understand the field's growth over time (8). Top-cited articles provide quantitative data about the countries and affiliations of the authors, facilitating the identification of key contributors and collaborations (9). Bibliometric analysis also aids researchers in finding potential collaborators and selecting high-quality journals (10).

This study contributes to the literature by providing an extensive picture of the historical development of anatomy education in nursing, guiding future research with important considerations such as methodologies, key concepts, top journals, institutions, publications, and authors. Understanding leading universities in anatomy education research may indicate regional tendencies in the field. The study's results will benefit companies, policymakers, decision-makers, analysts, and academics globally by shedding light on anatomy education research and its evolution. The motivation behind this study is to analyse publications on anatomy education using bibliometric analysis, offering a novel contribution to the literature and a comprehensive picture of the current state of anatomy education knowledge.

LITERATURE REVIEW

Current State of Anatomy Education in Nursing Programs

Anatomy education holds a pivotal role in nursing programs, providing essential knowledge of human body structures critical for understanding physiological processes, disease mechanisms, and clinical procedures. Al Mushaiqri et al. (11) highlight a preference among nursing students for deep learning approaches over rote memorization, as seen in their study at Sultan Qaboos University, which showcases students' motivation to engage deeply with anatomical content. The anatomy curriculum typically covers major body systems, including musculoskeletal, cardiovascular, respiratory, nervous, digestive, urinary, and reproductive systems. Most programs emphasize clinically relevant anatomical knowledge, aligning with The Anatomical Society's core syllabus, underscoring foundational knowledge for clinical practice (12,13).

Pedagogically, theoretical content is primarily delivered through lectures, supplemented by practical sessions using models, specimens, and, in some institutions, cadavers (14-16), cadaveric materials are integrated into some curricula, such as the Silent Mentor Program in Taiwan, which also aims to develop students' humanistic skills (17). However, only a limited number of nursing programs provide cadaveric experience (16). The details of integrating cadaveric materials and the formats of teaching sessions often remain unclear. There is a growing trend towards using digital resources, such as 3D anatomical software and virtual dissection tables, to enhance learning experiences. Virtual reality 3D human cadaver tables (e.g., Anatomage or Sectra) have been reported to be effective in enhancing anatomical knowledge (18). The Anatomical Society advocates for integrating modern technological tools alongside traditional methods to aid students' visualization and comprehension of complex structures (13).

In the United Kingdom, the Nursing and Midwifery Council (NMC) mandates that registered nurses apply knowledge of anatomy, physiology, and related sciences in person-centred care (19). Similarly, the European Federation of Nurses Associations (EFN) expects EU nurses to understand human body structure and function (20). In Canada, the National Nursing Education Framework highlights the necessity of health sciences knowledge for nursing assessments and interventions (21). These regulatory bodies emphasize the application of bioscience knowledge to deliver effective, person-centred care.

Frameworks supporting bioscience education for nursing curricula include (22) and (13). However, how these learning outcomes are met is open to interpretation. A crucial but often neglected discussion is the method of teaching this content to ensure students' understanding and application in practice. Despite several frameworks offering insights into anatomy education content and numerous studies promoting various teaching methodologies, a comprehensive, unified approach that ties these methodologies together is lacking (24). Significant variations exist across nursing programs regarding dedicated anatomy courses versus integrated Anatomy and Physiology units (5). While evidence suggests nursing students are adopting deep learning approaches, challenges persist (11). Future research should investigate the long-term impact of different teaching strategies on retaining and applying anatomical knowledge in clinical practice, ensuring nursing students acquire a robust foundation in anatomy essential for high-quality patient care.

Innovations and Challenges in Anatomical Training

Anatomy education in nursing faces various challenges, including packed curricula, perceptions of difficulty, limited hands-on experience, and the integration of theoretical knowledge with clinical practice. Educators are actively addressing these challenges through the implementation of interactive learning tasks, problem-based learning, and frequent low-stakes assessments that emphasise their clinical relevance. Previous studies have shown that interactive tasks and quizzes significantly contribute to deep learning (11). Active learning techniques have also been practised in nursing education including escape rooms (25), concept cartoons (27), flipped classrooms (26), simulation (27), and case-based learning (28). Further research into active learning methodologies within the nursing education domain is necessary.

Technologies such as virtual reality (VR) and augmented reality (AR) enhance anatomy training by offering immersive, interactive learning opportunities, surpassing conventional techniques like cadaveric dissection (29). These technologies improve spatial understanding and provide practical learning through 3D printed models

and digital dissection tables (30). VR simulators allow students to practice clinical scenarios safely (31), and AR/VR has been shown to increase student engagement and academic performance (32).

