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CONCEPTUAL APPROACHES TO THE INTEGRATION OF GENERATIVE ARTIFICIAL INTELLIGENCE INTO SIMULATION-BASED TRAINING FOR MEDICAL STUDENTS

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The rapid expansion of generative artificial intelligence (GenAI) is transforming medical education by creating new opportunities for simulation-based learning, clinical reasoning development, and personalized educational support. Despite increasing adoption of large language models in health professions education, their integration into simulation remains fragmented, with limited methodological guidance and a lack of standardized pedagogical frameworks.

To develop a conceptual model for integrating GenAI into simulation-based medical education and to define methodological principles for its safe, pedagogically sound, and evidence-based implementation.

A narrative analysis of contemporary literature, international recommendations, and methodological documents published between 2023 and 2026 was conducted. Current evidence regarding the educational applications, benefits, limitations, ethical considerations, and implementation strategies of GenAI in medical education and healthcare simulation was synthesized. Based on these findings, a conceptual framework and methodological principles for GenAI integration into simulation-based learning were developed.

The proposed framework integrates GenAI across all stages of simulation-based education, including scenario design, educational content generation, adaptive virtual patient interactions, clinical reasoning support, formative feedback, debriefing assistance, and reflective learning. Eight methodological principles were identified: pedagogical appropriateness, prioritization of clinical reasoning, human-in-the-loop supervision, evidence-based clinical content, comprehensive integration throughout the simulation process, academic integrity, ethics and data privacy, and continuous educational evaluation. The model emphasizes that GenAI should augment rather than replace educators, with faculty maintaining responsibility for instructional design, expert validation of AI-generated content, learner assessment, and educational debriefing.

GenAI has considerable potential to enhance simulation-based medical education by improving educational efficiency, adaptability, and learner engagement. However, its successful implementation requires standardized pedagogical frameworks, continuous human oversight, adherence to evidence-based medicine, academic integrity, ethical principles, and data protection. The proposed conceptual model provides a methodological foundation for the responsible integration of GenAI into undergraduate medical education and may support future research evaluating its educational effectiveness and impact on competency development.

Key words: generative artificial intelligence, simulation-based medical education, clinical reasoning, large language models, health professions education.

Павлюкович Н., Павлюкович О. Концептуальні підходи до інтеграції генеративного штучного інтелекту в навчання студентів-медиків на основі симуляцій

Стрімке поширення генеративного штучного інтелекту (ШІ) трансформує медичну освіту, створюючи нові можливості для розвитку клінічного мислення та індивідуалізованої освітньої підтримки. Попри доволі широке застосування великих мовних моделей у підготовці фахівців галузі охорони здоров'я, методика навчання на основі симуляцій залишається не достатньо розробленою і потребує ґрунтовних системних досліджень.

Розробити концептуальну модель інтеграції генеративного ШІ в медичну освіту на основі симуляцій та визначити методологічні принципи його безпечного, педагогічно обґрунтованого та науково підкріпленого впровадження.

Було проведено аналіз сучасної літератури, міжнародних рекомендацій та методологічних документів, опублікованих у період з 2023 по 2026 рік. Узагальнено сучасні дані щодо освітніх застосувань, переваг, обмежень, етичних аспектів та стратегій впровадження генеративного ШІ у медичну освіту та симуляційне навчання в галузі охорони здоров'я

Запропонована модель передбачає інтеграцію генеративного ШІ на всіх етапах симуляційного навчання, включаючи розробку сценаріїв, генерацію навчального контенту, адаптивну взаємодію з віртуальними пацієнтами, підтримку клінічного мислення, формувальний зворотний зв'язок, допомогу в проведенні дебрифінгу та рефлексивне навчання. Було визначено вісім методологічних принципів застосування ШІ в освітньому процесі: педагогічна доцільність; пріоритетність формування клінічного мислення; нагляд з участю людини; клінічний контент, базований на наукових доказах; всебічна інтеграція впродовж усього процесу використання симуляції; академічна доброчесність; етика та конфіденційність даних; безперервний моніторинг навчальних досягнень. Модель акцентована на доповнюваній ролі генеративного ШІ. Повну відповідальність за розробку навчальних програм, експертну валідацію контенту, згенерованого ШІ, оцінювання студентів та зворотній зв'язок несе науково-педагогічний працівник.

