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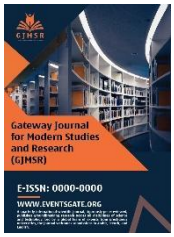

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Artificial Intelligence in Pharmaceutical and Health Sciences Education: A PRISMA-Guided Narrative Literature Review of Educational Applications, Ethical Challenges, and Future Directions

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Abstract: Artificial intelligence (AI) increasingly influenced pharmaceutical and health sciences education by transforming teaching, assessment, simulation-based learning, and curriculum development. This PRISMA-guided narrative literature review evaluated current educational applications, examined associated ethical challenges, and identified future directions for responsible curricular integration. A structured search of PubMed, Scopus, Web of Science, Google Scholar, and ScienceDirect identified English-language publications from 2020 to 2026. After duplicate removal, title and abstract screening, and full-text eligibility assessment, 32 studies and policy documents met the predefined criteria and were included in a qualitative narrative synthesis. Data were extracted and synthesized thematically. The review showed that AI-driven systems supported adaptive learning, virtual patient simulations, learning analytics, automated assessment, generative AI, and large language models, improving personalized learning, student engagement, educational efficiency, and clinical training. Important challenges involved data privacy, algorithmic bias, academic integrity, transparency, equitable access, AI literacy, and institutional governance. International policy recommendations emphasized ethical implementation and responsible governance in higher education. Overall, AI demonstrated considerable potential to improve pharmaceutical and health sciences education when combined with evidence-based educational practices, comprehensive faculty and student training, and robust ethical and regulatory frameworks. Continued interdisciplinary collaboration and responsible governance remained essential to ensure that AI complemented, rather than replaced, human-centered teaching and learning.

Keywords: Artificial intelligence, Pharmaceutical education, Health sciences education, Ethical challenges, Adaptive learning

2. Introduction

The rapid digital transformation of higher education has fundamentally changed the way teaching, learning, assessment, and curriculum development are delivered in academic disciplines. Advances in artificial intelligence, machine learning, natural language processing, learning analytics, and immersive technologies have created new opportunities to enhance educational quality through personalized instruction, automated assessment, adaptive learning environments, and data-driven decision making. These innovations have accelerated

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considerably in recent years, particularly following the increased adoption of digital learning environments after the COVID-19 pandemic, making AI one of the most influential technologies in shaping modern education (Fu et al., 2024; Gao et al., 2025).

Within health professions education, artificial intelligence has emerged as an important educational technology capable of improving competency-based learning, clinical reasoning, simulation-based instruction and learner assessment. Artificial intelligence supports virtual patients, intelligent tutoring systems, predictive learning analytics, and generative tools, which have been increasingly integrated into medical, nursing, dental, and allied health education to support individualized learning experiences while improving educational efficiency (Masters et al., 2025; Sun et al., 2023; Hersh, 2025). Simultaneously, concerns regarding data privacy, algorithmic bias, academic integrity, transparency, accountability, and equitable access have highlighted the need for responsible and ethical AI implementation in health professions education (Marín et al., 2025; Porayska-Pomsta et al., 2024; UNESCO, 2022).

Pharmaceutical and health sciences education has also undergone substantial changes owing to the integration of Generative AI tools. Recent studies have reported that artificial intelligence enhances pharmacy education through adaptive learning platforms, virtual patient simulations, digital health education, automated assessments, and competency-based clinical training. These technologies have improved student engagement, learning outcomes, and professional preparedness while facilitating innovative educational practices for future healthcare professionals (Abdel Aziz et al., 2024; Sun et al., 2023).

Although several reviews have examined artificial intelligence in higher education, medical education, pharmacy education, and digital health separately, most have focused on individual technologies, specific educational settings, and ethical issues. Few studies have comprehensively synthesized the educational applications, ethical challenges, governance considerations, AI literacy requirements, and future directions of artificial intelligence, specifically in pharmaceutical and health sciences education. Furthermore, the rapid emergence of generative AI and large language models has created new educational opportunities and challenges that have not been comprehensively addressed in earlier reviews (Kasneci et al., 2023; Malik et al., 2025; Reimers, 2026).

Therefore, this PRISMA-guided narrative literature review aimed to synthesize the current evidence regarding the educational applications of large language models (LLMs) in pharmaceutical and health sciences education, evaluate the associated ethical and governance challenges, identify major themes emerging from recent literature published between 2020 and 2026, and provide evidence-based recommendations for the responsible integration of AI into pharmacy and health professions education. By integrating findings from research studies and international policy documents, this review provides a comprehensive overview of current developments and identifies priorities for future research, educational practice, and institutional policy.

2. 1 Background

Owing to recent advances in technology, new advanced computational tools are becoming available that can be applied in personalized and experiential learning in the education of pharmaceutical and health sciences. An intelligent tutoring system (ITS) is one such enhancement (Al-Zahrani and Alasmari, 2024; Malik et al., 2025). This review builds on past research on ITS and shows the need for a better analysis of learning materials and a focus on

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the prior knowledge of the learner to advance to the next learning step (Yang et al., 2025; Fu et al., 2024). Artificial intelligence is used in these frameworks to establish a learner model that can be continuously enhanced, enabling learners to progress through the curriculum at their own pace (Olatunbosun Bartholomew & Nwankwo Charles, 2024).

The use of virtual characters and immersive VR environments may support ITS, bringing rich and complex clinical practices to health sciences students and allowing them to practice their clinical reasoning and psychomotor skills without putting real patients at risk (Abdel Aziz et al., 2024; Sun et al., 2023; Hersh, 2025). Training simulations replicate real-world healthcare environments, including diagnosis, emergency procedures, and actions. Such experiences solidly reinforce experiential learning while boosting students' confidence (Sun et al., 2023). AI-powered learning analytics can improve the educational ecosystem by processing data generated by students on a large scale, and forecasting may help detect at-risk students (Yang et al., 2025; Fu et al., 2024). Studies have consistently reported that learning analytics enables educators to adapt their instructional strategies, thereby improving student performance and learning outcomes.

Although there is hope surrounding the use of artificial intelligence in medical education, challenges remain. The ethical consequences of confidentiality and security of data used in artificial intelligence, whose beneficiaries are students and patients (Marín et al., 2025; Porayska-Pomsta et al., 2024; Siau & Wang, 2020). Furthermore, when the datasets are either small or unbalanced, this bias can occur, which can disadvantage learners or reinforce stereotypes (Gao et al., 2025). Several studies have expressed concerns that excessive dependence on AI may reduce opportunities for direct human interaction. This study raises many teaching-related issues for experts only; therefore, it is important to consciously balance skills throughout the healthcare profession (Abbas et al., 2025; UNESCO, 2022).

2.2 Problem Statement

The implementation of artificial intelligence technologies in pharmaceutical and health sciences education opens up opportunities for personalized learning, simulation-based training, and data-informed teaching. However, such implementation raises ethical and practical issues that must be addressed. Access to equity is one of the most important issues, since AI-related tools can, as a rule, be implemented only if the educational institution or geographical area has a robust digital infrastructure and resources to support them. Thus, educational inequalities may worsen, and the potential of technology to democratize access may be diminished. The use of AI in assessments introduces new academic integrity challenges that require attention (Al-Zahrani & Alasmari, 2024; Ersoy, 2025). Although automated grading and AI-assisted formative assessments can improve efficiency, they also raise important concerns regarding fairness, transparency, and accountability. In addition, the use of predictive analytics and AI-supported assessment systems may create opportunities for academic misconduct, including cheating and inappropriate manipulation of educational outcomes (Kasneci et al., 2023; Marín et al., 2025). Sensitive information related to students must be protected through relevant policies and data security measures to avoid breaches and unauthorized access (Porayska-Pomsta et al., 2024; Siau & Wang, 2020). The lack of data protection means that people will not have confidence in it. Several studies have expressed concern that excessive reliance on AI technologies may reduce teacher–student interaction and adversely affect the development of communication, empathy, and other essential professional competencies (Gao et al., 2025; Sun et al., 2023).

