



Artificial intelligence in wound care education: Scoping review

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ABSTRACT

Background: Artificial intelligence is transforming healthcare education, offering innovative teaching and skill development approaches. However, its implementation and effectiveness in wound care education remain unclear.

Objective: To map and analyze the available evidence on the potential impact of artificial intelligence in wound care education, identify knowledge gaps, and provide recommendations for future research.

Design/methods: This scoping review followed the Joanna Briggs Institute guidelines for scoping reviews and the PRISMA-ScR guidelines. The search was first conducted in December 2023 and updated on 30 November 2024 across the following databases: CINAHL Ultimate, MEDLINE, Cochrane Library, Academic Search Complete, Scientific Electronic Library Online (SciELO), Scopus, and Web of Science. Grey literature was accessed through Scientific Open Access Scientific Repositories of Portugal (RCAAP), ProQuest Dissertations and Theses, OpenAIRE, and Open Dissertations. Additional searches were performed in Google Scholar and specific journals, including the International Wound Journal, Skin Research and Technology, Journal of Wound Care, and Wound Repair and Regeneration. Eligibility criteria encompassed any study design exploring the use of artificial intelligence in wound care education, published in English, Portuguese, or Spanish, with no restrictions on publication date.

Results: This review revealed diverse artificial intelligence applications in wound care education, including adaptive e-learning platforms, virtual and augmented reality simulations, generative artificial intelligence for educational content, and diagnostic and treatment tools. These technologies offer personalized learning experiences, real-time feedback, and interactive engagement to enhance clinical skills. Despite their promise, most studies lacked empirical validation, highlighting significant gaps in integrating artificial intelligence into wound care education.

Conclusions: This review highlights artificial intelligence's transformative potential to revolutionize wound care education by fostering interactive and evidence-based learning environments. This work highlights the need for collaboration among educators, policymakers, and researchers. Future research is needed to ensure effective, ethical, and equitable integration of artificial intelligence in wound care education.

1. Introduction

Wound care is a critical area of healthcare, dedicated to effectively managing and treating wounds to promote timely healing and reduce complications such as infections and amputations. Wounds and their treatment represent a significant financial burden on healthcare worldwide. In 2022, the estimated cost of wound care reached \$148.65 billion in the United States, making it the highest global spender,

followed by China (\$42.78 billion) and Japan (\$22.91 billion). European countries like Germany (\$23.33 billion) and the United Kingdom (\$13.31 billion) also report substantial financial costs in wound management (Queen and Harding, 2024). The costs associated with wound management are multifaceted, encompassing direct expenses such as advanced wound dressings, diagnostic tools, wound assessment technologies, and professional care services. Additionally, indirect costs affect the health care system, patients, and society, including reduced

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life expectancy and diminished quality of life, prolonged hospital stays, and adverse effects on physical, psychological, and social well-being (Black, 2025). Recognizing these financial implications is essential for policymakers, healthcare providers, and educators to optimize resource allocation, develop preventive strategies, and integrate cost-effective innovations into wound care education and practices.

Wound assessment and management are a significant challenge for healthcare professionals, requiring accurate diagnosis, precise treatment, consideration of healing factors, patient education, and a focus on underlying causes and treatment principles (Ahtiala and Kielo-Viljamaa, 2024). Treating wounds requires the appropriate knowledge and skills to maximize patient outcomes (Powers et al., 2016; Welsh, 2018). Education in wound care is essential for students and healthcare professionals, as it enhances their ability to understand the principles of wound care, perform accurate assessments, identify risk factors, and develop critical thinking for clinical decision-making (Ahtiala and Kielo-Viljamaa, 2024). This facilitates the implementation of evidence-based interventions and innovative practices into patient care, ultimately improving patient outcomes and healthcare efficiency.

Wound care education has traditionally followed established methods, primarily focusing on theoretical knowledge and fundamental techniques. However, there has been a growing recognition of the importance of hands-on experience and active learning, highlighting the need for a more integrated and dynamic approach to enhance care effectiveness. In recent years, innovative technologies such as simulation, peer mentoring, and online and blended learning have transformed wound care education, providing more effective and efficient opportunities to improve training and care practices (Ahtiala and Kielo-Viljamaa, 2024). Previous studies have demonstrated that simulation improves students' knowledge, skills, clinical reasoning, performance, satisfaction, and self-confidence (Luo, 2024; MacLean et al., 2024; Silva et al., 2020). Moreover, comprehensive training, incorporating debriefing sessions, theoretical education, and practice with standardized patient simulations, has led to more sustained knowledge and better clinical performance (Ahtiala and Kielo-Viljamaa, 2024).

Given the evolving nature of wound care, it is essential to continually innovate and refine teaching strategies to ensure that learners acquire a solid theoretical foundation and develop the practical skills necessary to deliver high-quality care. By tailoring educational methods to the needs of undergraduate and postgraduate learners, educators can provide a more effective and realistic learning experience, which helps students apply theory to practice. Healthcare education is evolving significantly in response to advancements in medical technology, particularly the integration of artificial intelligence, highlighting the need for new research on teaching methods (Ahtiala and Kielo-Viljamaa, 2024).

The exact definition of artificial intelligence remains a subject of ongoing discussion. Proposed by John McCarthy in 1955, the term generally refers to the ability of machines to perform tasks and solve problems that usually require human intelligence, such as image recognition, decision-making, and natural language processing (Helm et al., 2020; Jakhar and Kaur, 2020; Wang, 2019). It can be broadly defined as incorporating human intelligence and behavior into machines. Machine learning is a subset of artificial intelligence and frequently involves training models to identify patterns and generate predictions using a specified dataset. Deep learning, a more advanced subset of machine learning, involves training neural networks with multiple layers to perform complex tasks like image classification, speech recognition, and numerical modeling through weight adjustments (Jakhar and Kaur, 2020; Sheikh et al., 2023). Generative artificial intelligence uses machine learning and deep learning techniques to create new content—such as images, text, or audio—by learning patterns from existing data and generating outputs that mimic the original set. Generative artificial intelligence has many applications; generative adversarial networks are commonly utilized for image creation, and recurrent neural networks are applied in natural language processing to generate text (Preiksaitis and Rose, 2023; Sheikh et al., 2023; Yu and

Guo, 2023).