Генеративний ШІ має значний потенціал для вдосконалення медичної освіти на основі симуляцій шляхом підвищення ефективності навчання, адаптивності та залученості студентів. Однак його успішне впровадження вимагає стандартизованих педагогічних рамок, постійного людського нагляду, дотримання принципів доказової медицини, академічної доброчесності, етичних принципів та захисту даних. Запропонована концептуальна модель забезпечує методологічну основу для відповідальної інтеграції генеративного ШІ у медичну освіту та може стати основою для майбутніх досліджень, спрямованих на оцінку її освітньої ефективності та впливу на формування професійної та розвиток ключових компетентностей.

Ключові слова: генеративний штучний інтелект, медична освіта на основі симуляції, клінічне мислення, великі мовні моделі, освіта у сфері охорони здоров'я.

Introduction. The rapid digital transformation of the healthcare system and medical education is changing traditional approaches to training future professionals, prompting a review of pedagogical models, teaching methods and mechanisms for developing professional competences. One of the most significant catalysts for these changes has been the rapid implementation of generative artificial intelligence (GenAI), in particular large language models (LLMs) such as ChatGPT, Gemini, Claude, Copilot and others. Unlike previous generations of artificial intelligence systems, which primarily performed analytical or predictive functions, modern generative models are capable of conducting dialogue in natural language, generating text, analysing clinical scenarios, explaining complex medical concepts, creating educational materials and supporting the clinical decision-making process. This is precisely why GenAI is increasingly being viewed not merely as a new digital tool, but as a technology that has the potential to fundamentally transform the very paradigm of medical education [1].

The pace at which GenAI has been adopted has proved unprecedented. Whilst the roll-out of e-learning platforms, distance learning systems and simulation technologies took years, large language models became an integral part of the educational process almost immediately after their emergence. They are already being used by students, lecturers and doctors to search for information, analyse clinical cases, create test questions, develop teaching materials, prepare research papers, simulate communication with patients and support clinical reasoning. According to international research, the majority of medical students regularly use generative artificial intelligence during their studies, regardless of whether their higher education institution has an official policy on the matter [2, 3], which highlights the need to move away from banning the use of such technologies towards developing effective mechanisms for their pedagogically sound integration.

A particularly promising area is the use of GenAI in simulation-based training. Over recent decades, simulation has become one of the fundamental components of healthcare professionals' training, as it enables the development of clinical competencies in a safe educational environment without putting patients at risk. Simulation-based training allows for the repeated practising of clinical skills, decision-making, teamwork, communication and protocols for the provision of medical care. The integration of GenAI has the potential to expand these possibilities by automatically generating clinical scenarios of varying levels of complexity, modelling the behaviour of a virtual patient, adapting the scenario to the student's level of training, providing automated debriefing, personalised formative feedback and supporting reflective learning [4]. Thus, GenAI may become not a standalone digital service, but an integrated component of a modern simulation-based educational environment. At the same time, international professional organisations emphasise that the rapid implementation of GenAI is accompanied by a number of pedagogical, ethical, legal and safety challenges. Among the main risks cited are the potential for generating inaccurate or fabricated information ('hallucinations'), algorithmic biases, a lack of transparency in decision-making mechanisms, breaches of academic integrity, risks to the confidentiality of personal data, and students' excessive reliance on automated responses [5]. In medical education, these issues take on particular significance, as errors formed during training can directly affect the quality of future clinical practice and patient safety. This is precisely why international organisations have already developed the first regulatory documents on the responsible use of GenAI in education. The UNESCO Guidance for Generative AI in Education and Research [6] emphasises that the use of GenAI must be based on the principles of human-centredness, transparency, accountability, academic integrity, personal data protection, digital equity and critical thinking. The Association of American Medical Colleges (AAMC) emphasises that medical education must train future doctors to use AI responsibly, ensuring the development of critical thinking, human oversight of AI use, the ability to evaluate its outcomes, and the application of these technologies in accordance with ethical principles and safety requirements [7]. Current AMEE guidelines regard GenAI as a promising component of the educational process, the integration of which should be based on pedagogical theory, principles of ethical use, the development of students' and teachers' competences, as well as appropriate pedagogical support and ongoing assessment of its impact on learning outcomes [8].

Despite the considerable interest in this subject area, the current academic literature is characterised by a certain degree of fragmentation. Most published works focus on evaluating the capabilities of individual language models [9], comparing their performance when completing test tasks [10], sitting professional licensing exams [11] or analysing clinical cases [12]. Another group of studies describes individual examples of using ChatGPT in teaching or for students' self-directed learning [13]. At the same time, considerably less attention has been paid to the development of comprehensive pedagogical models for integrating GenAI into the educational process. Most studies lack a description of the structure of interaction between the student, the lecturer, the simulation environment and the artificial intelligence system; the optimal stages for using GenAI during a simulation session have not been defined; and mechanisms for assessing learning outcomes, quality control of AI responses, risk management and ensuring academic integrity have not been sufficiently developed.