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This study explored the ethical and fair use of AI in health education and proposed strategies to address these challenges. If the health sciences education process is to take full advantage of AI and preserve the human spirit, accountability in governance, teacher training, and inclusiveness in policy frameworks (Abbas et al., 2025; UNESCO, 2022). Yang et al. (2024) systematically reviewed a decade of research on AI-powered systems that refined STEM education and reported that artificial intelligence supports personalized learning, intelligent tutoring systems, adaptive instruction, learning analytics, and curriculum innovation. Their review highlighted the growing integration of neural network model technologies into educational environments, emphasizing the importance of evidence-based implementation, ethical considerations, educator preparedness, and future research to maximize educational effectiveness.

This intellectual framework consists mainly of educational data collection, the process used, and the useful information. These elements will help seamlessly embed AI technologies into STEM education (Abdel-Aziz et al., 2024). The framework highlights how machine learning models can deliver personalized instruction that changes dynamically to meet student needs and provide curriculum assessment and adjustments based on the real-time progress or struggles of students (Olatunbosun Bartholomew & Nwankwo Charles, 2024).

In addition to personalization, the framework also considers adopting predictive analytics to measure students' performance trends and intervene to improve their learning outcomes. Incorporating AI powers with existing LMS creates a synergy where feedback loops help in the continuous improvement of curriculum design (Yang et al., 2025; Hooshyar et al., 2025). Through this iterative process, educational delivery is optimized, and learner engagement, retention, and understanding improve (Vaithiyanathan, 2024; Yu & Guo, 2023).

The use of standard performance metrics to evaluate the case study indicates that AI-assisted methods enabled educational analytics to be useful for increasing learners' engagement and retention in STEM. It remains a powerful response but also grapples with the challenges posed by AI (Yang et al., 2025). Significant challenges include data privacy, ethical issues related to the use of AI in learning, and difficulty in measuring the impact of AI on learning (Hooshyar et al., 2025; Porayska-Pomsta et al., 2024). Yang et al. (2024) stated that a wide range of stakeholders can be affected by AI-driven analytics. This includes teachers, policymakers, and technology developers. To make developments equitable, the guidelines will help stakeholders follow responsible practices while implementing AI in education. The preceding conceptual framework explains how AI-powered learning analytics can provide educational support in STEM. The framework shows that this approach enables an increasingly data-informed, personalized, and impactful educational environment. Moreover, students' learning outcomes across all STEM areas are likely to improve, which will lessen the problem of AI implementation and use (Yang et al., 2025; Fu et al., 2024).

2.3 Comparison with Previous Reviews

Several recent review articles have examined the application of artificial intelligence in higher education, medical and pharmacy education, and health professions. These reviews have substantially contributed to the understanding of the educational potential of AI by discussing topics such as adaptive learning, virtual simulation, learning analytics, generative AI, ChatGPT, and ethical considerations. As summarized in Table 1, most previous reviews focused on a single educational discipline, a specific AI technology, or a limited range of educational outcomes. In addition, many were conducted before the widespread adoption of

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generative AI and large language models in higher education, and few synthesized international policy recommendations related to responsible AI implementation.

This study differs from previous reviews by adopting a PRISMA-guided narrative literature review that integrates evidence from research studies and international policy documents published between 2020 and 2026. Rather than focusing on a single AI application or educational discipline, this review provides a comprehensive synthesis of educational applications, ethical and governance challenges, AI literacy, institutional policy considerations, and future directions specifically related to pharmaceutical and health sciences education. This broader perspective provides educators, researchers, and policymakers with an updated understanding of current developments and identifies priorities for the responsible integration of artificial intelligence into pharmaceutical and health sciences education. Table 1 presents a comparison between representative previous reviews that are most closely aligned with the scope of the present study and the current review, illustrating the broader scope, unique contributions, and updated synthesis provided by the present review.

Table 1 compares representative previous reviews that are closely aligned with the scope of the present study.

Previous Review	Scope	Main Findings	Difference from the Current Review
Holmes & Tuomi (2022)	Artificial intelligence in education	It discusses the state-of-the-art and current practices of artificial intelligence in education, highlighting major AI applications, emerging educational opportunities, implementation challenges, and future research priorities. The review emphasizes personalized learning, intelligent tutoring systems, adaptive learning environments, and responsible AI adoption in education.	Provided a broad overview of AI in education but did not specifically focus on pharmaceutical and health sciences. Unlike the current review, it does not comprehensively examine AI applications in health professions education, AI literacy, governance frameworks, international policy recommendations, or future directions specific to pharmaceutical and health sciences education.
Sun et al. (2023)	Artificial intelligence in healthcare and medical education	AI applications in healthcare education, clinical training, and medical education were reviewed, emphasizing educational opportunities and implementation challenges.	It is dedicated primarily to medical education and healthcare training without specifically addressing pharmaceutical education, AI governance, AI literacy, international policy frameworks, and future educational strategies.
Kasneci et al. (2023)	Large language models (ChatGPT) in education	The educational opportunities and challenges associated with ChatGPT and other large language models, discussing their applications in teaching, learning, assessment, feedback generation, and academic support, were examined in this study, while highlighting concerns regarding bias, hallucinations, academic integrity, transparency, and ethical implementation.	It specifically focuses on large language models and ChatGPT in education. Unlike the current review, it provides a narrower perspective and does not comprehensively synthesize broader AI technologies, adaptive learning, virtual simulation, learning analytics, AI governance, international policy frameworks or pharmaceutical and health sciences education.
Abdel Aziz et al. (2024)	Artificial intelligence in pharmacy education	Conducted a scoping review of AI applications in pharmacy education, highlighting the educational benefits, curriculum	It is restricted mainly to pharmacy education and does not comprehensively examine ethical governance, responsible AI, AI

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Previous Review	Scope	Main Findings	Difference from the Current Review
		integration, and implementation barriers.	literacy, international policy recommendations, or broader health sciences education.
Fu et al. (2024)	Artificial intelligence in education	Performed a scoping meta-review and bibliometric analysis of AI research across educational settings, identifying research trends and publication patterns.	A broad educational focus without concentrating on pharmaceutical and health sciences education or examining ethical governance and policy implications in healthcare education.
Pham et al. (2025)	Generative AI in health professions education	The impact of generative AI on student learning in health professional education was systematically reviewed, reporting improvements in learning support alongside concerns regarding bias, academic integrity, and responsible implementation.	It emphasizes generative AI and student learning outcomes rather than providing a comprehensive review of AI applications, governance, AI literacy, policy frameworks, and future educational directions in pharmaceutical and health sciences education.
Hersh (2025)	Generative artificial intelligence in biomedical and health professions education	We reviewed the emerging applications of generative AI in biomedical and health professions education, highlighting its potential to enhance teaching, learning, assessment, clinical reasoning, and academic productivity while emphasizing challenges related to accuracy, ethical use, academic integrity, and responsible implementation.	It primarily focused on the educational implications of generative AI in biomedical and health professions education. Unlike the current review, it does not comprehensively synthesize broader AI applications, adaptive learning, virtual simulation, AI literacy, governance frameworks, international policy recommendations (e.g., UNESCO and OECD), or future directions specifically for pharmaceutical and health sciences education.
Masters et al. (2025)	Artificial intelligence in health professions education assessment	Developed evidence-based recommendations for AI-supported assessment in health professions education through the AMEE Guide 178.	Focused specifically on assessment practices and did not comprehensively examine AI applications in teaching, curriculum design, governance, AI literacy, ethical frameworks or international policy recommendations.
Liang et al. (2025)	Artificial intelligence in higher education	This study systematically reviewed the early impact of AI on curriculum, instruction, and assessment in higher education, highlighting opportunities and implementation challenges.	Examined higher education broadly and did not specifically focus on pharmaceutical and health sciences education, ethical governance, AI literacy, or healthcare-specific policy recommendations.
Current PRISMA-guided narrative literature review (2026)	Artificial intelligence in pharmaceutical and health sciences education	Synthesizes evidence from 32 studies and policy documents (2020–2026) regarding AI applications in teaching and learning, curriculum development, assessment, simulation, personalized learning, AI literacy, ethical challenges, governance frameworks, international policy recommendations, and future research.	It provides the most comprehensive and up-to-date synthesis specifically focused on pharmaceutical and health sciences education by integrating educational applications, responsible AI, governance, ethics, AI literacy, international policy guidance (e.g., UNESCO and OECD), and future directions in a PRISMA-guided narrative literature review.