Artificial intelligence has become a transformative technology across various sectors, including finance, entertainment, healthcare, and education. Its applications enable the efficient execution of complex tasks, such as data analysis, information integration, event prediction, and decision-making support (Ganesan et al., 2024; Martinez-Ortigosa et al., 2023). Previous studies stated that generative artificial intelligence transformed medical education by introducing innovative approaches to personalized learning, case-based learning, simulation-based training, continuous professional development, and support for research activities (Preiksaitis and Rose, 2023).

While specific studies directly addressing the role of artificial intelligence in wound care education are limited, this emerging technology holds considerable potential in the healthcare sector, with applications in robotic surgery, predictive analytics, medical imaging, patient monitoring, early diagnosis, workflow improvement, information sharing, personalized medicine, decision-making support, virtual patients, and health chatbots (Alhejaily, 2024; Ali et al., 2023; Dave and Patel, 2023; Rony et al., 2024).

Early applications of artificial intelligence in wound care, particularly machine learning and computer vision, have shown potential benefits in enhancing wound assessment and management (Chen, 2024; Rippon et al., 2024; Sarp et al., 2021). Artificial intelligence systems can analyze wound images, improve diagnostic accuracy, and significantly contribute to early detection, risk stratification, intelligent treatment, outcome prediction, and prognosis evaluation (Chen, 2024; Griffa et al., 2024; Rippon et al., 2024).

In healthcare education, artificial intelligence has emerged as a transformative approach, enhancing the training and education of professionals through innovative applications that include intelligent tutoring systems, chatbots, robots, performance analytics, virtual patient simulators, personalized learning platforms, chatbots, augmented reality with artificial intelligence, procedure guidance for trainees and automated assessment tools (Dave and Patel, 2023; Gordon et al., 2024; Mah, 2023). These advancements provide tailored, efficient, immersive, and realistic learning experiences through adaptive learning, equipping students and teachers with machine-supported tools for immediate guidance on learning progress and areas for improvement (Chiu et al., 2023; De Gagne, 2023; Hamilton, 2024; Zarei et al., 2024). This approach may be extended to wound care education, highlighting the importance of exploring its potential applications.

A search across CINAHL Ultimate, MEDLINE (PubMed), Cochrane Database of Systematic Reviews, PROSPERO, and Open Science Framework databases revealed that, at present, there are no published or ongoing scoping reviews or systematic reviews concerning the use of artificial intelligence in wound care education. The literature highlights many artificial intelligence applications for wound care; however, its integration into wound care education remains uncertain. To address this, the authors conducted a scoping review to map and analyze the available evidence on the potential impact of artificial intelligence in wound care education, identify knowledge gaps, and provide recommendations for future research.

2. Methods

A scoping review approach was determined to be the most appropriate method, given the limited knowledge about artificial intelligence applications in wound care education, the emerging nature of this topic, and the purpose of mapping the evidence (McGowan et al., 2016; Peters et al., 2020).

The scoping review follows the Joanna Briggs Institute's methodology for scoping reviews (Peters et al., 2020; Tricco et al., 2018) and the Guidance for Conducting Systematic Scoping Reviews (Peters et al., 2020). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines were used in reporting the study results (McGowan et al., 2016; Tricco et al.,

2018). A protocol review was registered on the Open Science Framework platform and published as a scientific paper (Encarnação et al., 2024). Minor changes were made to the data extraction table, specifically in the terminology used and its structure, to facilitate the data extraction process.

A stepwise process was employed to ensure the inclusion of all relevant literature, regardless of study design. This involved formulating a research question, conducting a comprehensive search for relevant studies, screening eligible studies, charting, synthesizing extracted data, and presenting the results.

2.1. Research questions

Scoping review questions should be broad, defining the concept, target population, and health outcomes to ensure clarity and a robust search strategy (Levac et al., 2010). Research questions for this review were developed collaboratively with the research team and stakeholders, including advanced practice nurses, nurse researchers, and educators in digital health technologies and health education.

To address the study's aims, the research question was formulated using the PCC (Population, Concept, Context) mnemonic: What evidence currently exists on the application of artificial intelligence in wound care education?

2.2. Search strategy

A search was conducted in the following databases: CINAHL Ultimate (via EBSCOhost), MEDLINE (via PubMed), Cochrane Library, Academic Search Complete, Scientific Electronic Library Online (Scielo), Scopus, and Web of Science. Electronic searches were also conducted in the Scientific Open Access Scientific Repositories of Portugal (RCAAP) and ProQuest Dissertations and Theses, OpenAIRE, and Open Dissertations databases to access grey literature. Additionally, searches were performed on Google Scholar and specific journals such as the International Wound Journal, Skin Research and Technology, Journal of Wound Care, and Wound Repair and Regeneration.

The search strategy, including all identified keywords and index terms, was customized for each literature source (see Supplementary material Table S1).

The search was initially conducted in December 2023 and was rerun on 30 November 2024 to capture the most recent and relevant studies before finalizing this scoping review. All results were imported into the Rayyan web application (rayyan.ai) (Ouzzani et al., 2016), and duplicated studies were removed.

2.3. Eligibility criteria

The PCC framework was used to establish the eligibility criteria:

- Population: this study will encompass all literature that discusses participants as healthcare practitioners, students, and educators.
- Concept: this review will include literature that analyses artificial intelligence and its influence on wound care education.
- Context: education. To expand the scope of the review, the context will be broad and involve any educational settings without geographic restrictions.

Articles were included if they addressed artificial intelligence applications in wound care education. Given the emerging nature of this topic, all study designs and grey literature, such as conference abstracts, theses, government reports, clinical practice guidelines, and editorial or opinion papers, were included. Exclusion criteria comprised studies that (1) did not focus on wound care education, (2) were unrelated to artificial intelligence, or (3) were not published in English, Portuguese, or Spanish. No restrictions were applied regarding the year of publication to avoid inadvertently excluding relevant studies.

2.4. Evidence screening and study selection

The screening process was first pilot-tested. Following this, the initial phase involved independent screening of all titles and abstracts by two reviewers for eligibility criteria using the Rayyan web application (Ouzzani et al., 2016). In the second phase, potentially relevant records were fully obtained through institutional access or by emailing the authors. The full text of potentially relevant evidence was screened according to the inclusion criteria by two independent reviewers. Searching of reference lists of key papers was also undertaken. In cases of uncertainty, decisions were made by consensus after discussions between reviewers, with any disagreements resolved through consultation with a third reviewer until complete agreement was reached.