This gap is particularly pronounced in the field of simulation-based education. Despite the rapid spread of GenAI, there are currently virtually no standardised conceptual models that define the role of large language models within the structure of simulation-based learning, regulate the functions of the lecturer, student and AI system at different stages of the learning process, establish criteria for the pedagogical appropriateness of using GenAI, or ensure its compliance with international principles of safe and responsible education. As a result, each higher education institution or individual lecturer is forced to determine their own approaches to the use of GenAI, leading to significant variability in practices, a lack of uniform standards and difficulties in assessing their effectiveness.

Modern generative artificial intelligence models open up new opportunities for improving simulation-based learning, covering virtually all stages of the educational process – from designing a lesson to analysing its outcomes. Unlike traditional digital tools, which perform individual functions, large language models are capable of supporting interactive engagement with students [14-16], generating new educational content [17], adapting it to the user's level of proficiency, and providing personalised learning support [5].

One of the most promising areas of implementation for GenAI is the creation of clinical scenarios. Using large language models, a lecturer can quickly generate clinical cases of varying complexity, tailoring them to the topic of the lesson, the learning outcomes and the students' level of preparation. GenAI enables the simulation of patient histories, physical examination findings, laboratory and diagnostic test results, as well as the prediction of various possible outcomes of a clinical situation. This significantly reduces the time required to prepare a simulation session and helps to diversify the teaching content.

Equally important is the ability to automatically generate test questions and teaching materials. GenAI can create questions of varying levels of difficulty, clinical problems, scenario-based cases, checklists, instructions for students, action algorithms and materials for self-study. Provided they are verified by experts, such materials can significantly optimise a lecturer's teaching practice.

Of particular interest is the use of GenAI when working with virtual patients. Thanks to their natural language processing capabilities, modern language models facilitate dynamic dialogue between the student and the virtual patient, simulating various clinical scenarios and the patient's responses to the questions asked. Unlike traditional scenarios with pre-determined responses, GenAI enables more natural communication, closely resembling real clinical practice.

An important area of application for GenAI is supporting the development of clinical reasoning. GenAI can encourage students to formulate a differential diagnosis, analyse clinical data, select the optimal diagnostic and therapeutic strategies, justify their own decisions and reflect on any mistakes made. At the same time, it is of fundamental importance that artificial intelligence does not replace the process of clinical reasoning, but acts as a tool for its development.

Once the simulation scenario has been completed, GenAI can be used for automated debriefing and to provide personalised feedback. By analysing a student's actions, GenAI is able to identify common errors, highlight critical aspects of clinical patient management, suggest additional sources of information and provide personalised recommendations for further learning. At the same time, international guidelines emphasise that the results of such an analysis should be regarded as a supplementary tool and cannot replace the pedagogical debriefing conducted by a tutor [18].

Thus, GenAI can support all stages of simulation-based learning – from the creation of educational content to the assessment of learning outcomes. At the same time, its integration must be based on the principles of pedagogical appropriateness, the evidence-based nature of medical content, the development of clinical reasoning, and the preservation of the instructor's leading role in the educational process.

Despite the significant potential of GenAI to enhance simulation-based learning, its integration into the educational process is accompanied by a number of methodological, ethical, legal and organisational challenges. Unlike traditional digital resources, large language models not only reproduce existing information but also generate new content, which necessitates constant monitoring of its quality and compliance with current clinical guidelines. This is precisely why the effective use of GenAI in medical education is only possible provided that the potential risks are understood and mechanisms are developed to minimise them.

One of the most hotly debated issues is the *reliability of information* generated by artificial intelligence. Large language models can produce logically coherent but factually incorrect or fabricated responses (so-called 'hallucinations'). In medical education, this poses a particular danger, as incorrect information may be perceived by students as reliable and subsequently influence the development of their clinical reasoning. The risk is exacerbated by the fact that responses from language models are often presented with confidence and without any indication of the level of reliability or the sources of the information. Consequently, the use of GenAI requires mandatory expert verification of clinical content by a lecturer and comparison of the responses obtained with current clinical guidelines and the principles of evidence-based medicine.