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2.4 Review Questions

This PRISMA-guided narrative literature review synthesizes and critically evaluates the current evidence regarding the application of artificial intelligence in pharmaceutical and health science education. Rather than testing formal hypotheses, this review was guided by the following research questions:

RQ1. What are the reported educational applications of artificial intelligence in pharmaceutical and health sciences education?

RQ2. What educational outcomes have been associated with the implementation of AI technology in pharmaceutical and health sciences education?

RQ3. What ethical, legal, and governance challenges have been identified regarding the use of AI in pharmaceutical and health sciences education?

RQ4. What future directions and recommendations have been proposed for the responsible integration of AI into pharmaceutical and health sciences education?

2.5 Review Objectives

This PRISMA-guided narrative literature review aimed to synthesize the current evidence regarding the application of artificial intelligence in pharmaceutical and health sciences education. Specifically, this review sought to:

- The current educational applications of artificial intelligence technologies, including adaptive learning platforms, intelligent tutoring systems, virtual patient simulations, learning analytics, automated assessment, and generative AI tools, were examined.
- Evaluate the educational outcomes associated with AI implementation, including student engagement, learning effectiveness, competency development, and teaching efficiency.
- Critically analyze the ethical, legal, and governance challenges related to AI integration, including data privacy, algorithmic bias, transparency, accountability, academic integrity, and equitable access.
- Identify emerging trends, research gaps, and evidence-based recommendations to support the responsible and effective integration of AI into pharmaceutical and health sciences education.

2.6 Significance of the Study

The application of artificial intelligence in pharmaceutical education and healthcare training will result in the continuous digitalization of education and training services in the sector. This is a crucial topic, as AI-enabled platforms provide new opportunities for personalized learning and competency-based education, aiding in making health and pharmaceutical education more convenient and accessible.

Malik et al. (2025) indicated that artificial intelligence tools improve students' abilities and availability and equip them for their future careers in the pharmacy field. Healthcare experts at all levels must have adequate equipment, knowledge, and capabilities to address ethical issues (Marín et al., 2025; Ukwandu et al., 2025). Applications created with evidence as proof have been used in healthcare education and to make decisions regarding clinical and administrative

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activities and diagnoses (Abdel Aziz et al., 2024; Sun et al., 2023; Ukwandu et al., 2025). Artificial intelligence has the potential to transform pharmaceutical and healthcare education and practice (Hersh, 2025). The nature of educational digitalization is complex and intricate, requiring reliable, pedagogically optimized, robust, and equitable uptake (Yang et al., 2025). The application of artificial intelligence in different contexts, including ethical and regulatory contexts, familiarizes students and healthcare professionals with new technologies and equips them to face challenges (Marín et al., 2025; Porayska-Pomsta et al., 2024). In conclusion, the model offers timely perspectives on the implementation of digital tools in pharmaceutical and health sciences education while outlining the challenges of responsible design concerning ethical, regulatory, practical, and other sustainable innovation features.

3. Research Methodology and Methods: PRISMA-guided narrative literature review

3.1 Review Design

The literature on the application of AI in teaching pharmaceutical and health sciences was identified, screened, and synthesized using a PRISMA-guided narrative literature review. Although some PRISMA 2020 principles were followed to enhance transparency and consistency in reporting, this study undertook a structured narrative review rather than a complete systematic review or meta-analysis of the subject matter. This study did not include human subjects, surveys, interviews, or experiments.

3.2 Data Sources and Search Strategy
A comprehensive literature search was conducted using the PubMed, Scopus, Web of Science, Google Scholar, and ScienceDirect platforms to identify studies examining the application of artificial intelligence in pharmaceutical and health sciences education. The search focused on educational applications, teaching and learning strategies, assessments, simulations, AI literacy, ethical considerations, governance, and future directions.

The search strategy combined controlled vocabulary (e.g., Medical Subject Headings [MeSH], where applicable) with free-text keywords. The primary search terms included artificial intelligence, Machine Learning, Generative AI, ChatGPT, Pharmacy Education, Health Sciences Education, Medical Education, Learning Analytics, Adaptive Learning, Virtual Patient Simulation, Educational Technology, Ethics, algorithmic bias, Data Privacy, Transparency, and AI Governance.

The search strategy was adapted to the indexing terms and search syntax of each database. A representative Boolean search strategy is presented in Figure 1.

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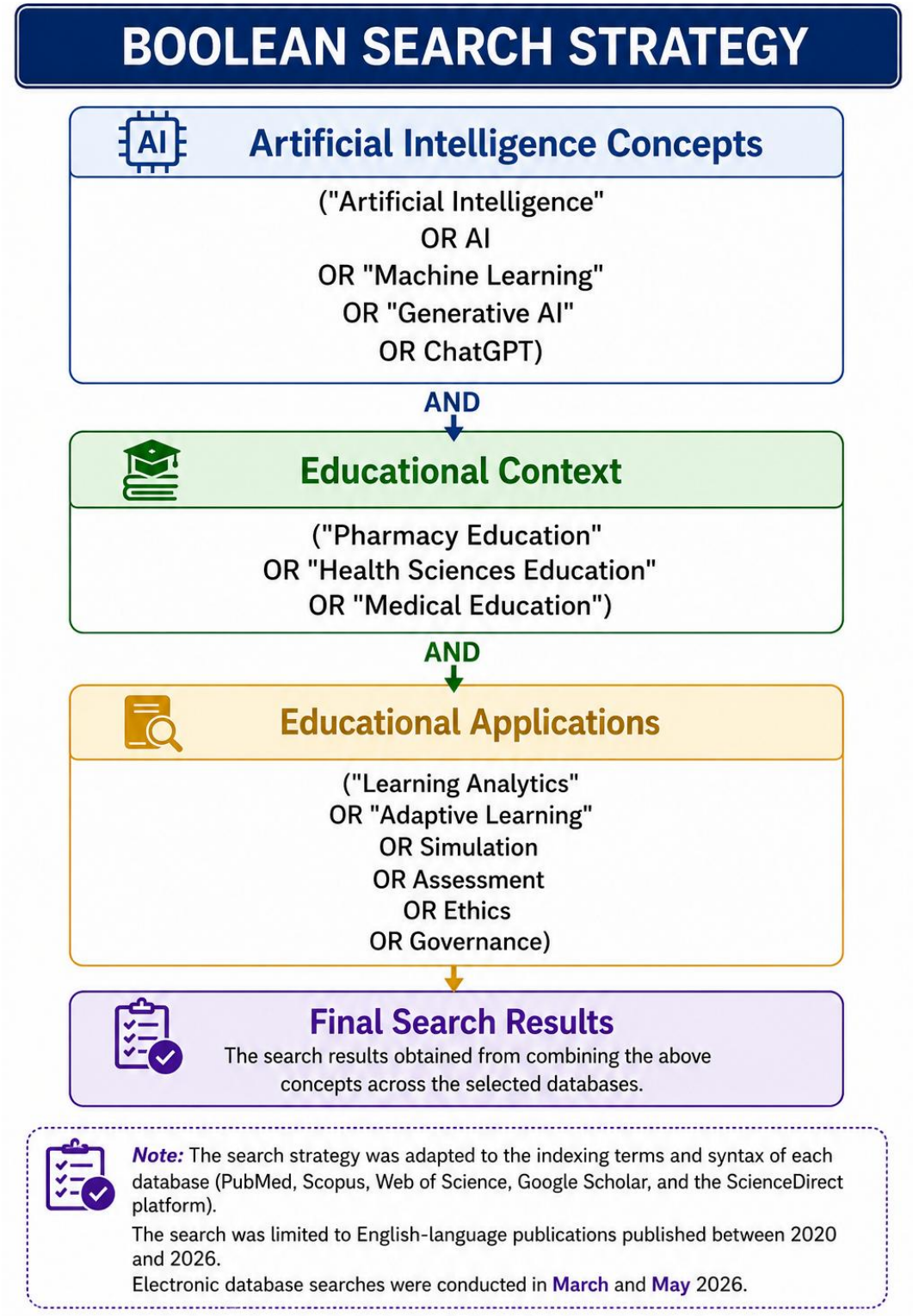

Figure 1. Boolean Search Strategy Used for the Literature Search

3.3 Eligibility Criteria

3.3.1 Inclusion Criteria:

Studies were included if they met the following criteria.