The methodological quality of the included studies was not assessed, as this is generally not recommended in scoping reviews because the aim is to map the available evidence rather than provide a synthesized and clinically meaningful answer (Peters et al., 2020, 2024).

2.5. Data charting

The data extraction tool was created and pilot-tested by the review team based on the Joanna Briggs Institute instrument for extracting study details, characteristics, and results (Peters et al., 2020, 2024). Two reviewers also completed data extraction for each article, and the third reviewer confirmed and achieved the results as needed. Additionally, unclear data were clarified by contacting the respective authors. Extracted data consisted of study characteristics (title of publication, authors, year of publication, country of origin, type of publication, study design, study aim, end users of artificial intelligence), wound specifics, education details, artificial intelligence details, key findings, educational implications, and study limitations.

2.6. Data analysis

The same reviewers involved in the previous step conducted this procedure independently, with a third reviewer consulted to resolve any differences and reach a consensus. Data were analyzed using descriptive statistics, while qualitative data were synthesized using content analysis. The included publications were categorized based on the modality in which artificial intelligence was used to support wound care education. As the data were heterogeneous, a meta-analysis was not performed.

3. Results

3.1. Literature search and selection process

Identified studies from databases and registers included 7420 publications after de-duplication and language restrictions. Of these, 7332 publications were excluded after abstract and title screening, and 72 publications were assessed for full-text examination. Identified studies from grey literature and citation searching included 1664 publications. Twenty-nine of these were submitted for full-text examination. Fifty-six publications identified from databases and registers and 28 from the grey literature and citation searching were excluded as they did not meet the inclusion criteria (Fig. 1). Finally, 17 publications were included in this review.

3.2. Study characteristics

The characteristics of the included publications are summarized in Table 1, with full results presented in the corresponding data extraction table (see Supplementary material Table S2). All reports were published between 2006 and 2024, seven of which were in the last three years, which suggests a growing interest in this field. The type of publications included eight conference papers (47.1%), eight journal articles (47.1%)

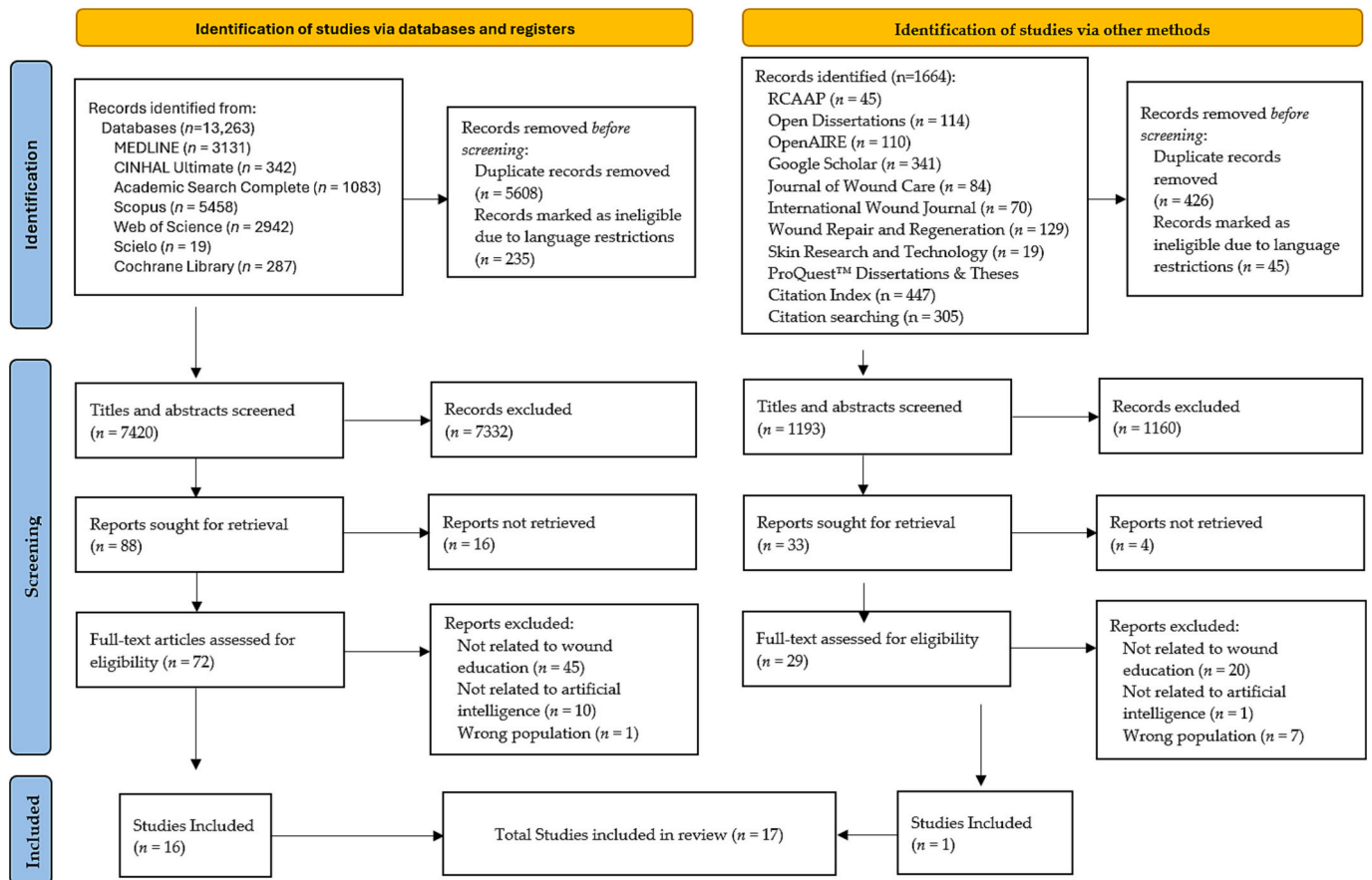


Fig. 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 flow diagram.