Another significant challenge is *algorithmic bias*. The outputs of generative artificial intelligence depend on the data on which the model was trained; consequently, they may reflect biases present in that data, social stereotypes, or the under-representation of certain clinical situations. This can lead to inaccuracies when modelling clinical cases or providing recommendations for the diagnosis or treatment of specific categories of patients. Therefore, clinical scenarios created using GenAI must undergo expert validation before being used in the teaching process.

The issue of *academic integrity* is no less pressing. GenAI makes it significantly easier to produce written assignments, answers to test questions and other educational materials, which creates a risk of tasks being completed mechanically without proper understanding of the subject matter. At the same time, a complete ban on the use of GenAI is largely ineffective, as these technologies have already become an everyday tool in educational activities. Instead, it is advisable to establish clear rules for the responsible use of artificial intelligence, to develop skills for critically evaluating its responses, and to introduce assessment methods that primarily test clinical reasoning rather than the ability to reproduce ready-made information.

Issues of *confidentiality and the protection of personal data* require particular attention. When working with generative models, there is a risk of inputting information containing patients' personal data or other confidential information. This may contravene the requirements of data protection legislation and the principles of medical ethics. Therefore, when using GenAI in the educational process, it is essential to use only depersonalised clinical cases or specially created training scenarios that do not contain any information that could identify the patient.

Another challenge is an excessive reliance on the answers provided by GenAI (*automation bias*). There is a risk that students will gradually come to regard the answers provided by language models as definitive and infallible, thereby reducing their own active involvement in the process of analysing clinical information. Such an approach runs counter to the fundamental principles of medical education, where the development of clinical reasoning, the ability to analyse alternative diagnoses, critically evaluate evidence and make clinical decisions independently are of paramount importance. This is precisely why GenAI should be regarded as a learning support tool, rather than a source of definitive clinical conclusions.

In the context of integrating GenAI, the role of the tutor remains of fundamental importance. Despite the high level of development of modern language models, they cannot fully replace the pedagogical guidance, professional experience, clinical reasoning and mentorship provided by a tutor. It is the teacher who sets the educational objectives, designs the structure of the simulation session, carries out expert review of the materials, assesses the accuracy of students' clinical decisions and conducts the debriefing. In this process, GenAI should serve as a supporting tool that enhances the lecturer's capabilities, but does not replace their pedagogical role.

Consequently, the effective use of generative artificial intelligence in simulation-based training requires a balanced approach that combines the use of modern digital technologies with adherence to the principles of evidence-based medicine, academic integrity, ethical responsibility and patient safety. Recognising the potential risks and implementing appropriate mechanisms to minimise them is a necessary prerequisite for developing the methodological framework for integrating GenAI into the training of future doctors.

The effective use of GenAI in simulation-based training requires not only modern digital technologies but also a clear methodological framework that will ensure pedagogical appropriateness, safety and the alignment of the educational process with current requirements in medical education. Based on an analysis of current international recommendations and the results of scientific research, we have proposed a system of methodological principles for integrating GenAI into simulation-based training for medical students (Table 1).

The proposed methodological principles can be applied at all stages of simulation-based learning. GenAI should be used not as a standalone tool, but as an integrated component of the educational process, supporting lesson preparation, the conduct of simulations and post-simulation analysis of results. However, the teacher continues to play a key role in planning the training, expert verification of clinical content and assessment of results.

The figure illustrates the proposed model for integrating GenAI into a simulation session. The practical implementation of the proposed model can be demonstrated using the example of a simulation session on the topic of 'Acute decompensated heart failure'. During the preparation stage, the tutor uses GenAI to create a clinical scenario, which includes the patient's complaints, medical history, physical examination findings, laboratory results, an electrocardiogram and a chest X-ray. In addition, GenAI can generate a list of learning objectives, a checklist for assessing students' practical skills, questions for debriefing and test questions to assess knowledge. Once generated, all materials are reviewed by an expert lecturer in accordance with current clinical guidelines.