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- Peer-reviewed research articles, systematic reviews, scoping reviews, meta-analyses, educational guidelines, and internationally recognized policy documents were included.
- Published in English between 2020 and 2026.
- Examined the applications of artificial intelligence in pharmaceutical or health sciences education.
- Reported educational outcomes, ethical considerations, governance issues, AI literacy, curriculum development, and future recommendations relevant to AI in education.

3.3.2 Exclusion Criteria

Studies were excluded if they met any of the following criteria:

- Conference abstracts or summaries without full-text availability were excluded.
- Non-peer-reviewed publication.
- Studies focusing exclusively on clinical AI applications without educational relevance.
- Publications unrelated to AI-supported teaching, learning, assessment, simulation, or ethics in pharmaceutical and health sciences education.
- Articles published in languages other than English.

3.4 Screening Process

The screening process followed the PRISMA 2020 guidelines to ensure a transparent and systematic study-selection process. Records identified through the database search were imported into reference management software, and duplicate records were removed prior to screening. The author screened the titles and abstracts according to the predefined inclusion and exclusion criteria. Full-text articles considered potentially eligible were subsequently reviewed for their suitability for inclusion in the narrative review. Any uncertainties regarding study eligibility were resolved through repeated evaluation of the full texts to ensure consistency with the review objectives. Data extracted from the included studies comprised publication characteristics, educational context, AI applications, reported educational outcomes, ethical considerations, governance issues, and recommendations for future research and practice.

3.5 Quality Assessment

As this study was conducted as a PRISMA-guided narrative literature review, a formal risk-of-bias assessment was not performed. Instead, the methodological quality and relevance of the included studies were evaluated using predefined criteria to ensure the credibility and applicability of the evidence. Each publication was assessed based on its relevance to the review objectives, clarity of study aims, methodological rigor, educational significance, and contribution to understanding the educational applications, ethical implications, and future directions of artificial intelligence in pharmaceutical and health sciences education. Preference was given to peer-reviewed research articles, systematic reviews, scoping reviews, meta-analyses, educational guidelines, and internationally recognized policy documents published in English. Publications with insufficient methodological details, limited relevance to pharmaceutical and health sciences education, duplicate findings, or a primary focus on non-educational AI applications were excluded. This quality assessment process refined the transparency, consistency, and methodological rigor of the narrative syntheses.

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3.6 PRISMA Screening Summary

A systematic literature search was conducted following the PRISMA 2020 guidelines to identify publications related to artificial intelligence in pharmaceutical and health sciences education. Searches were performed on PubMed, Scopus, Web of Science, Google Scholar, and the ScienceDirect platform. A total of 1,245 records were identified. After removing 165 duplicate records, 1,080 unique records remained for title and abstract screening. After the screening process, 850 records were excluded because they did not meet the predefined inclusion criteria. Consequently, 230 full-text articles were assessed for their eligibility. During the full-text review, 198 publications were excluded because they were outside the scope of the review, lacked sufficient methodological quality, were duplicate reports of the same evidence, or did not directly address the application of artificial intelligence in pharmaceutical and health sciences education. Thirty-two studies and policy documents met the eligibility criteria and were included in the final qualitative narrative synthesis (Table 2). A PRISMA 2020 flow diagram was used to illustrate the study selection process and enhance reporting transparency (Figure 2).

Table 2: PRISMA Table

Screening Stage	Number of Records
Records identified through database searching	1,245
Records after duplicates removed	1,080
Records screened (title/abstract)	1,080
Records excluded	850
Full-text articles assessed for eligibility	230
Full-text articles excluded	198
Studies and policy documents included in the qualitative narrative synthesis	32

Figure 2. PRISMA 2020 flow diagram illustrating the study selection process for the PRISMA-guided narrative literature review of artificial intelligence applications in pharmaceutical and health sciences education.

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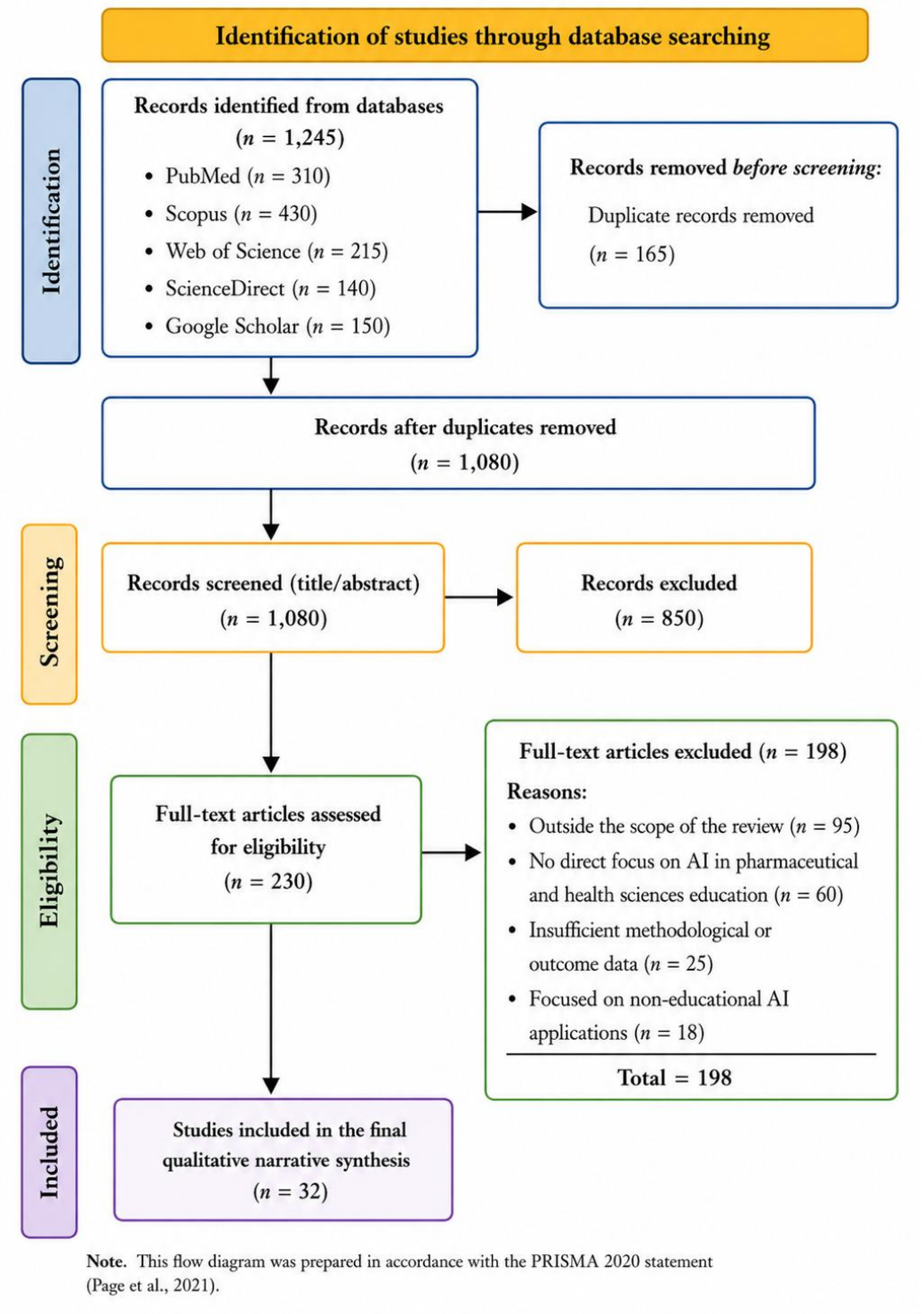

Figure 2. PRISMA 2020 Flow Diagram of the Study Selection Process

3.7 Data Extraction and Thematic Analysis

Data were systematically extracted from each included study using a standardized data extraction framework. The extracted information included the author(s), year of publication, study type, educational setting, artificial intelligence application, educational context, study objectives, principal findings, ethical considerations, governance implications, and recommendations for future research and educational practice. The extracted data were

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reviewed, compared, and organized into evidence tables to facilitate cross-study comparisons and thematic syntheses.