%), and one editorial paper (5.9 %). Regarding study design, 9 were developmental studies (53 %), five experimental studies (29.4 %), and three original articles in other categories (17.7 %). Most studies were conducted in Europe (70.6 %, n = 12), followed by Asia (11.8 %, n = 2), North America (11.8 %, n = 2), and Oceania (5.9 %, n = 1). The included studies address various types of wounds, with some focusing specifically on certain types, such as pressure ulcers, leg ulcers, and diabetic foot ulcers.

All studies explored the use of artificial intelligence to enhance wound care education. Key objectives included developing artificial intelligence-driven e-learning platforms for wound image analysis and adaptive learning (Morente et al., 2011; Morente and Veredas, 2013; Prodan et al., 2010a; Veredas et al., 2014) and exploring tools like virtual and augmented reality incorporated with artificial intelligence simulations (Ousey et al., 2018), computer vision for suturing assessment (Kil et al., 2024; Noraset et al., 2024), and smartphone applications for wound detection (Lau et al., 2022). Generative artificial intelligence tools were also investigated for creating educational resources (Goktas et al., 2024; Koljonen, 2023), while case-based reasoning systems were developed to support evidence-based learning in diabetic foot ulcer care (Bender et al., 2022). Broader explorations of artificial intelligence benefits and limitations in wound care education were also conducted (Heerschap, 2023). Overall, the main goals of the studies were to develop, validate, and explore the potential of artificial intelligence technologies to improve teaching, learning, and clinical skill development in wound care education.

3.3. Educational program details

The educational domains covered by the included studies primarily focused on artificial intelligence usage in assessment, learning, and

teaching. Most studies addressed all three domains simultaneously, highlighting the application of artificial intelligence in these areas. However, some studies concentrated on specific domains, such as assessment (Kil et al., 2024; Noraset et al., 2024), or provided a comprehensive analysis of artificial intelligence applications in teaching, learning, and assessment (Heerschap, 2023). Administrative domains were not explicitly addressed in any of the included studies.

The potential recipients of wound care education included nursing, medical, and pharmacy students at undergraduate and graduate levels, practicing nurses, clinicians, surgical residents, and other healthcare professionals in clinical settings. Two studies focused exclusively on undergraduate nursing students (Morente and Veredas, 2013; Veredas et al., 2014), while two others targeted postgraduate healthcare professionals (Bender et al., 2022; Kil et al., 2024). Thirteen studies addressed different educational levels, demonstrating artificial intelligence's adaptability to diverse learning needs.

The included studies are in multiple educational contexts, illustrating the multidisciplinary nature of wound care education. Nursing education was the predominant context, with artificial intelligence-driven simulation tools and platforms designed to enhance wound diagnosis and treatment competencies in undergraduate and postgraduate nursing programs (Bender et al., 2022; Morente and Veredas, 2013; Veredas et al., 2014). Surgical education focuses on tools to train healthcare professionals in complex procedural skills such as suturing (Kil et al., 2024; Noraset et al., 2024; Seth et al., 2024). These tools combined traditional methods with artificial intelligence-driven simulations to improve precision and decision-making in clinical settings.

Beyond nursing and surgery, some studies explored broader healthcare education applications, fostering interdisciplinary learning among healthcare professionals (Bender et al., 2022; Heerschap, 2023; Noraset et al., 2024).

Table 1
Characteristics of articles included in the scoping review (n = 17).

Author(s), year, country	Type of publication	Study design	Study aim	End users of artificial intelligence	Wound type
Prodan et al., 2006 Romania	Conference paper	Developmental study	Presents a Java framework integrated into e-learning tools for analyzing and processing wound images.	Students and residents in medicine and pharmacy.	Pressure ulcers, burns, venous leg ulcers, diabetic foot ulcers, and wounds related to other chronic diseases.
Prodan et al., 2008a Romania	Conference paper	Developmental study	To develop e-learning tools for analyzing and understanding wound images, promoting e-learning technologies based on artificial intelligence for creating intelligent and practical scenarios.	Medical, pharmacy, and healthcare students.	Pressure ulcers, burns, venous leg ulcers, diabetic foot ulcers, and wounds related to other chronic diseases.
Prodan et al., 2008b Romania	Conference paper	Developmental study	To investigate the efficacy of artificial intelligence in analyzing and understanding wound images as a basis for creating scenarios.	Medical, pharmacy, and healthcare students.	Pressure ulcers, burns, venous leg ulcers, diabetic foot ulcers, and wounds related to other chronic diseases.
Prodan et al., 2009 Romania	Conference paper	Developmental study	Presents a Java framework based on artificial intelligence for analyzing, processing, and understanding wound images, which can be used in teaching, learning, and research activities.	Medical, pharmacy, and healthcare students.	Pressure ulcers, burns, venous leg ulcers, diabetic foot ulcers, and wounds related to other chronic diseases.
Prodan et al., 2010a Romania	Conference paper	Developmental study	Development of an artificial intelligence-driven framework and simulation tools for wound image analysis and healing simulation, designed for use in medical education.	Students and residents in medicine, pharmacy, and healthcare.	Pressure ulcers, burns, venous leg ulcers, diabetic foot ulcers, and wounds related to other chronic diseases.
Prodan et al., 2010b Romania	Conference paper	Developmental study	Development of intelligent e-tools framework using Java and artificial intelligence tools for image processing, analysis, simulation, and subsequent evaluation.	Students in medicine and pharmacy.	Various wound types.
Morente et al., 2011) Spain	Conference paper	Developmental study	Development of a computational tool combining artificial intelligence for diagnosing, managing, and learning about pressure ulcers.	No participants.	Pressure Ulcers
Morente and Veredas, 2013 Spain	Conference paper	Randomized controlled trial	To develop and validate an adaptive e-learning tool to improve pressure ulcer evaluation and treatment skills compared to traditional teaching methods.	73 undergraduate nursing students.	Primarily focused on pressure ulcers, with potential applicability to other wound types.
Veredas et al., 2014 Spain	Journal article	Randomized controlled trial	To develop and validate an adaptive e-learning tool for autonomous learning of pressure ulcer diagnosis and treatment, comparing its effectiveness with traditional teaching methods.	72 undergraduate nursing students (30 in the experimental group and 42 in the control group).	Pressure ulcers
Ousey et al., 2018 United Kingdom	Editorial Paper	Developmental study	To explore the potential of artificial intelligence-driven virtual reality and augmented reality in enhancing nurses' skills in wound care management.	Not specified (target audience: nurses and frontline staff).	Leg ulcers
Lau et al., 2022 China	Journal article	Feasibility study	To develop and evaluate a deep learning-based smartphone app for real-time detection and staging classification of pressure injuries.	None explicitly involved.	Pressure injuries
Bender et al., 2022 Denmark	Journal article	Developmental study	To develop and present a case-based reasoning prototype system as an interactive, evidence-based learning tool for enhancing nurses' knowledge and evidence-based practice in diabetic foot ulcer care.	None were directly involved; retrospective data was from a Danish database.	Diabetic foot ulcers
Heerschap, 2023 Canada	Journal article	Narrative review	To explore artificial intelligence's benefits and limitations in wound care education.	Student, healthcare professional, and educator.	Various wound types
Koljonen, 2023 Finland	Journal article	Exploratory Study	To explore the use of artificial intelligence-generated images for medical teaching scenarios.	None explicitly mentioned.	Subcutaneous tumor, wound, and skin tumor.
Kil et al., 2024 USA	Journal article	Experimental Study	Presents a computer vision algorithm for extracting image-based metrics for suturing skill assessment.	12 participants: 5 attending surgeons and 7 surgical residents.	Simulated radial sutures on synthetic leather membranes.
Seth et al., 2024) Australia	Journal article	Experimental Study	To evaluate the quality and accuracy of generative artificial intelligence models (generative adversarial network) for creating educational images of skin ulcers.	4 board-certified plastic surgeons and 3 plastic surgeon residents.	Skin ulcers (arterial, venous, diabetic, pressure, Buruli, and Marjolin ulcers).
Noraset et al., 2024 Thailand	Journal article	Experimental Study	To develop a deep learning model for extracting suture metrics and assessing suture quality in medical education.	Medical students and healthcare professionals (novices and experts).	Surgical wounds — simulated simple interrupted sutures.