However, advanced training methods face challenges, including the high cost of VR equipment, 3D printers, and software, as well as the need for regular updates and technical expertise (32). Accessibility is also a concern, with educational institutions needing to ensure all students have the necessary resources (33). While cadaveric dissection remains invaluable for hands-on experience (34), it raises ethical and safety concerns. Alternatives like synthetic cadavers and digital tools offer solutions but also face challenges related to cost and realism. Balancing innovative methods with traditional techniques is crucial for providing comprehensive anatomical education.

Importance of Anatomy Knowledge in Advanced Nursing Roles

Anatomy education enhances nursing students' medical expertise while fostering essential humanistic skills. This combination supports their professional growth, improves efficiency in delivering compassionate care, and nurtures a strong sense of professionalism (35). A solid grasp of anatomy enables nurses to perform physical assessments more accurately and interpret diagnostic tests with greater precision (5). Moreover, also enhances nurses' ability to engage in evidence-based practice (36).

Excellent anatomy and physiology knowledge contributes to patient safety. Nurses with advanced anatomical knowledge are better equipped to identify potential complications and recognize early signs of deterioration in patients (37). This is especially important in critical care settings where advanced practice nurses often work. Nurses with stronger anatomical knowledge were more capable of identifying potential complications and intervening earlier, thereby improving patient safety outcomes (5,39).

Furthermore, anatomy knowledge plays a critical role in facilitating advanced nursing roles and specializations. According to (35) advanced practice nurses, such as nurse practitioners and clinical nurse specialists, rely heavily on their in-depth understanding of anatomy to perform advanced procedures and make complex clinical decisions (5) highlight those specialized areas of nursing, that require enhanced anatomy knowledge to provide high-quality care in the specialized settings. Continuous professional development and lifelong learning in anatomy are crucial for nurses due to the evolving nature of medical knowledge and practice. Ongoing education in anatomy helps nurses stay current with discoveries and advancements in medical science, which directly impacts patient care quality (39).

MATERIALS AND METHODS

Research questions

Bibliometric analysis methodology was employed for the construction of clear and concise research questions. This study addresses the following research questions to explore various trends related to research productivity, collaboration and knowledge dissemination in anatomy education in nursing programs. The following research questions (RQs) were formulated:
RQ1. What are the publication trends in anatomy education in nursing programs?
RQ2. Who are the major contributing authors in anatomy education in nursing programs?
RQ3. Which articles have the highest citation count in anatomy education in nursing programs?
RQ4. Which countries are the most productive in anatomy education in nursing programs?
RQ5. What is the most frequently used author keyword in anatomy education in nursing programs?

Sources of Data and Search Strategy

A keyword search was conducted in the Scopus database on 1 June 2024, covering publication timelines ranging from 2004 to June 2024. The search was limited to articles in English, with no restrictions on document type or source type. Specific keywords were used to target relevant literature in the article title, abstract and keywords fields. The search parameters were: ((TITLE-ABS-KEY ("anatomy" OR "anatom*" OR "anatom* edu*" OR "anatom* teach*" OR "anatom* pedagogy" OR "human anatomy") AND TITLE-ABS-KEY ("nurse" OR "nursing") AND TITLE-ABS-KEY ("undergrad*")) AND PUBYEAR >2003 AND PUBYEAR <2025 AND (LIMIT-TO (LANGUAGE, "english")). This search yielded 111 papers related to anatomy education in nursing programs. As this is based on secondary data analysis, no ethics approval was required.

Scopus was chosen for this study due to its comprehensive and multidisciplinary coverage, particularly in the fields of nursing and health sciences, making it well-suited for capturing relevant research in anatomy education. The database's rigorous selection process ensures that only high-quality, peer-reviewed literature is included, which is crucial for the reliability of our bibliometric analysis. Scopus also offers advanced bibliometric tools and reliable citation data, supporting a robust analysis of research trends and impact.

Data Screening

All the documents obtained have been screened for duplications or any irrelevant documents to the topic of the study. We then further removed 6 articles that were not related to the topics, resulting in a final total of 105 publications for bibliometric analysis. The publication-

related data were exported as comma-separated values (.csv) and format files and saved for further analysis.