A qualitative thematic analysis was conducted to identify recurring concepts, patterns, and emerging themes across the included studies. Studies addressing similar educational applications, challenges, and recommendations were grouped into common thematic categories through an iterative comparison and synthesis process. The final themes included AI-supported personalized learning, virtual simulation and clinical training, learning analytics and automated assessment, generative AI and large language models, AI literacy and faculty development, ethical, legal, and governance considerations, and future directions for the responsible integration of AI into pharmaceutical and health sciences education.

Table 3 summarizes the characteristics of the included research studies, Table 4 summarizes the international policy documents included in the review, and Table 5 presents the major themes identified through qualitative narrative synthesis.

Table 3. Characteristics of the Included Research Publications (n = 30)

Author (Year)	Study Type	Educational Area	AI Technology/Topic	Key Educational Findings
Abbas et al. (2025)	Meta-analytic thematic review	Higher education	AI governance	Identified global trends, policy initiatives, and governance gaps in AI implementation in higher education.
Abdel Aziz et al. (2024)	Scoping review	Pharmacy education	Artificial intelligence	AI applications in pharmacy education were summarized, highlighting the educational benefits and implementation challenges.
Al-Zahrani and Alasmari (2024)	Review	Higher education	Artificial intelligence	Examined the ethical, social, and educational implications of AI integration in higher education.
Chan and Hu (2023)	Qualitative study	Higher education	Generative AI	This study explored students' perceptions, educational benefits, and challenges associated with the use of generative AI in higher education.
Ersoy (2025)	Book chapter	Higher education	Artificial intelligence	The study discusses inclusive AI transformation and educational innovation.
Fu et al. (2024)	Scoping meta-review	Education	Artificial intelligence	Identified major research trends in AI-supported education through bibliometric and meta-review analyses.
Gao et al. (2025)	Systematic review	Public health education	Artificial intelligence	Technological advances, ethical

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Author (Year)	Study Type	Educational Area	AI Technology/Topic	Key Educational Findings
				concerns, and governance pathways for AI in public health education were reviewed.
Garcia et al. (2025)	Book chapter	Education	Artificial intelligence	The highlighted educational risks include bias, misuse, and skill obsolescence associated with AI integration.
Hersh (2025)	Narrative review	Biomedical and health professions education	Generative AI	Examined the educational implications of generative AI in biomedical and health professions education.
Holmes and Tuomi (2022)	State-of-the-art review	Education	Artificial intelligence	The current state, opportunities, and future directions of AI in education were reviewed.
Hooshyar et al. (2025)	Review	Education	Responsible AI	Proposed hybrid human–AI approaches for responsible AI implementation in education.
Kasneci et al. (2023)	Review	Higher education	ChatGPT and large language models	Opportunities and challenges associated with large language models in education were discussed.
Liang et al. (2025)	Systematic review	Higher education	Artificial intelligence	Examined the early impact of AI on curriculum, instruction, and assessment in higher education.
Malik et al. (2025)	Survey	Higher education	ChatGPT	Investigated faculty perspectives on AI in teaching, research and ethics.
Marín et al. (2025)	Review	University education	Artificial intelligence	Examined the ethical challenges associated with AI adoption in university education.
Masters et al. (2025)	AMEE Guide	Health professions education	Artificial intelligence	Provided evidence-based recommendations for AI-supported assessment in health professions education.
Olatunbosun Bartholomew and Nwankwo Charles (2024)	Review	STEM education	AI and machine learning	The opportunities and challenges of integrating AI and machine learning into STEM education were discussed.
Pandey (2025)	Review	Higher education	Artificial intelligence	Evaluated the influence of AI on teaching, learning, and

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Author (Year)	Study Type	Educational Area	AI Technology/Topic	Key Educational Findings
				institutional development..
Pham et al. (2025)	Systematic review	Health professions education	Generative AI	Synthesized evidence regarding the impact of generative AI on student learning in health professions education.
Porayska-Pomsta et al. (2024)	Book chapter	Education	AI ethics	The ethical principles guiding responsible AI adoption in education were reviewed.
Radianti et al. (2020)	Systematic review	Higher education	Virtual reality	Immersive virtual reality applications supporting higher education teaching and learning were reviewed.
Reimers (2026)	Review	Health sciences education	Generative AI	Discussed AI-assisted written communication in health science education.
Siau and Wang (2020)	Review	Information systems	AI ethics	Described the ethical principles for trustworthy and responsible AI systems.
Sun et al. (2023)	Systematic review	Medical education	Artificial intelligence	AI applications across healthcare and medical education were summarized.
Ukwandu et al. (2025)	Review	Higher education	Emerging AI technologies	The future directions for teaching and learning in the era of emerging AI technologies are discussed.
Vaithiyanathan (2024)	Review	Higher education	AI governance	Proposed governance models for supporting sustainable AI implementation in higher education.
Xu et al. (2025)	Scale development and validation	Language education	AI literacy	A domain-specific AI literacy assessment scale for students was developed and validated.
Yang et al. (2024)	Systematic review	STEM education	Artificial intelligence in STEM education	Synthesized a decade of AI applications in STEM education, highlighting trends in personalized learning, intelligent tutoring systems, learning analytics, adaptive instruction and future research opportunities.
Yavuz et al. (2025)	Experimental study	Higher education	AI-supported flipped classroom	Demonstrated improvements in learning experience, student perceptions, and AI literacy through AI-

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Author (Year)	Study Type	Educational Area	AI Technology/Topic	Key Educational Findings
				supported flipped classroom applications.
Yu and Guo (2023)	Review	Education	Generative AI	This study reviewed the educational opportunities, challenges, and future prospects of generative AI in education.

Note. The included research publications comprised meta-analyses, systematic, scoping, narrative, and state-of-the-art reviews; surveys; qualitative, conceptual, and experimental studies; book chapters; an evidence-based guidance document; and scale-development studies published between 2020 and 2026.

Table 4. International Policy Documents Included in the Narrative Review (n = 2)

Policy Document	Organization	Publication Type	Focus Area	Contribution to the Present Review
UNESCO (2022). Recommendation on the Ethics of Artificial Intelligence	UNESCO	International recommendation	AI ethics, human rights, transparency, accountability, equity, inclusion, and education	It provides internationally recognized ethical principles and policy guidance to support responsible AI implementation in education and healthcare.
Organisation for Economic Co-operation and Development (OECD). (n.d.). Artificial Intelligence	OECD	International policy framework	Trustworthy AI, governance, innovation, risk management, and public policy	It provides international governance principles and policy recommendations for the responsible development, deployment, and regulation of AI technologies across educational and healthcare systems.

Note. These international policy documents complemented the research evidence by providing globally recognized ethical and governance frameworks that informed the interpretation of the findings and the development of recommendations for the responsible integration of artificial intelligence in pharmaceutical and health sciences education.