The curricular structure and duration of the educational programs varied significantly across the included studies, with the majority (n = 10, 58.8 %) not providing specific details. This lack of explicit reporting may be attributed to the studies' experimental or developmental lab-based nature. Among the studies that described curricular frameworks, blended learning emerged as the predominant approach, integrating traditional face-to-face teaching methodologies with artificial intelligence-supported e-learning scenarios centered on real-world medical cases and active learning strategies (Morente and Veredas,

2013; Prodan et al., 2010a; Veredas et al., 2014).

Duration was explicitly mentioned in only one study, which implemented a 10-week intervention as part of an undergraduate nursing program focused on pressure ulcer diagnosis and treatment (Veredas et al., 2014). The curriculum included theoretical and practical components, with the experimental group using an autonomous e-learning platform while the control group followed traditional classroom-based methods.

Several studies emphasized the adaptability of educational tools,

suggesting their potential for flexible integration into existing curricula (Bender et al., 2022; Heerschap, 2023; Morente and Veredas, 2013; Prodan et al., 2010a). The tools in three studies were designed to support continuous, active, autonomous, and adaptive learning, tailoring content to the individual needs of learners (Morente et al., 2011; Morente and Veredas, 2013; Veredas et al., 2014).

The included studies reported a wide range of potential outcomes for students regarding the application of artificial intelligence in wound care education. A key focus was enhancing practical and analytical skills in wound assessment and management, often achieved through interactive tools and simulations (Prodan et al., 2009, 2010a, 2010b). Artificial intelligence-based technologies were also associated with personalized and adaptive learning, offering tailored educational experiences that align with individual student needs, improve decision-making, and enable skill acquisition in online and offline settings (Heerschap, 2023; Morente and Veredas, 2013; Veredas et al., 2014).

The use of immersive and interactive simulations, including virtual and augmented reality incorporated with machine learning, was reported to enhance engagement and provide realistic practice environments potentially (Ousey et al., 2018; Prodan et al., 2008b, 2009). Similarly, real-time feedback was highlighted as a critical feature of artificial intelligence-based tools, offering automated and objective assessments that could improve specific clinical skills, such as suturing precision (Kil et al., 2024; Noraset et al., 2024) and wound assessment (Heerschap, 2023).

Student engagement and motivation were identified as key benefits of artificial intelligence integration, with studies indicating potential increased satisfaction and interest in learning due to adaptive and interactive features (Lau et al., 2022; Prodan et al., 2008b; Veredas et al., 2014). Furthermore, artificial intelligence technologies demonstrated the potential to support diverse learning needs, providing multilingual accessibility, simplified explanations tailored to performance levels, and summarized best practice recommendations (Heerschap, 2023).

Other potential outcomes for students included an improved understanding of pathophysiological processes and treatment rationales and enhanced clinical decision-making skills (Bender et al., 2022; Koljonen, 2023). These tools could also facilitate knowledge acquisition in complex scenarios, such as diabetic foot ulcer management or wound healing pattern recognition (Bender et al., 2022; Koljonen, 2023).

One study did not explicitly state student-related outcomes (Seth et al., 2024), focusing on the broader context of generative adversarial networks application in wound care education.

Regarding potential outcomes for educators, the included studies suggest multiple outcomes resulting from integrating artificial intelligence in wound care education. A common outcome was the ability to combine traditional teaching methods with innovative artificial intelligence technologies to enhance teaching efficiency and effectiveness (Prodan et al., 2009, 2010a, 2010b). Many studies highlighted artificial intelligence's role in facilitating feedback-driven teaching strategies and providing tools for real-time student evaluation (Noraset et al., 2024; Ousey et al., 2018; Prodan et al., 2009). Teachers also benefited from tools that simplified progress tracking, customized evaluations, and performance assessments, enabling more adaptive and personalized teaching approaches (Morente et al., 2011; Morente and Veredas, 2013; Veredas et al., 2014).

Artificial intelligence technologies were further associated with reducing educators' workload by automating teaching tasks and resource creation, such as quizzes, synthesized educational materials, and lesson plans (Heerschap, 2023). These tools allowed teachers to focus on other curricular aspects and refine their teaching strategies (Heerschap, 2023; Morente and Veredas, 2013). Additionally, artificial intelligence-enabled resources supported the development of interactive and ethically responsible teaching material, including privacy-compliant educational content (Koljonen, 2023).