Data Cleaning and Harmonisation

Data cleaning and harmonisation are critical steps in bibliometric analysis to ensure the accuracy and reliability of the results, particularly due to the potential redundancies and inconsistencies in the raw data extracted from Scopus. In our study, we employed a systematic approach to data cleaning and harmonisation using biblioMagika® and OpenRefine (https://openrefine.org/) tools. These software tools were used to clean and harmonize unstandardized data and essential bibliographic information (40).

biblioMagika® Microsoft Excel filters, developed by Ahmi (41) was employed to conduct extended bibliometric measurements of factors such as total publications (TP), number of contributing authors (NCA), number of cited publications (NCP), total citations (TC), citations per paper (C/P), citations per cited paper (C/CP), citations per author (C/A), citable year, and h-index. The h-index (or Hirsch index) and g-index are metrics that are used to measure the productivity and impact of a researcher's publications. The h-index is the highest number of h; thus, at least h publications in the list have been cited h times each (42). Initially, the bibliographic data, including keywords, author names and affiliations, were extracted and reviewed for duplications and inconsistencies. This is essential for the next steps in using the VOSviewer tool to ensure that incomplete or inaccurately formatted data is not uploaded, as it could lead to incorrect results. We found missing data and variations in author names (e.g., consolidating "J. Smith" and "John Smith"), single-name authors, author's initials, affiliations (e.g., "Leeds University" and "Leeds Business School") and countries. The standardization process was facilitated by biblioMagika®.

Later, we used OpenRefine, an open-source data management tool to standardise variations and duplication more efficiently in author names and institutional affiliations, ensuring uniform representation across the dataset. Furthermore, we corrected inconsistencies such as misspellings and variations in keywords by cross-referencing with authoritative sources. This process was crucial for maintaining data integrity and ensuring that each publication was accurately categorized. We also employed OpenRefine to normalize keywords by grouping synonymous terms (e.g., "VR" and "virtual reality") under a single cluster, thus ensuring consistent thematic analysis. Publications were also categorised based on their focus areas, such as "educational technology", "curriculum development", or "anatomy education." This was done using a combination of automated keyword analysis and manual verification to ensure accuracy. Following the initial cleaning, the data were manually reviewed for accuracy, with multivalued cells rejoined to maintain consistency, and then exported in its original format for further analysis. By meticulously applying these methods, the dataset was rendered more robust, facilitating a more reliable and valid bibliometric analysis.

Bibliometric analysis tools

We employed various tools to conduct a comprehensive bibliometric analysis. We used biblioMagika® Microsoft Excel filters to compute the frequency and percentage of each publication and to create appropriate graphical representations. We also used the freely available VOSviewer (version 1.6.17) software (http://www.vosviewer.com) to create and visualise the bibliometric networks, and Harzing's Publish and Perish tool was used to compute the citation metrics.

RESULTS

Publication profiles

During the period of the year 2004 to June 2024, we retrieved a total of 105 publications in various types and sources. In terms of document types, articles predominate (82.86%), followed by reviews (9.52%), and smaller numbers of books, conference papers, and book chapters. This diversification suggests different dissemination approaches for various academic audiences. The distribution of source types reveals a strong reliance on journal publications (93.33%), reflecting trust in peer-reviewed journals for validating and communicating research findings. The inclusion of books and conference proceedings, though limited, indicates a supplementary role in reaching broader or specialized audiences.

Based on the dataset, 435 authors contributed to the study of anatomy education in nursing programs. Authorship data shows a collaborative research environment, with an average of 4.14 authors per paper. This indicates interdisciplinary collaboration likely involving experts in anatomy, nursing education, and pedagogy. Citation metrics reveal a substantial engagement with the literature, totalling 1,252 citations. The average citations per paper (11.92) and per cited paper (14.23) suggest that while many papers are cited, a subset of highly influential works drives up the averages. The citation per author metric (2.88) measures individual impact, although it may vary with the contributions of co-authors. The h-index of 18 and g-index of 30 indicate both depth and breadth of impactful research, while the m-index of 0.857 reflects sustained academic interest.

Publication Trends

The analysis of the annual volume of publications regarding anatomy education in nursing programs, as detailed in Fig.1, provides a longitudinal perspective

on the research output and impact of studies related to anatomy education in nursing programs. The total number of publications indicated a fluctuating but overall upward trend in research activity over the two-decade period. In the early years (2004-2007), research activity was relatively modest, with only one to two publications annually. However, these early works demonstrated significant impact, as indicated by high citation averages (e.g., 39 citations per publication in 2004 and 53 in 2006). This suggests that foundational studies during this period laid the groundwork for future research, garnering substantial attention and setting the stage for subsequent academic inquiry. From 2008 onwards, there was a noticeable increase in both the number of publications and contributing authors, reflecting a growing interest and collaborative efforts in the field. Notably, 2013 marked a peak in average citations per publication (31.33), signifying that the research produced during this time continued to build on earlier influential works, maintaining a high level of academic engagement.