Table 5. Major Themes Identified Through the Narrative Synthesis

Theme	Description	Representative Included Studies and Policy Documents
AI-Supported Personalized Learning and Adaptive Education	These techniques support adaptive learning, personalized instruction, intelligent tutoring, and individualized educational experiences that enhance student engagement, learning outcomes, and competency development.	Yang et al. (2024); Fu et al. (2024); Yu and Guo (2023); Liang et al. (2025); Xu et al. (2025); Yavuz et al. (2025)

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Theme	Description	Representative Included Studies and Policy Documents
Virtual Simulation, Immersive Learning, Clinical Training, and Digital Learning Environments	AI-supported virtual simulation, virtual reality, and digital learning environments strengthen clinical reasoning, communication skills, experiential learning, and professional competency development in pharmacy and health science education.	Radianti et al. (2020); Abdel Aziz et al. (2024); Sun et al. (2023); Hersh (2025); Pham et al. (2025)
Learning Analytics, Curriculum Innovation, and Student Assessment	AI-driven learning analytics enable the continuous monitoring of student performance, personalized feedback, competency-based assessment, curriculum enhancement, and early identification of learning needs.	Yang et al. (2024); Fu et al. (2024); Masters et al. (2025); Liang et al. (2025); Pandey (2025)
Generative AI and Large Language Models in Education	ChatGPT and other generative AI tools support tutoring, content generation, academic writing, clinical reasoning, communication, and decision-making while raising concerns regarding academic integrity, bias, and excessive dependence on AI-generated content.	Kasneci et al. (2023); Chan and Hu (2023); Hersh (2025); Malik et al. (2025); Pham et al. (2025); Reimers (2026); Yu and Guo (2023)
AI Literacy, Faculty Development, and Student Readiness	Successful AI integration requires the development of AI literacy, digital competencies, curriculum redesign, faculty professional development, and responsible AI use among educators and students.	Holmes and Tuomi (2022); Malik et al. (2025); Xu et al. (2025); Yavuz et al. (2025); Liang et al. (2025); Ukwandu et al. (2025)
Ethical, Legal, Governance, and Responsible AI Considerations	The major challenges include data privacy, algorithmic bias, transparency, accountability, intellectual property, academic integrity, equitable access, and institutional governance for responsible AI implementation.	Abbas et al. (2025); Al-Zahrani and Alasmari (2024); Marín et al. (2025); Porayska-Pomsta et al. (2024); Siau and Wang (2020); UNESCO (2022); OECD (n.d.); Vaithiyanathan (2024); Hooshyar et al. (2025); Holmes & Tuomi (2022)
Future Directions and Sustainable AI Integration	Future implementation should emphasize human–AI collaboration, responsible innovation, interdisciplinary partnerships, institutional governance, evidence-based educational policies, continuous faculty development, and sustainable AI adoption in pharmaceutical and health sciences education.	Gao et al. (2025); Ersoy (2025); Hooshyar et al. (2025); Garcia et al. (2025); Ukwandu et al. (2025); UNESCO (2022); OECD (n.d.)

4. Results

4.1 AI-Supported Adaptive Learning and Personalized Education

Across the included studies, AI-supported adaptive learning frameworks facilitated personalized instruction by aligning educational content, learning pace, and formative feedback with individual learner needs. Intelligent tutoring systems and adaptive platforms enable continuous monitoring of student progress and support the development of tailored learning pathways. Across the reviewed studies, these technologies were associated with improvements in student engagement, knowledge retention, and learning performance. Yang et al. (2025) described the role of AI-driven educational analytics in supporting personalized learning, whereas Yu and Guo (2023) emphasized the ability of generative AI to produce customized educational materials. Fu et al. (2024) similarly reported that AI-supported systems can improve instructional effectiveness across educational settings. However, Xu et al. (2025) emphasized that students require adequate AI literacy to use personalized AI tools effectively

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and critically. Collectively, the evidence suggests that adaptive learning technologies may strengthen individualized education, although their effectiveness depends on student readiness, appropriate instructional design, and institutional support.

4.2 Virtual Patients and Simulation-Based Clinical Training

Evidence from the included studies showed that AI-supported virtual patients, immersive simulations, and digital learning environments enhance experiential learning in pharmaceutical and health sciences education. The reviewed evidence indicated that virtual reality and simulated clinical scenarios allowed students to practice clinical reasoning, communication, and decision-making in controlled environments without exposing actual patients to training-related risks. Abdel Aziz et al. (2024), Sun et al. (2023), and Pham et al. (2025) associated virtual simulations with improvements in clinical reasoning, professional competency development, student confidence, and self-efficacy, respectively. Radianti et al. (2020) also reported that immersive virtual reality could increase learner engagement and provide opportunities for repeated practice. Overall, simulation-based technologies appeared to provide valuable support for clinical training, while the reviewed literature emphasized their role as a complement to supervised patient interaction and authentic clinical experience, rather than a replacement.

4.3 Learning Analytics and Student Performance Monitoring

Learning analytics is a frequently discussed application of AI in the literature. AI-based systems collect and analyze student performance data to identify learning patterns, predict academic difficulties, and support early educational interventions. Yang et al. (2025) reported that intelligent tutoring systems, adaptive learning modules, and learning analytics play important roles in personalized STEM education and learner retention. Masters et al. (2025) further indicated that AI-assisted analytics could support competency-based assessments and provide evidence for curriculum and institutional decision-making. Pandey (2025) similarly described the potential of AI to improve monitoring, feedback, and institutional planning in education. Collectively, these findings suggest that learning analytics can help educators identify students requiring additional support; however, the reviewed literature emphasizes the need for professional oversight when interpreting predictive data to avoid inaccurate or overly deterministic judgments.

4.4 AI-Assisted Assessment and Educational Efficiency

The included evidence indicates that AI can improve the efficiency of educational assessment by supporting automated grading, rapid feedback, and continuous competency monitoring. Malik et al. (2025) reported that faculty perceived AI as potentially reducing administrative workload and improving teaching and assessment efficiencies. However, Masters et al. (2025) emphasized that AI-assisted assessment should retain meaningful human oversight to ensure validity, fairness, and professional accountability. Kasneci et al. (2023) similarly noted that language models could support tutoring, formative feedback, and interactive learning while also creating concerns related to academic integrity, inaccurate content, and inappropriate dependence on AI-generated responses. Overall, AI-assisted assessment appeared to offer efficiency benefits, while the reviewed studies emphasized the importance of transparent criteria, educator supervision, and safeguards against misconduct and unreliable output.

4.5 Data Privacy and Ethical Considerations

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Data privacy has emerged as a major ethical concern in the literature. AI-supported learning analytics, adaptive platforms, and virtual simulations often require the collection and processing of extensive student or simulated patient data, creating risks related to confidentiality, unauthorized data use, cybersecurity breaches, and unclear ownership. Marín et al. (2025) and Porayska-Pomsta et al. (2024) emphasize the need for clear privacy policies, informed data-use practices, and defined institutional responsibilities. UNESCO (2022) similarly highlighted transparency, accountability, privacy protection, and human rights as essential principles of responsible AI implementation. Siau and Wang (2020) further argue that clear accountability mechanisms are necessary to build trust in AI systems. Taken together, the evidence consistently emphasizes the importance of establishing privacy safeguards and governance procedures before adopting data-intensive AI technologies.

4.6 Algorithmic Bias and Equity

Algorithmic bias is an important threat to fairness and equitable access in AI-supported education. Systems trained on unrepresentative, culturally narrow, or historically biased datasets may generate inaccurate predictions or recommendations that disadvantage certain learner groups. Al-Zahrani and Alasmari (2024) and Marín et al. (2025) described how biased grading systems and predictive analytics could reinforce inequities in educational assessment and opportunities. Gao et al. (2025) and Garcia et al. (2025) warned that biased educational simulations and AI-generated content could influence future health professionals and potentially contribute to existing healthcare disparities. Across the included literature, representative datasets, continuous algorithmic auditing, transparent model evaluation, and equitable access strategies were identified as the central approaches to reducing bias. Collectively, the evidence indicates that both technical safeguards and institution-level policies are necessary to promote inclusion and fairness.

4.7 AI Governance and Faculty Readiness

Across the included publications, successful AI integration depended not only on technological capacity but also on institutional governance, faculty preparation, and organizational readiness. Abbas et al. (2025) and Vaithiyanathan (2024) emphasize the need for multidisciplinary governance structures that address transparency, ethical oversight, accountability, and regulatory compliance. The Organisation for Economic Co-operation and Development (OECD, n.d.) similarly supports the development of trustworthy, human-centered, and risk-aware approaches to AI governance. Malik et al. (2025) and Pandey (2025) identified faculty development, curriculum redesign, and institutional support as important factors influencing educators' acceptance and effective implementation. Hooshyar et al. (2025) further emphasized hybrid human–AI approaches in which AI supports rather than replaces professional judgment and pedagogical expertise. Collectively, the evidence identified coordinated governance, continuous faculty development, clear implementation policies, and meaningful human oversight as the central conditions for sustainable AI adoption. Table 6 provides a narrative synthesis of the principal artificial technologies identified in the included studies, along with their educational applications, reported outcomes, associated challenges, and representative sources.