Some studies highlighted specific tools for enhancing teaching efficiency, such as apps for demonstrating wound staging and assessment

(Lau et al., 2022) or reducing the time required to evaluate students' suture practices (Noraset et al., 2024). Two studies did not explicitly report teacher outcomes (Bender et al., 2022; Seth et al., 2024).

3.4. Artificial intelligence within wound care education

The included studies highlight a diverse range of artificial intelligence technologies and applications in wound care education, reflecting varying levels of complexity and functionality. The main functions include real-time feedback (Heerschap, 2023; Kil et al., 2024; Lau et al., 2022; Noraset et al., 2024), automated assessment (Kil et al., 2024; Morente and Veredas, 2013; Noraset et al., 2024; Veredas et al., 2014), adaptive learning (Heerschap, 2023; Morente and Veredas, 2013; Prodan et al., 2010a; Veredas et al., 2014), and interactive engagement (Heerschap, 2023; Kil et al., 2024; Lau et al., 2022; Ousey et al., 2018).

Artificial intelligence potential technologies to be used as teaching tools include expert systems, such as Bayesian inference and case-based reasoning (Bender et al., 2022; Prodan et al., 2010a), machine learning (Heerschap, 2023; Ousey et al., 2018; Morente et al., 2011), deep learning (Lau et al., 2022; Noraset et al., 2024), computational intelligence (Morente et al., 2011; Morente and Veredas, 2013; Veredas et al., 2014), and neural networks (Morente et al., 2011; Veredas et al., 2014). Specific applications also included computer vision techniques for wound image segmentation and tissue classification (Morente and Veredas, 2013; Veredas et al., 2014), and suturing metrics extraction for performance evaluation (Kil et al., 2024).

Generative artificial intelligence tools, like DALL-E 2 (OpenAI), Blue Willow (LimeWire), and Midjourney (Midjourney, Inc.), were used to create realistic wound images and educational content while preserving patient privacy (Koljonen, 2023; Seth et al., 2024). Although generative adversarial networks like DALL-E2 (OpenAI) and Midjourney (Midjourney, Inc.) produced lifelike images, limitations in accuracy and medical terminology recognition restricted their immediate applicability in clinical education (Seth et al., 2024). However, their ability to create non-identifiable images presents opportunities for teaching while maintaining patient confidentiality and privacy (Koljonen, 2023).

Artificial intelligence technologies also contributed to personalized and adaptive learning experiences. Large language models like OpenAI's ChatGPT can simulate virtual patients and teaching assistants to provide real-time feedback, multilingual support, and tailored educational content (Heerschap, 2023).

Several studies emphasized the value of artificial intelligence-based frameworks and e-learning platforms in facilitating interactive and active learning.

Java tools incorporating artificial intelligence tools provided functionalities for wound image analysis, tissue classification, and healing simulations, underscoring their potential to enhance diagnostic efficiency and support simulation-based learning and clinical decision-making training in medical education (Prodan et al., 2009, 2010a).

Adaptive platforms outperformed traditional pressure ulcer training, significantly improving participants' assessment skills on pressure ulcers (Morente and Veredas, 2013; Veredas et al., 2014). The effectiveness of these tools as adaptive educational platforms was validated through pre and post-test comparisons, demonstrating their potential capacity to enhance wound care learning outcomes. Positive feedback on their adaptive features and user-friendly interface further supported their educational impact.

Integrating artificial intelligence-powered simulations and interactive technologies was highlighted as a potential innovation in wound care education. Virtual reality and augmented reality tools allowed the simulation of realistic wound care scenarios, combining haptic, visual, and auditory feedback to improve nurses' clinical skills in dynamic and interactive settings (Ousey et al., 2018). Artificial intelligence supported the creation of e-learning scenarios designed for active learning environments, incorporating feedback mechanisms, visual recognition, and interactive decision-making to enhance students' clinical skills and

understanding of wound image analysis (Morente and Veredas, 2013; Prodan et al., 2010a; Veredas et al., 2014).

In another study, case-based reasoning systems matched new wound cases with historical data, offering evidence-based diagnostic and treatment recommendations, and potentially enhancing nurses' competence and decision-making (Bender et al., 2022).

Other artificial intelligence tools included a smartphone application using deep learning algorithms for real-time wound detection and classification, which could improve students' motivations and skills in wound assessment and staging (Lau et al., 2022).

These technologies had the potential to enable progressive education by tailoring content to user performance (Morente et al., 2011; Morente and Veredas, 2013; Veredas et al., 2014), facilitating collaborative evaluation, and providing automated metrics for skill assessment (Heerschap, 2023; Kil et al., 2024; Noraset et al., 2024). In surgical contexts, artificial intelligence tools for skill evaluation and feedback objectively assess suturing precision with a high correlation to human measurements (Kil et al., 2024; Noraset et al., 2024). These tools enhanced training by offering real-time feedback and objectivity in skill assessment.

Data presented in the included studies regarding artificial intelligence validation and testing metrics was limited. One study presented artificial intelligence validation and testing metrics, reporting a global accuracy of 91.5 % for tissue classification (Morente et al., 2011). Another study demonstrated an overall prediction accuracy of 63.2 %, with high specificity (85.1 %–100 %) but variable sensitivity (55.6 %–73.3 %) for wound detection and staging (Lau et al., 2022). Other studies assessed artificial intelligence-generated images' validity and realism through expert judgment and pre/post-test evaluations (Kil et al., 2024; Koljonen, 2023; Morente and Veredas, 2013). Several studies did not explicitly mention artificial intelligence metrics or validation, relying instead on inferred effectiveness or user feedback (Bender et al., 2022; Ousey et al., 2018; Prodan et al., 2010a; Veredas et al., 2014).

Regulatory approvals were not addressed, and interoperability was only mentioned in Java-based tools, highlighting their potential for integration with web-based systems (Prodan et al., 2008b, 2010a, 2010b).

4. Discussion

This scoping review highlights the transformative potential of artificial intelligence in wound care education, demonstrating its capacity to enhance skill development, promote interactive learning, and support evidence-based decision-making. The studies reviewed described diverse artificial intelligence applications, including adaptive e-learning platforms, virtual reality and augmented reality simulations embedded with artificial intelligence, generative artificial intelligence for educational content, and diagnostic tools. These technologies enable personalized learning experiences by tailoring content to individual student needs and providing real-time feedback to refine clinical skills, aligning with existing literature on artificial intelligence's ability to deliver dynamic, immersive, and personalized educational experiences (Chiu et al., 2023; De Gagne, 2023; Preiksaitis and Rose, 2023).