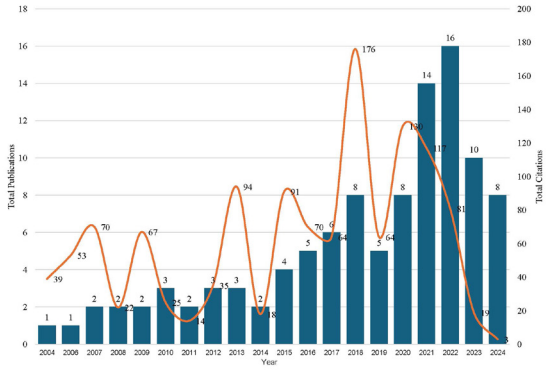

Figure 1: Total Publications and Citations by Year.
Source: Generated by the author(s) using biblioMagika® (41)

The period from 2015 to 2020 saw a significant surge in publication output, peaking at 16 publications in 2022. The year 2018 stands out with the highest total citations (176), indicating that the publications from this year had a substantial influence on subsequent research. despite a high number of publications in 2021 and 2022, the total citations were lower (117 and 81, respectively). This indicates that while more research was being conducted and published, the impact of individual papers varied, with some achieving substantial recognition and others contributing to the growing body of knowledge with more modest citation counts, suggesting that it may take time for these newer publications to be fully recognized and cited by the academic community.

Publications by Authors

In total, 435 authors contributed to this field of research. The top 10 authors included two from Griffith University, two from University College Dublin, and one from each of the following institutions: The University of Queensland, Federation University Australia, Auckland University of Technology, McGill University, Karolinska Institutet and James Cook University (Table I). The leading author in this research area was Amy N.B. Johnston from The University of Queensland, Australia, with 4 publications and 92 citations, averaging 23 citations per paper. Her work maintains a consistent impact with an h-index and g-index of 4, indicating broad and sustained influence within the field. Similarly, Michael S. Barbagallo from Federation University Australia and Stephen J. Brown from Auckland University of Technology in New Zealand have each contributed 3 publications. Barbagallo's publications have garnered 9 citations, averaging 3 citations per paper, with an h-index and g-index of 2 and 3 respectively. Meanwhile, Brown's contributions have accrued 35 citations, averaging 11.67 citations per paper, with an h-index and g-index of 3, demonstrating a robust impact on the field.

Table I: Most Productive Authors

Author's Name	Current Affiliation	Country	TP	NCP	TC	C/P	C/CP	h	g	m
Johnston, Amy N.B.	The University of Queensland	Australia	4	4	92	23	23	4	4	0.33
Barbagallo, Michael S.	Federation University Australia	Australia	3	2	9	3	4.5	2	3	0.4
Brown, Stephen J.	Auckland University of Technology	New Zealand	3	3	35	11.67	11.67	3	3	0.3
Ventura, Nicole M.	McGill University	Canada	3	2	7	2.33	3.5	1	2	0.25
Barton, Matthew J.	Griffith University	Australia	3	3	32	10.67	10.67	3	3	0.33
Todorovic, Michael	Griffith University	Australia	3	3	32	10.67	10.67	3	3	0.33
Ryan, Grace	University College Dublin	Ireland	2	2	10	5	5	2	2	0.67
Silйn, Charlotte	Karolinska Institutet	Sweden	2	2	44	22	22	2	2	0.13
Hillman, Elspeth	James Cook University	Australia	2	2	38	19	19	2	2	0.2
Mangina, Eleni	University College Dublin	Ireland	2	2	10	5	5	2	2	0.67

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; g=g-index; m=m-index.
Source: Generated by the author(s) using biblioMagika® (Ahmi, 2024)

Nicole M. Ventura from McGill University in Canada and Matthew J. Barton from Griffith University in Australia have also produced notable research outputs, each contributing 3 publications. Ventura's work has received 7 citations, averaging 2.33 citations per paper, with an h-index and g-index of 1 and 2 respectively. Barton's publications have accumulated 32 citations, averaging 10.67 citations per paper, with an h-index and g-index of 3, indicating substantial scholarly influence.

Overall, the authors listed in Table II demonstrate a diverse range of research contributions, from prolific publication outputs to impactful citation metrics.

Their collective efforts contribute to advancing the understanding and application of anatomy knowledge in undergraduate nursing education, fostering a robust scholarly dialogue and shaping future research directions in the field.

Highly Cited Documents

Table II lists the top 20 highly cited articles related to anatomy education in nursing programs, providing insights into influential studies and their impact within the field. One of the most cited articles, authored by Uruthiralingam and Rea (43) in 2020, reviews the use of augmented and virtual reality in anatomical education, garnering 74 citations. This systematic review highlights the growing interest and effectiveness of immersive technologies in enhancing anatomical learning experiences, averaging 14.80 citations per year.