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Table 6. Narrative Synthesis of AI Technologies, Educational Applications, Outcomes, and Associated Challenges

AI technology category	Primary educational settings/applications	Key educational and operational outcomes	Main associated challenges and risks	Representative sources
Adaptive learning platforms and intelligent tutoring systems	Personalized curriculum delivery, student-paced instruction, adaptive feedback, and individualized learning pathways.	It improves knowledge retention, increases student engagement, and provides personalized feedback.	Potential content bias, unequal access to infrastructure, implementation costs, and inadequate student AI literacy were also identified.	Yang et al. (2025); Fu et al. (2024); Yu & Guo (2023); Xu et al. (2025)
Virtual patient simulations and virtual reality	Experiential clinical training, simulated diagnostic exercises, repeated skills practice and risk-free clinical scenarios.	Improved clinical reasoning, professional competency development, and greater student confidence and self-efficacy were observed.	Overreliance on simulation, reduced exposure to authentic patient interactions, limited development of interpersonal skills, and unequal access to technology.	Abdel Aziz et al. (2024); Sun et al. (2023); Pham et al. (2025); Radianti et al. (2020)
Learning analytics systems	Continuous student performance monitoring, predictive modeling, early identification of learning difficulties, and targeted intervention.	Competency-based assessment, early educational intervention, personalized feedback, and data-informed curriculum planning.	Student surveillance concerns, privacy risks, algorithmic bias, and inappropriate interpretation of predictive data.	Yang et al. (2025); Masters et al. (2025); Pandey (2025)
Generative AI and large language models	Content development, summarization, personalized tutoring, formative feedback, academic writing support, and written communication.	Improved administrative efficiency, rapid feedback, and increased access to individualized learning support were observed.	Academic integrity concerns, inaccurate or fabricated outputs, privacy risks, and reduced critical thinking are associated with overreliance.	Kasneci et al. (2023); Hersh (2025); Malik et al. (2025); Reimers (2026); Chan & Hu (2023)

Note. AI: artificial intelligence; ITS: intelligent tutoring systems; VR: virtual reality; LLMs: large language models.

5. Discussion

5.1 Overview and synthesis of the AI-in-health-education landscape

The body of work synthesized here presents a coherent view that artificial intelligence (AI) is increasingly embedded in pharmaceutical and health sciences education, with multiple modalities being explored to enhance learning, assessment, and governance. Across the included literature, AI-enabled adaptive learning platforms, intelligent tutoring systems, virtual patient simulations, learning analytics, automated assessment, and, more recently, generative AI tools have been repeatedly identified as core components shaping contemporary curricula and instructional design. These technologies are capable of personalizing instruction, supporting clinical reasoning, and enabling scalable, data-informed decision-making within health professions education. Simultaneously, the present review found that the potential benefits of AI depend on responsible implementation with attention to equity, transparency, and accountability (Abdel Aziz et al., 2024; Fu et al., 2024; Hersh, 2025; Sun et al., 2023).

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5.2 Educational applications and outcomes

The findings of the present review indicate that adaptive learning, intelligent tutoring systems, and personalized feedback represent central mechanisms through which AI can accommodate learners' baseline knowledge, learning pace, and individual educational needs, supporting broader efforts to integrate AI across STEM and health professions curricula. Virtual patients, immersive simulations, and AI-enabled simulations are highlighted for their capacity to operationalize experiential learning, sharpen clinical reasoning, and provide safe environments for practice before exposure to real patients. Learning and predictive analytics are described as tools to monitor engagement, identify at-risk learners, and inform timely interventions, thereby supporting retention and the attainment of competencies. Automated and formative assessments improve efficiency and scalability, although they raise critical questions about fairness, transparency, and integrity in evaluation processes. Overall, the reported educational benefits included refined engagement, improved perceived preparedness, and more efficient teaching and assessment workflows. These findings are broadly consistent with previous reviews by Holmes and Tuomi (2022), Abdel Aziz et al. (2024), Radianti et al. (2020), and Liang et al. (2025), who similarly reported that AI-supported learning environments improve personalization, learner engagement, and instructional efficiency. However, the present review extends these observations by integrating evidence published until 2026 and synthesizing educational outcomes alongside governance, AI literacy, ethics, and international policy frameworks. Although the included studies generally reported positive educational outcomes, the evidence remains heterogeneous with respect to study quality, educational settings, AI technologies, and outcome measures, thereby limiting the generalizability of some of the findings (Liang et al., 2025; Masters et al., 2025; Pham et al., 2025; Yang et al., 2025).

5.3 Generative AI and large language models (LLMs)

The rapid emergence of generative AI and LLMs is a recurring theme, with authors recognizing both the opportunities and challenges. Generative tools offer the potential for rapid content generation, individualized feedback, and simulation-based scenario creation, but they also raise concerns about accuracy, bias, data privacy, and the potential for academic misuse. Several references call for explicit governance and ethical frameworks to govern the adoption of GAI in health professions education and delineate roles, responsibilities, and accountability mechanisms. Collectively, the reviewed studies suggest that effective implementation of generative AI in health professions education requires integrating pedagogical evidence with ethical and governance considerations rather than focusing solely on technological capability (Chan & Hu, 2023; Hersh, 2025; Kasneci et al., 2023; Yu & Guo, 2023; Reimers, 2026).

5.4 Ethical, governance, and equity considerations

Across the corpus, ethics and governance emerged as the central pillars guiding responsible AI integration. Key concerns include data privacy and security, algorithmic bias, transparency in decision-making, accountability for AI-driven outcomes, and the potential for widening educational disparities in institutions with uneven digital infrastructure. Fairness and inclusivity in access to AI-enabled tools are repeatedly linked to broader questions about equity in education and health outcomes, particularly for students and institutions with limited resources. The literature converges on the need for robust governance structures, explicit policy guidance, and ongoing educator development to ensure that AI enhances rather than undermines core professional values such as empathy, patient-centered care, and integrity (Abbas et al., 2025; Al-Zahrani & Alasmari, 2024; Marín et al., 2025; Siau & Wang, 2020).

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5.5 Policy and governance implications

Several sources underscore the value of aligning AI deployment with international policies and ethical principles. They advocate governance frameworks that articulate accountability for AI-enabled educational processes, establish data governance and privacy protections, and promote transparency about how AI systems influence learning pathways and assessment results. The reviewed literature consistently emphasizes that policy-informed guidance supports consistency across institutions, facilitates the sharing of best practices, and promotes equitable access to AI-enabled educational resources (Organisation for Economic Co-operation and Development [OECD], n.d.; Porayska-Pomsta et al., 2024; UNESCO, 2022; Vaithiyanathan, 2024).

5.6 AI literacy, curriculum, and faculty development

A recurrent theme is the necessity for AI literacy among students and educators. As AI tools become more integrated into teaching and assessment, explicit training in understanding AI's capabilities, limitations, and ethical considerations is deemed essential to maximize positive outcomes and mitigate risks. The literature calls for curricular elements that cultivate critical appraisal skills for AI-generated content, methodological literacy for interpreting analytics, and competencies related to data privacy and professional responsibility in AI-enabled contexts. Faculty development is also emphasized to prepare instructors to design, implement, and govern AI-enhanced learning environments effectively and ethically while integrating AI competencies into STEM and health professions curricula (Holmes & Tuomi, 2022; Malik et al., 2025; Olatunbosun Bartholomew & Nwankwo Charles, 2024; Ukwandu et al., 2025; Xu et al., 2025).

5.7 Methodological reflections and gaps

The included literature comprised systematic reviews, scoping reviews, empirical studies, conceptual papers, educational guidelines, and international policy documents published between 2020 and 2026. The diversity of study designs provided a broad perspective on AI integration in pharmaceutical and health sciences education but also introduced heterogeneity in study quality, educational settings, and reported outcomes. Several gaps were consistently identified: (a) differential evidence quality across AI modalities and health disciplines; (b) limited longitudinal data on the sustained impact of AI-enabled interventions; (c) incomplete integration of policy and ethical analyses with pedagogical outcomes; and (d) a need for standardized measures of AI literacy and governance effectiveness in health sciences education. These gaps point to prioritized avenues for future research, including rigorous multi-institutional trials, longitudinal assessments of competency development, and cross-disciplinary policy studies that connect governance with instructional outcomes (Fu et al., 2024; Liang et al., 2025; Pham et al., 2025).