Several studies underscored the role of artificial intelligence in fostering active learning and practical experiences by integrating real-world scenarios into e-learning platforms. Advanced artificial intelligence paradigms such as Bayesian inference, case-based reasoning, and intelligent agents enhance students' abilities to analyze wound images, identify critical healing barriers (e.g., infection, inflammation, and moisture imbalance), and improve diagnostic accuracy. Moreover, artificial intelligence-generated images emerged as innovative tools for pattern recognition and clinical case discussions, preserving patient privacy and supporting learning objectives. Smartphone-based applications and large language models, such as ChatGPT (OpenAI), demonstrated their potential to offer accessible and personalized content.

Despite these advancements, this review highlights several challenges and limitations. Most included studies focused on system development and conceptual frameworks, lacking empirical assessments of their outcomes. This focus on preliminary designs limits the generalizability and applicability of findings to real-world educational contexts. To address these challenges, future research should adopt mixed-method approaches, combining qualitative and quantitative evaluations to assess the effectiveness of artificial intelligence tools in improving wound care education. Additionally, pilot programs, longitudinal studies, and collaborations with software developers could be implemented to test usability, refine algorithms, and ensure seamless integration into curricula. Artificial intelligence tools also demonstrated promising results (Morente and Veredas, 2013; Veredas et al., 2014). Still, their evaluations were based on small sample sizes or narrow applications, such as pressure ulcer management, constraining their broader clinical relevance.

Technical and usability challenges also emerged as critical barriers to implementation. Issues such as long processing times, high storage demands, and interoperability constraints may hinder the scalability of artificial intelligence tools in educational settings. Potential strategies to address these challenges include collaborating with software developers to optimize algorithms for efficiency, conducting pilot testing in diverse academic environments to identify usability gaps, and employing cloud-based infrastructures to manage storage and processing requirements. Furthermore, a notable lack of artificial intelligence evaluation metrics, including accuracy, sensitivity, and specificity, was observed in many studies. To improve reliability, studies should incorporate standardized validation protocols and performance benchmarks. Only a few studies reported validation outcomes (Lau et al., 2022; Morente et al., 2011), highlighting the need for more rigorous testing and transparent reporting. The absence of regulatory approvals and explicit discussions on compliance raises additional concerns about artificial intelligence safety, reliability, and ethical integration in wound care education.

The integration of artificial intelligence into nursing education demands critical attention to its ethical, legal, and social implications. Bias resulting from non-representative training datasets can lead to inaccurate predictions, particularly for marginalized or minority groups, thereby reinforcing structural inequities (Glauber et al., 2023; Dunlap and Michalowski, 2024). This concern is especially relevant in healthcare education, where simulations and decision-support tools risk becoming misleading if developed without considering demographic diversity.

Furthermore, the opacity of AI systems undermines trust and compromises the ability of educators and clinicians to validate outputs, while potential data privacy breaches threaten the rights of students and patients (WHO, 2021; Ghane et al., 2024). These challenges are exacerbated when institutions lack governance mechanisms to ensure data quality, traceability, and accountability.

Despite these risks, AI can also serve as a tool to reduce harm if designed and implemented with ethical safeguards. The use of inclusive and high-quality datasets, adherence to principles of explainability and transparency, and the establishment of clear responsibility structures are essential for safe deployment (ANA, 2022; Dunlap and Michalowski, 2024). Institutions and educators must adopt a proactive role in guiding the ethical integration of AI, ensuring that its use aligns with the foundational nursing values of safety, equity, and human dignity.

4.1. Practical implications and challenges

Artificial intelligence technologies have implications for both students and educators. Tools like large language models and generative artificial intelligence can reduce educators' workloads by automating tasks such as creating teaching materials and providing multilingual educational support (Hobensack et al., 2024; Lee, 2024). Chatbots have emerged as valuable tools for fostering engagement, providing effective feedback, and enabling educators to track students' progress and

identify areas for improvement (Goktas et al., 2024; Tam et al., 2023; Zhang et al., 2024). However, their effectiveness depends on their ability to adapt to learners' needs while maintaining accuracy and reliability.

Artificial intelligence technologies have the potential to enhance knowledge acquisition and clinical skills, but concerns remain regarding their impact on clinical decision-making (Gerlich, 2025). Educators fear that an overreliance on artificial intelligence could negatively impact the development of students' critical thinking and problem-solving abilities (Lee, 2024; Tam et al., 2023). Similar concerns have been raised in other healthcare contexts, where the efficacy of artificial intelligence tools depends on the quality of training datasets and extensive testing (Sallam, 2023). In wound care education, high-quality data is essential to minimize biases in artificial intelligence algorithms, which could otherwise distort educational content.

Addressing the ethical considerations of artificial intelligence, including algorithm transparency, interpretability, and accountability, is needed. Ensuring educators have sufficient technological skills and support to integrate artificial intelligence tools into their teaching practices is critical for successful implementation.

The ethical deployment of AI in education requires more than technical competence; it demands a robust culture of data literacy and critical reflection among educators and institutions. Nurse educators must be equipped not only to use AI tools but to recognize their limitations, mitigate algorithmic risks, and ensure equitable learning experiences (Dunlap and Michalowski, 2024). The American Nurses Association (ANA, 2022) emphasizes the importance of safeguarding patient privacy, upholding transparency, and preserving core nursing values, including compassion and human connection. Likewise, the Nursing and Artificial Intelligence Leadership (NAIL) Collaborative emphasizes the importance of empowering nurses to take leading roles in shaping the ethical adoption of AI across practice and education (Glauber et al., 2023).

4.2. Future directions

The swift integration of artificial intelligence into wound care education signals a transformative era, yet it also raises critical questions that demand a thorough investigation. Future research must assess the immediate educational benefits and examine the long-term effects of artificial intelligence on student performance, instructor-student dynamics, and ethical considerations.