Saab et al. (44) conducted a qualitative study exploring nursing students' perspectives on incorporating virtual reality into nurse education, accumulating 69 citations. This study underscores the value of virtual reality in nursing education, with an average of 17.25 citations per year, indicating significant recognition and adoption within educational practices. Johnston et al. (45) discuss digital lecture recording in nursing education, cautioning about its implications, with 60 citations and an average of 5.00 citations per year. Their findings contribute to ongoing discussions on effective pedagogical approaches in nursing education.

Kaveevivitchai et al. (46) investigated multimedia computer-assisted learning to enhance nursing students' skills in vital signs assessment, with 59 citations and an average of 3.69 citations per year. This study highlights innovative approaches to integrating anatomy and physiology content into educational technologies. Other notable articles include studies on interprofessional education in anatomy (47), augmented reality technology in medical education (48), and the core anatomy syllabus for nursing (13). These articles contribute diverse perspectives and methodologies, shaping the discourse on effective anatomy education strategies for nursing students.

Publications by Countries

Our analysis determines the comparative analysis of the top 10 countries contributing to publications on anatomy education in nursing programs, categorised by their respective regions. This analysis underscores regional variations in publication output, citation metrics, and scholarly impact within the field. In Western regions, the United States and Australia emerge as leading contributors. The United States leads with 24 publications and 325 citations, averaging 13.54 citations per publication and 16.25 per cited publication. Australia follows closely with 19 publications and 210 citations,

Table II. Top 20 highly cited articles

	Authors	Title	Source Title	Cites	Cites
1	Uruthiralingam and Rea, (2020)	Augmented and Virtual Reality in Anatomical Education – A Systematic Review	Advances in Experimental Medicine and Biology	74	14.80
2	Saab et al. (2021)	Incorporating virtual reality in nurse education: A qualitative study of nursing students' perspectives	Nurse Education Today	69	17.25
3	Johnston et al. (2013)	Digital lecture recording: A cautionary tale	Nurse Education in Practice	60	5.00
4	Kaveevivitchai et al. (2009)	Enhancing nursing students' skills in vital signs assessment by using multimedia computer-assisted learning with integrated content of anatomy and physiology	Nurse Education Today	59	3.69
5	Stein et al. (2006)	Using audience response technology for pretest reviews in an undergraduate nursing course	Journal of Nursing Education	53	2.79
6	Herrmann et al. (2015)	Interprofessional education in anatomy: Learning together in medical and nursing training	Anatomical Sciences Education	47	4.70
7	Sugiura et al. (2019)	The Use of Augmented Reality Technology in Medical Specimen Museum Tours	Anatomical Sciences Education	41	6.83
8	Connolly et al. (2018)	The Anatomical Society's core anatomy syllabus for undergraduate nursing	Journal of Anatomy	38	5.43
9	Farkas et al. (2016)	Learning style versus time spent studying and career choice: Which is associated with success in a combined undergraduate anatomy and physiology course?	Anatomical Sciences Education	31	3.44
10	Birks et al. (2015)	Teaching science content in nursing programs in Australia: A cross-sectional survey of academics	BMC Nursing	21	2.10
11	Chakraborty and Cooperstein (2018)	Exploring anatomy and physiology using iPad applications	Anatomical Sciences Education	21	3.00
12	Salvage-Jones et al. (2016)	Developing and evaluating effective bioscience learning activities for nursing students	Nurse Education in Practice	18	2.00
13	Birks et al.. (2018)	Science knowledge needed for nursing practice: A cross-sectional survey of Australian Registered Nurses	Collegian	17	2.43
14	Menon et al. (2022)	Augmented Reality in Nursing Education – A Pilot Study	Clinical Simulation in Nursing	17	5.67
15	Romo-Barrientos et al. (2020)	Anxiety levels among health sciences students during their first visit to the dissection room	BMC Medical Education	16	3.20
16	Brown et al. (2017)	Introductory anatomy and physiology in an undergraduate nursing curriculum	Advances in Physiology Education	14	1.75
17	Thompson et al. (2020)	Nursing students' engagement and experiences with virtual reality in an undergraduate bioscience course	International Journal of Nursing Education Scholarship	14	2.80
18	Narnaware and Neumeier (2020)	Second-Year Nursing Students' Retention of Gross Anatomical Knowledge	Anatomical Sciences Education	14	2.80
19	Al-Neklawy and Ismail, (2022)	Online anatomy team-based learning using blackboard collaborate platform during COVID-19 pandemic	Clinical Anatomy	14	4.67
20	Lai et al. (2019)	Nursing Students' Perceptions of a Silent Mentor Program in an Anatomy Course	Anatomical Sciences Education	12	2.00

Source: Generated by the author(s) using biblioMagika® (Ahmi, 2024)

demonstrating robust academic output with an average of 11.05 citations per publication and 14.00 per cited publication. These countries exhibit strong research productivity and influence, contributing significantly to advancing anatomical education in nursing.

