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Artificial Intelligence in Pharmacology Education Across Undergraduate Health Professions Programmes: A Scoping Review

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ABSTRACT

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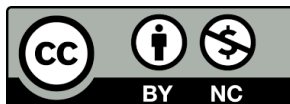
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Background: This scoping review aimed to map how AI tools have been used in undergraduate pharmacology education across medicine, pharmacy, nursing, dentistry, and allied health; how their performance on pharmacology assessments; their instructional applications; the perceptions and engagement of students and educators; and to identify the gaps and future directions reported in the literature.

Methods: We searched four databases from January 2016 to March 2026. Eligibility followed the Population–Concept–Context framework of undergraduate health professions students or educators, AI tools applied in pharmacology education and any global setting. Two authors independently screened records and extracted data.

Results: From an initial pool of 455 records identified according to the eligibility criteria, 52 studies across 28 countries were selected for the final data extraction. Most were published from 2023 onwards. Large language models (LLMs), particularly the GPT family, dominated the evidence base, achieving pharmacology accuracy rates of approximately 87–93% on standardised licensing examinations, though performance varied on assessments requiring clinical reasoning and pharmacological integration. Instructional applications were promising but remained at the proof-of-concept stage. Student attitudes were broadly positive, while formal institutional integration remains poorly established. Recurrent gaps included methodological limitations, limited faculty readiness, and the absence of AI standards in pharmacology accreditation frameworks.

Conclusion: These findings highlight that AI is entering undergraduate pharmacology education faster than institutions are adapting to it. The educators and students showed markedly different patterns of readiness and engagement. Realising its potential will require a structured, faculty-governed approach to AI literacy taught alongside it.

Keywords: Artificial intelligence (AI); Pharmacology; Education; Medical; Pharmacy; Nursing

INTRODUCTION

Pharmacology is an essential course across undergraduate health professions students in medicine, pharmacy, nursing, and allied health, as it sits between the basic science and clinical practice (1). Understanding drug mechanisms, dosing, interactions, and adverse effects requires background knowledge to protect patient safety. The World Health Organisation reported in the Global Patient Safety Challenge: Medication Without Harm in 2024 that nearly 50% of medication-related harm accounts for preventable harm in medical care globally (2). The most common errors occur among junior doctors and fresh graduates in applying pharmacology knowledge for safe prescribing and administering of drugs (3).

Despite this clinical urgency, pharmacology education faces several issues. Curricula are increasingly integrated and competency-based, pharmacological knowledge continues to expand and examination formats have evolved from traditional memorisation to clinical skills (4). However, the teaching time and training adequacy in undergraduate programmes of some health professions are being shortened (5). Medical students felt overwhelmed by the complexity of the clinical pharmacology topics, which were challenging to understand and apply the knowledge gained (6). In addition, pharmacology educators from diverse backgrounds require uniform competency in bridging the preclinical and clinical content within evolving curricula (3). Given current curricular realities, a shift from teaching-centered to technology-inspired, student-centered and active participation could help in pharmacology learning.

ChatGPT, an artificial intelligence (AI) system, was first released in November 2022, triggering widespread interest among educators and students. By January 2023, the platform had exceeded 100 million users, recognised as the fastest-growing consumer application at the time of its launch (7). Large language models (LLMs) demonstrated the capacity to pass components of medical licensing examinations (8). The use of natural language processing (NLP) models facilitated personalised tutoring and the practical application of medical knowledge that could lead to improved case analysis and diagnosis (9). These capabilities have generated interest in AI as a vehicle for learning opportunities, automated question generation, real-time

feedback, and scalable curriculum support. However, AI literacy among educators has to be improved (10).