A crucial priority for future studies lies in evaluating the effectiveness of artificial intelligence-based educational tools in enhancing core competencies, including knowledge retention, diagnostic accuracy, problem-solving abilities, critical thinking, and clinical decision-making. These assessments should utilize robust methodologies, integrating qualitative and quantitative approaches to capture nuanced educational outcomes. Furthermore, research must broaden its scope by encompassing a wider range of wound types, including complex chronic and atypical presentations, and by incorporating larger, more diverse samples to strengthen generalizability across various educational and cultural contexts.

Artificial intelligence's potential to personalize learning experiences, simulate clinical scenarios, and provide real-time feedback opens exciting avenues for pedagogical innovation. However, its implementation also introduces pressing ethical dilemmas, particularly regarding privacy, algorithmic transparency, and bias. Sharing sensitive patient information among students, educators, and healthcare professionals underscores the need for comprehensive data governance frameworks. Establishing standardized protocols for data security, algorithmic accountability, and informed consent is paramount to fostering trust and upholding ethical standards in artificial intelligence-enhanced education.

Furthermore, future investigations should examine artificial intelligence's potential to bridge global wound care education gaps by providing scalable solutions for underserved regions. Adaptive learning

platforms and virtual simulations could democratize access to specialized knowledge, thus reducing disparities in healthcare training worldwide.

Moreover, the implementation of AI across diverse educational and geographical contexts presents several challenges. The integration of AI-based tools requires not only technological infrastructure but also curriculum redesign to align with AI-supported pedagogies. The absence of AI literacy among teachers creates a significant barrier to the effective integration of AI in the classroom (Rincón et al., 2025; Tan et al., 2025). This highlights the need to equip educators with specific competencies to critically use, interpret, and integrate these tools into their teaching practices. Simultaneously, institutions must allocate dedicated resources, which can be financially demanding, for ongoing technical support and maintenance to ensure the sustainable adoption of these solutions.

In geographically diverse settings, disparities in access to digital infrastructure are particularly concerning. Institutions in low- and middle-income countries may lack stable internet connectivity, modern hardware, or secure data systems necessary for AI deployment (Rincón et al., 2025). Additionally, varying levels of digital literacy among educators and students may affect adoption and engagement, particularly in contexts where professional development in educational technologies is limited.

Language barriers and cultural variations may further influence the acceptance and usability of AI tools, especially those relying on natural language processing or region-specific clinical content. In multicultural contexts, disparities in proficiency with the AI's default language, without proper linguistic support, can hinder students' learning experiences and compromise educational outcomes (Lifshits and Rosenberg, 2024). Ethical and regulatory considerations, such as equitable access, also present ongoing concerns. To enable the effective and responsible use of AI in wound care education, implementation strategies must address these practical and systemic issues, ensuring that tools are adaptable, inclusive, and responsive to the diverse needs of various learning environments worldwide. Therefore, future initiatives must address these disparities by promoting the development of flexible, context-aware, and linguistically accessible platforms.

In this regard, AI systems must be developed and deployed with a priority on inclusivity, transparency, and cultural sensitivity. This is particularly relevant in wound care education, where clinical presentations and management practices may vary widely depending on regional epidemiology, healthcare resources, and patient demographics. Taking this into consideration, institutions can enhance the quality of training while ensuring that learners across diverse settings are equally equipped to assess, classify, and manage wounds in diverse clinical scenarios.

To fully realize artificial intelligence's transformative potential, interdisciplinary collaboration among educators, engineers, clinicians, data scientists, and ethicists must be encouraged. These partnerships can drive the joint creation of artificial intelligence systems that are not only technologically advanced but also ethically sound and culturally sensitive. Ultimately, advancing artificial intelligence in wound care education will require a delicate balance between innovation and integrity. This approach prioritizes human values while leveraging machine intelligence to enhance learning experiences and improve patient outcomes.

4.3. Limitations

Although this scoping review was conducted following the JBI methodology, a few limitations exist. The restriction of studies published in English, Portuguese, and Spanish may have excluded relevant research in other languages, although no studies were excluded based on country of origin.

The findings may have constrained applicability and transferability to healthcare systems, educational environments, or regions with

distinct practices, cultural frameworks, and resource availability. Variations in institutional priorities, regulatory standards, and technological infrastructure could further influence the generalizability of the results. Future studies should seek to incorporate multilingual sources and examine settings with broader contextual diversity to enhance the robustness and global relevance of the findings.

Future developments should prioritize the creation of inclusive and high-quality datasets, alongside the development of tailored ethical frameworks for nursing education. A data-centric approach to AI—shifting the focus from model optimization to the quality, fairness, and governance of data—has been proposed as a critical strategy to build responsible and sustainable AI solutions (Dunlap and Michalowski, 2024). Such strategies demand collaboration among diverse stakeholders, including patients, educators, community representatives, and ethics experts, to ensure that AI technologies enhance—not compromise—human dignity and patient safety.

5. Conclusions

This scoping review highlights artificial intelligence's potential to transform wound care education, offering innovative approaches to teaching and learning. However, several limitations and gaps in the current literature emphasize the need for further research to establish artificial intelligence efficacy and practical application in this field. The generalizability of these findings is limited due to the small number of included studies, the emerging nature of this topic, and the specificity of the contexts in which the studies were conducted.

A balanced approach is crucial, integrating artificial intelligence technologies as complementary tools rather than replacements for traditional educational methods. Comprehensive evaluations are needed to assess the impact of these tools on student outcomes, including knowledge retention, problem-solving abilities, and critical thinking skills. The challenge lies in preserving academic integrity while validating the effectiveness of artificial intelligence in wound care education.

The integration of artificial intelligence must be guided by empirical evidence, ethical considerations, and a commitment to preserving the human elements of medical practice. By addressing existing challenges, artificial intelligence has the potential to revolutionize wound care education, equipping healthcare professionals with the skills and knowledge to improve wound diagnosis, treatment, and management, ultimately enhancing patient care quality.

Nevertheless, as AI becomes further integrated into nursing curricula, it is imperative to ensure that innovation does not outpace ethical safeguards. Educational strategies must balance technological advancement with humanistic values, reinforcing trust, inclusivity, and professional accountability.

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CRedit authorship contribution statement

Rúben Encarnação: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **José Alves:** Writing – review & editing, Visualization, Formal analysis, Data curation. **Ana Marques:** Writing – review & editing, Visualization, Formal analysis, Data curation. **João Neves-Amado:** Writing – review & editing, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Paulo Alves:** Writing – review & editing, Visualization, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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