Within the European context, the United Kingdom leads with 10 publications and 201 citations, averaging 20.10 citations per publication and 25.13 per cited publication. This high citation average highlights impactful research outputs, supported by an h-index of 7 and a g-index of 10, underscoring the UK's prominent role in shaping educational practices and research agendas related to anatomy in nursing education. In East Asian countries like Japan, notable contributions are seen with 4 publications and 44 citations, averaging 11.00 citations per publication and 14.67 per cited publication. Japan's strong citation impact reflects its significant role in advancing anatomical education research, contributing valuable insights and methodologies to the global discourse. Countries in South Asia, such as India, also make substantial contributions despite a smaller publication output. India's 4 publications have garnered 33 citations, averaging 8.25 citations per publication and 8.25 per cited publication. This indicates emerging research endeavours and impacts within the region, enriching the global understanding of anatomy education in nursing.

Overall, regional dynamics in research output and impact metrics across Western, East Asian, and South Asian countries contribute to anatomy education in nursing programs. These findings illustrate the diverse perspectives, methodologies, and contributions that shape the global landscape of anatomical education, fostering international collaborations and advancements in nursing practice and education worldwide.

Top Keyword Analysis

The co-occurrence analysis of keywords using VOSviewer provides a comprehensive visualisation of the thematic structure and research trends within the field of anatomy education in nursing programs (Figure 2). The circle size represents the frequency of occurrences; the higher the frequency of the keyword, the larger the circle size (49). Using a minimum number of occurrences of two, 212 out of 752 keywords were identified. Central keywords such as "human," "nursing undergraduate," "medical education," "anatomy education," and "clinical competence" dominate the network, indicating a strong focus on the human aspects of nursing education and the learning processes of nursing students.

The co-occurrence analysis highlights several focal areas. The blue and green clusters emphasize educational strategies and academic performance, with keywords like "human experiment," "nursing undergraduate," and "anatomy and physiology", including "medical education" and "clinical practice," reflecting the integration of anatomy education within broader medical training. The red cluster shows significant interest in advanced technologies like "simulation," "virtual reality," and "augmented reality" to enhance clinical competence. The yellow and purple clusters underscore interdisciplinary education, with keywords like "interprofessional education" and "learning outcomes," highlighting the importance of collaborative learning across healthcare disciplines.

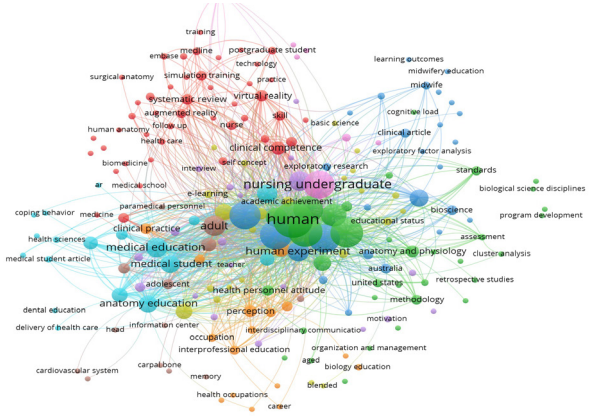

Figure 2: Network visualization of co-occurrence analysis by keywords Source: Developed by the author(s) using VOSviewer

The analysis indicates a need for further exploration of advanced technologies, integrated curricula, and interdisciplinary approaches in anatomy education. Balancing quantitative and qualitative methods will provide comprehensive insights into the effectiveness of educational strategies, better preparing nursing students for modern healthcare practice.

DISCUSSION

This study focused on the evolution of research in anatomy education within nursing programs, revealing several key trends and findings. The bibliometric analysis encompassed 105 publications spanning from 2004 to 2024, predominantly articles (82.86%) published in peer-reviewed journals (93.33%), reflecting a strong trust in these platforms for validating and disseminating research findings. The dominance of articles over other document types highlights a preference for rigorous, peer-reviewed research in advancing anatomical education for nursing students. The significant contribution of 435 authors, with an average of 4.14 authors per paper, highlights the interdisciplinary collaboration that is essential in this field. The citation metrics, with a total of 1,252 citations and an average of 11.92 citations per paper, highlight the substantial engagement and impact within the academic community (59). The h-index of 18 and g-index of 30 further reflect the depth and breadth of impactful research in this domain.