During the simulation session, the student works with a virtual patient who has presented with complaints of shortness of breath, orthopnoea, oedema of the lower limbs and general weakness. Using GenAI, the scenario can adapt depending on the student's actions: clinical parameters change, results of addi-

Table 1

Methodological principles for integrating generative artificial intelligence into simulation-based medical education

Principle	Practical implementation
Pedagogical appropriateness	Use GenAI only when it supports clearly defined learning outcomes and educational objectives
Priority of clinical reasoning	Encourage learners to analyse clinical information, justify decisions, and develop differential diagnoses rather than rely on AI-generated answers
Human-in-the-loop	Ensure continuous faculty oversight, expert validation, and pedagogical supervision throughout the learning process
Evidence-based clinical content	Verify all AI-generated clinical scenarios and recommendations against current clinical guidelines and evidence-based medicine
Comprehensive integration	Integrate GenAI throughout all stages of simulation-based learning, including preparation, scenario delivery, debriefing, and reflection
Academic integrity	Provide clear policies for responsible AI use and promote independent learning and critical evaluation of AI-generated content
Ethics and data privacy	Protect confidential information, use anonymised clinical cases, and ensure ethical and transparent AI implementation
Continuous evaluation	Regularly assess the educational effectiveness, accuracy, and impact of GenAI on learning outcomes and continuously refine implementation strategies

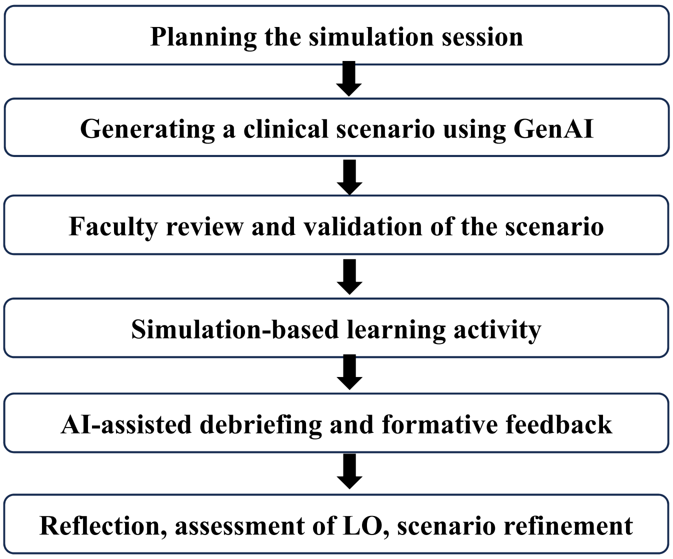

Fig. 1. Practical model for integrating generative artificial intelligence into simulation-based learning

tional investigations are provided, and the patient's response to the prescribed treatment is simulated – or, conversely, a deterioration in their condition is modelled in the event of incorrect clinical decisions. This approach enables the creation of a dynamic scenario that closely mirrors real-world clinical practice.

Particular attention is paid to the development of clinical reasoning. GenAI does not provide a ready-made diagnosis or treatment algorithm, but encourages students to analyse clinical information by posing additional questions, suggesting alternative diagnostic hypotheses and requiring them to justify their own decisions. For example, the system may ask a student to justify a differential diagnosis between acute heart failure, an exacerbation of chronic obstructive pulmonary disease and pulmonary embolism, or to explain the choice of diuretic therapy, oxygen support and the subsequent management strategy for the patient.

Once the simulation is complete, GenAI can automatically summarise the student's sequence of actions, identify the key stages of the patient's clinical management, generate personalised formative feedback and suggest questions for reflection. At the same time, the final debriefing, analysis of clinical decisions and assessment of the achievement of the programme's learning outcomes are carried out by the tutor, who provides pedagogical support and corrects any inaccuracies generated by the artificial intelligence.

The proposed model demonstrates that GenAI can be effectively integrated at all stages of simulation-based learning, enhancing the lecturer's capabilities and promoting the development of students' clinical reasoning. At the same time, its use must be based on the principles of pedagogical appropriateness, evidence-based medicine, academic integrity and mandatory human oversight (human-in-the-loop), ensuring the safe and effective application of artificial intelligence technologies in the training of future doctors.

Conclusions. Generative artificial intelligence is a promising tool for the development of simulation-based learning, capable of expanding the scope of training for future doctors by supporting the creation of clinical scenarios, simulating interactions with virtual patients, developing clinical reasoning, and personalising the educational process. At the same time, its effective use is only possible provided that it is integrated in a pedagogically sound manner, whilst maintaining the leading role of the lecturer and adhering to the principles of evidence-based medicine, academic integrity, ethical standards and the protection of personal data. The proposed methodological principles and practical model for integrating GenAI into simulation-based learning can serve as a conceptual framework for the implementation of generative artificial intelligence technologies in the educational process of higher medical education institutions, and lay the groundwork for further research into their impact on the development of professional competencies and the quality of training for future specialists.

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