5.8 Nuances and areas of debate

Where studies converge, they reveal nuanced disagreements and context-specific considerations. For example, while many authors have reported educational benefits from AI-enhanced simulations and analytics, others have cautioned against potential over-reliance on technology at the expense of essential human interactions, professional judgment, and empathy in healthcare education. The balance between automation and human-centered teaching remains a contested area, with calls for governance that preserves the human elements of

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education and care while leveraging AI to support learning. Similarly, while AI literacy is deemed essential, there is debate about the optimal scope and depth of training required for different health disciplines and career stages, reflecting a spectrum of preparedness among students and faculty members (Gao et al., 2025; Hooshyar et al., 2025; Sun et al., 2023).

5.9 Implications for practice and future directions

The findings of the present review support a phased, governance-informed approach to the integration of AI into pharmaceutical and health sciences education. The key practical implications are as follows (Abbas et al., 2025; Hooshyar et al., 2025; UNESCO, 2022):

- Develop and implement principled data governance, privacy, and security measures to safeguard student and patient information used in AI-enabled educational tools (Marín et al., 2025; Porayska-Pomsta et al., 2024; Siau & Wang, 2020).
- Transparent policies that define the purposes, capabilities, and limitations of AI systems, including clear lines of accountability for AI-driven decisions in learning and assessment, should be established (Abbas et al., 2025; OECD, n.d.; Vaithiyanathan, 2024).
- Invest in AI literacy across the curriculum and faculty development to build capabilities in critique, interpretation of analytics, and responsible innovation (Malik et al., 2025; Xu et al., 2025; Yavuz et al., 2025).
- Prioritize equitable access by aligning resource provision with institutional capacity and sharing best practices to mitigate disparities in digital infrastructure and tool availability (Ersoy, 2025; Garcia et al., 2025; UNESCO, 2022).
- Iterative, evidence-based implementation should be pursued with ongoing evaluation of learning outcomes, teacher-student interaction quality, and professional competencies, informed by both educational research and policy guidance (Liang et al., 2025; Masters et al., 2025; Ukwandu et al., 2025).

5.10 Limitations and transparency

Readers should interpret the conclusions in light of the methodological scope of this study. Although this PRISMA-guided narrative review synthesized evidence from peer-reviewed studies and international policy documents published between 2020 and 2026, the included literature was heterogeneous with respect to study design, educational setting, AI technologies, and outcome measures. Consequently, direct comparisons between studies should be interpreted cautiously. Furthermore, the rapid evolution of AI technologies means that emerging evidence may refine our current understanding of effective implementation strategies. Nevertheless, the inclusion of diverse evidence sources provides a comprehensive overview of the current educational applications, ethical considerations, governance frameworks, and future directions for AI integration in pharmaceutical and health sciences education.

6. Conclusion

The integrated body of evidence indicates that artificial intelligence (AI) has significant potential to transform pharmaceutical and health sciences education by supporting personalized learning, experiential and simulation-based education, and data-informed curriculum development. AI-enabled technologies, including adaptive learning platforms, intelligent tutoring systems, virtual patient simulations, generative AI tools, and learning analytics, have demonstrated the capacity to enhance learner engagement, strengthen clinical reasoning,

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improve instructional efficiency, and facilitate competency-based education. These benefits are most evident when AI is implemented within well-designed educational frameworks that emphasize AI literacy, transparent governance, ethical oversight and equitable access (Abdel Aziz et al., 2024; Fu et al., 2024; Masters et al., 2025; Yang et al., 2025).

Simultaneously, the review demonstrates that the educational benefits of AI cannot be separated from broader ethical, legal, and governance considerations. Concerns regarding data privacy, algorithmic bias, transparency, accountability, and unequal access remain major challenges that require coordinated institutional and policy responses. These findings consistently support the view that AI should complement rather than replace educators, preserving essential human-centered competencies such as empathy, ethical reasoning, communication, and professional judgment while leveraging AI to enhance teaching and learning (Gao et al., 2025; Marín et al., 2025; Porayska-Pomsta et al., 2024; UNESCO, 2022).

Overall, this review extends the previous literature by integrating recent evidence published between 2020 and 2026 while synthesizing educational applications, ethical challenges, AI literacy, governance, and international policy perspectives within a single PRISMA-guided narrative review. Collectively, these findings demonstrate that artificial intelligence can substantially enhance pharmaceutical and health sciences education when implemented responsibly within evidence-based educational practices and robust ethical and governance frameworks. The future directions outlined in the following section provide practical recommendations for supporting the safe, equitable, and sustainable integration of AI into health professions education.

7. Future Directions for Research, Policy, and Educational Practice

7.1 Institutional Policy and Ethical Governance

Higher-education institutions should establish comprehensive AI governance frameworks before large-scale implementation of AI-enabled educational technologies. These frameworks should clearly define the purposes, capabilities, limitations, and accountability of AI systems while ensuring compliance with ethical principles and international policy guidelines (Abbas et al., 2025; Vaithiyanathan, 2024).

- Establish multidisciplinary AI governance committees comprising educators, healthcare professionals, legal experts, AI developers, and student representatives to oversee AI implementation (Hooshyar et al., 2025; UNESCO, 2022).
- Regular algorithmic audits should be conducted to identify and mitigate bias, improve transparency, and ensure equitable educational outcomes (Al-Zahrani & Alasmari, 2024; Marín et al., 2025).
- Align institutional AI policies with international ethical frameworks, including the UNESCO Recommendation on the Ethics of Artificial Intelligence and OECD AI Principles.

7.2 Curriculum Integration and Educational Innovation

Rather than treating AI as an isolated topic, pharmacy and health sciences curricula should integrate AI competencies across foundational, clinical, and professional courses (Liang et al., 2025; Ukwandu et al., 2025).

The recommended actions include the following:

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- Embedding adaptive learning systems, intelligent tutoring, and generative AI into clinically relevant learning activities.
- Maintaining an emphasis on human-centered competencies, including communication, empathy, ethical reasoning, and clinical judgment.
- Developing authentic assessment strategies, such as objective structured clinical examinations (OSCEs), oral examinations, simulation-based assessments, and workplace-based assessments, to complement AI-assisted learning.

7.3 AI Literacy and Faculty Development

Developing AI literacy among students and educators is essential for responsible adoption (Holmes & Tuomi, 2022; Xu et al., 2025).

Institutions should:

- Integrate AI literacy throughout undergraduate, graduate, and continuing professional education.
- Structured faculty development on AI-assisted teaching, learning analytics, and ethical AI use should be provided.
- Educators and students should be trained to critically evaluate AI-generated content, recognize hallucinations and bias, and appropriately verify AI outputs before educational or clinical use.

7.4 Data Governance, Privacy, and Equity

Protecting learner data and ensuring equitable access should remain central priorities during AI implementation (Marín et al., 2025; UNESCO, 2022).

The recommended actions include the following:

- Robust cybersecurity infrastructure and transparent data governance policies must be implemented.
- Establish clear informed consent procedures for AI-supported educational data.
- Invest in scalable infrastructure and collaborative resource-sharing initiatives to reduce disparities in access to institutions and regions.

7.5 Priorities for Future Research

Future research should move beyond short-term descriptive studies toward rigorous empirical investigations that evaluate both educational effectiveness and implementation outcomes (Liang et al., 2025; Pham et al., 2025).

Priority areas include:

- Multicenter longitudinal studies evaluating long-term learning outcomes, competency development, and clinical performance are needed.
- Comparative studies examining the effectiveness of different AI modalities across various health disciplines.
- Implementation science research explores governance models, institutional readiness, cost-effectiveness, and scalability.

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- Development and validation of standardized instruments for assessing AI literacy, ethical competence, and governance effectiveness.
- Cross-disciplinary studies integrate educational research with policy analysis to inform international best practices.

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