The top-cited articles, focus on innovative educational methods such as augmented reality (AR) and virtual

reality (VR) (43,44), digital lecture recording (45), and interprofessional education in anatomy (47) suggesting a clear shift towards integrating advanced technologies in anatomy education. This shift is particularly significant given nursing students' increasing demands for enhanced anatomical understanding (43,44,48,60,61). Notable contributions from authors like Johnston (45,50-52), Barbagallo (53-55), and Brown (56-58) have significantly influenced the field, drove innovation and advanced best practices.

The integration of technologies like AR, VR, and digital platforms is transforming nursing education by offering innovative methods for students engagement with subjects like anatomy and physiology. These immersive tools enhanced student engagement and knowledge retention through interactive and realistic simulations, which often prove more effective than traditional methods (6). However, critical integration and faculty training are important for meaningful education experiences. This means investing in ongoing professional development for nursing educators so they can use these tools not as a gimmick but as an integral part of their teaching approach.

A major challenge we need to consider is accessibility. While VR and AR can make learning more engaging, they can also be expensive, and not all nursing schools have the resources to adopt these tools on a wide scale. VR has been reported to help students who don't have access to physical labs, but the reality is that many institutions, particularly in low- and middle-income countries, are still struggling to provide basic technology (43). To make these advancements more rightful, we need partnerships between schools, tech companies, and government agencies, making these tools accessible to all students, not just those in well-funded programs. More adaptive AR/VR systems should be developed to cater to diverse learning needs, which could also help level the playing field (33). This would ensure that all students, including those with disabilities or learning challenges, have an equal opportunity to benefit from these innovations.

One area that's often overlooked is the need for solid evidence to back up the use of new technologies. While we're seeing promising results, such as digital platforms helping during the pandemic (53-55), there's still a lot we don't know about the long-term effects of relying on digital tools for learning. It's essential to conduct more in-depth research to understand how these technologies influence students over time. Are they improving critical thinking and clinical skills, or are they creating a superficial understanding of the material? Nursing programs need this data to make informed decisions about how best to incorporate these tools into the curriculum.

Additionally, we must ensure that these new technologies are aligned with teaching goals and regulations. Many students have been noted to experience anxiety when studying complex subjects like biosciences (4). If VR and other digital tools are to reduce rather than increase this anxiety, their use needs to be well thought out. Educators must introduce these technologies in ways that support and guide learning, rather than overwhelming students. At the same time, the use of these tools must comply with professional standards, such as those outlined by the Nursing and Midwifery Council (NMC) in their 2018 guidelines. Nursing students need to develop not just technical skills but also the ability to critically evaluate and use technology in their future practice.

The geographical distribution of research outputs, led by the United States, Australia and the United Kingdom, reflects diverse educational strategies and curriculum development tailored to regional healthcare needs and educational frameworks. Each contributes distinct perspectives and methodologies to anatomical education in nursing. This diversity is crucial for addressing the varying requirements of nursing education globally (62). These findings indicate a growing emphasis on integrating advanced technologies and interdisciplinary approaches into anatomical education, aiming to improve learning outcomes and prepare nursing students for diverse healthcare environments (63). The prominence of specific authors and journals underscores their influence in shaping research agendas and methodologies, driving innovation and advancing best practices in anatomical education.

Implications for Practice

The findings from this study have significant implications for both educators and policymakers. Educators and curriculum developers should prioritize the integration of advanced technologies such as virtual and augmented reality into anatomy education suggesting a need for curriculum developers to integrate these tools more effectively. These technologies not only enhance student engagement and retention but also improve the retention of complex anatomical knowledge by providing immersive, interactive learning experiences. It also bridges the gap between theoretical knowledge and practical clinical skills (44,48,60), which are critical for nursing students. Educators can leverage the insights from highly cited studies to design more effective anatomical education programs. This can be achieved by investing in the necessary tools and providing training for educators to effectively integrate these findings into their teaching practices, in line with the evolving needs of healthcare environments.

To further enhance student performance and knowledge retention, it is recommended that nursing programs increase the number of learning hours dedicated to practical, hands-on experiences and student-centred learning approaches. Research has shown that student-

centred learning, which includes methods like problem-based learning, peer teaching, and simulation-based education, significantly improves knowledge retention and critical thinking skills among nursing students (11,25-28,32,34,39,44,48,60). By extending learning hours and focusing on these methodologies, educators can ensure that students not only grasp theoretical concepts but are also able to apply them effectively in clinical settings.

Policymakers play a critical role in creating an environment that supports the use of innovative educational technologies. By allocating resources for the implementation of virtual and augmented reality and student-centred learning initiatives in educational institutions, policymakers can help bridge the gap between theoretical knowledge and practical clinical skills, ensuring that nursing graduates are well-prepared for the demands of modern healthcare environments. National and regional educational policies should also encourage the adoption of best practices identified through research, ensuring that all nursing programs have access to the tools and methodologies that enhance student learning outcomes. This support could take the form of funding for pilot programs, professional development opportunities for educators, and the development of national or regional guidelines that encourage the adoption of these technologies.

Recommendations for Future Research

Several recommendations for future research emerge from our findings. Firstly, there is a need for further exploration into the long-term effectiveness and sustainability of virtual and augmented reality in anatomy education. While these technologies are increasingly adopted, their impact on learning outcomes over time and across different educational settings remains underexplored. Comparative studies that examine these technologies across diverse cultural contexts could provide deeper insights into their generalizability and effectiveness.

Additionally, future research should explore the integration of anatomical knowledge with emerging healthcare technologies such as artificial intelligence and telemedicine. These fields are rapidly evolving and offer new opportunities for enhancing nursing education and practice (64). As we've seen, while AR and VR technologies have shown promise, particularly in bridging the gap between theoretical knowledge and clinical skills, there is still much to learn about their broader applicability across different healthcare systems (6). Longitudinal studies that track the career outcomes of nursing graduates exposed to these educational interventions would be particularly valuable in assessing the long-term impact of innovative teaching methods.

Moreover, methodologically, qualitative inquiries into student perceptions and experiences with new learning technologies could enrich the understanding of their educational impact (61,65). It's essential to examine not just how these technologies influence test scores, but also how they shape students' confidence, critical thinking, and real-world readiness. Collaborative research initiatives across international borders could also facilitate knowledge exchange and the benchmarking of educational practices, fostering a global perspective on anatomical education in nursing.

Limitations

While this study offers valuable insights into anatomy education within nursing programs, several limitations warrant consideration. Bibliometric analysis focuses on quantifiable metrics such as publication counts, citation frequencies, and author influence. It offers a powerful tool for identifying trends and mapping the research landscape. However, this approach inherently emphasises quantitative data, which may not fully capture the qualitative dimensions of educational quality, pedagogical effectiveness, and the nuanced experiences of educators and students. Consequently, the analysis might overlook critical contextual factors that influence the integration and impact of emerging technologies in educational settings.

Recognising these limitations, future research could benefit from a mixed-methods approach that complements bibliometric analysis with qualitative methods such as case studies, interviews, or meta-analyses. As mentioned earlier, technologies like VR and AR have great potential, but without qualitative research to explore how these innovations affect students on a personal level, such as their engagement, anxiety, or confidence, our understanding will remain incomplete (6). By integrating qualitative insights, researchers can explore the deeper pedagogical implications and assess the practical effectiveness of these innovations, thereby offering more actionable recommendations for educators and policymakers.

Additionally, the study's exclusion of non-English publications introduces a language bias, potentially limiting the representation of global research efforts and skewing the findings towards English-speaking regions (66). This limitation could affect the generalisability of the conclusions, particularly in a field as globally diverse as nursing education. Moreover, the potential for biases in citation practices, such as the preferential citing of works from certain regions or prominent authors, may further influence the perceived impact of specific studies or researchers. To address these issues, future studies need to consider adopting more inclusive research practices. Conducting cross-linguistic analyses and incorporating publications from multiple languages could provide a richer, more diverse perspective on global trends in anatomical education. Additionally,

expanding the research scope to include other databases would enhance the comprehensiveness of the analysis. This broader inclusion would not only improve the robustness of the findings but also contribute to a more accurate and representative understanding of the global landscape of anatomy education.

CONCLUSION

This study systematically analysed publications on anatomy education within nurse programs using the Scopus database, identifying the key trends and the growing integration of advanced technologies in the curricula. These findings underscore the global interest in enhancing nursing education through innovative approaches. However, limitations of the study include dependence on a single database and English-language publications, which may introduce bias and limit the generalisability of the findings. To address these limitations, future research should broaden the scope to include diverse databases and non-English publications, providing a more comprehensive view of global trends. Moreover, complementing bibliometric analysis with other qualitative methods could offer richer insights into the practical applications and effectiveness of these emerging technologies. Evaluating the outcomes of specific educational interventions is also crucial for providing stronger evidence for the effectiveness of these technologies. For educators and policymakers, this study highlights the importance of integrating emerging technologies into nursing curricula. Institutions should not only invest in these tools but also rigorously evaluate their impact, while policymakers should develop guidelines that promote evidence-based adoption tailored to diverse educational contexts. In conclusion, this study underlines the transformative potential of technology in anatomy education within nursing programs. It emphasises the importance of recognising the limitations of technology and advocates for complementing bibliometric analysis with other research methods to advance global standards and ensure the reliability of future research. The study calls for continued research to explore diverse educational approaches and enhance global nursing education standards

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