Broader reviews of AI in undergraduate medical education exist (11). A recent scoping review has also begun to map AI use specifically within pharmacology education, though restricted to medical students at a single institution type across a smaller evidence base of 17 studies, with emphasis on AI tool performance rather than educator perspectives (12). However, to our knowledge, no prior review has jointly mapped AI use in pharmacology education across the full breadth of health professions. This distinction matters because pharmacology is shared across medicine, dentistry, pharmacy, nursing, and allied health, with distinct learning objectives, clinical reasoning, and assessment traditions (4). An approach that works well in one professional setting may potentially compromise the curriculum design. Therefore, this scoping review aimed to map the AI tools, how their performance on pharmacology assessments has been reported in the literature, their instructional applications and associated student learning outcomes. It also sought to understand the perceptions and engagement of students and educators documented in pharmacology education across undergraduate health professions programmes globally, and to identify the gaps and future directions reported in the literature.

METHODS

Study Design

This scoping review was performed using the protocol by Arksey and O'Malley (13). It is guided by the five-stage Joanna Briggs Institute (JBI) framework (14,15). The report is in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist (16).

Review Questions

This scoping review is guided by the following research questions:

- a) What AI tools have been used in pharmacology education across undergraduate health professions programmes globally?

- b) How was the performance of these AI tools in pharmacology assessments been reported?
- c) What instructional applications of AI have been documented, and what student learning outcomes are associated with them?
- d) What perceptions and engagement have been reported among students and educators?
- e) What gaps, barriers and future directions have been identified in the literature?

Inclusion Criteria

Eligibility was defined using the Population–Concept–Context (PCC) framework appropriate to scoping review methodology (14).

- a) Population: The population comprised undergraduate students and educators in health professions programmes. This includes disciplines from medicine, pharmacy, nursing, dentistry, and allied health. Studies involving postgraduate or healthcare populations without an explicit undergraduate component were excluded.
- b) Concept: The concept of interest was any artificial intelligence tool, system, platform, or application used in pharmacology education, learning or teaching. This included LLMs, adaptive learning platforms, AI-enhanced educational support tools, chatbots and virtual patient simulators. AI applications used for clinical diagnosis or pharmaceutical research, where pharmacology was not the primary or secondary subject, are excluded. This operational definition of an AI tool underpinned eligibility screening throughout the review.
- c) Context: The context was pharmacology education within undergraduate health professions settings globally, including university-based, online, and blended learning environments across any delivery mode. It also covered both self-directed use of AI tools by students (e.g., independent study) and institutional or curricular use (e.g., integrated into formal teaching, assessment, or faculty-led instruction). Studies published in English between 1 January 2016 and 31 March 2026 were eligible. Editorials, letters to the editor, and conference abstracts without accessible full text were excluded.

Information Sources and Search Strategy

An electronic search was performed using four databases: PubMed/MEDLINE, Scopus, Web of Science, and the Cochrane Library. The search covered publications from 1 January 2016 to 31 March 2026. A structured search string combining three concept blocks was applied across all databases: (i) artificial intelligence terms, including "artificial intelligence", "AI tool*", "machine learning", "large language model*", "ChatGPT", "generative AI", "chatbot*", and "natural language processing"; (ii) pharmacology terms, including "pharmacology", "pharmacotherapy", "drug knowledge", "medication*", "prescribing", "pharmacokinetic*", and "pharmacodynamic*"; and (iii) health professions education terms, including "undergraduate", "medical student*", "pharmacy student*", "nursing student*", "health professions education", "allied health", "dental student*", "medical education", and "curriculum". MeSH terms were applied in PubMed, database-specific field syntax was used in Scopus and Web of Science, and the Cochrane Library was searched using its native interface with the concept terms.

Study Selection

A total of 455 records were retrieved from the four databases and imported into EndNote. Automatic deduplication yielded 290 unique records for screening. Both authors independently screened all titles and abstracts against the eligibility criteria, with any discrepancies resolved by consensus. Following title and abstract screening, 198 records were excluded. Retrieval of the full-texts was attempted for the remaining 92 records. However, 22 could not be retrieved and were excluded. Both authors independently assessed the full eligibility criteria for the remaining 70 full-text articles. Eighteen records were excluded at the full-text stage. There were 9 studies involving postgraduate populations, and 9 did not use AI in pharmacology education as a primary or secondary area. The final included sample comprised 52 studies and is presented in the PRISMA-ScR flow diagram (Figure 1).

Data Charting

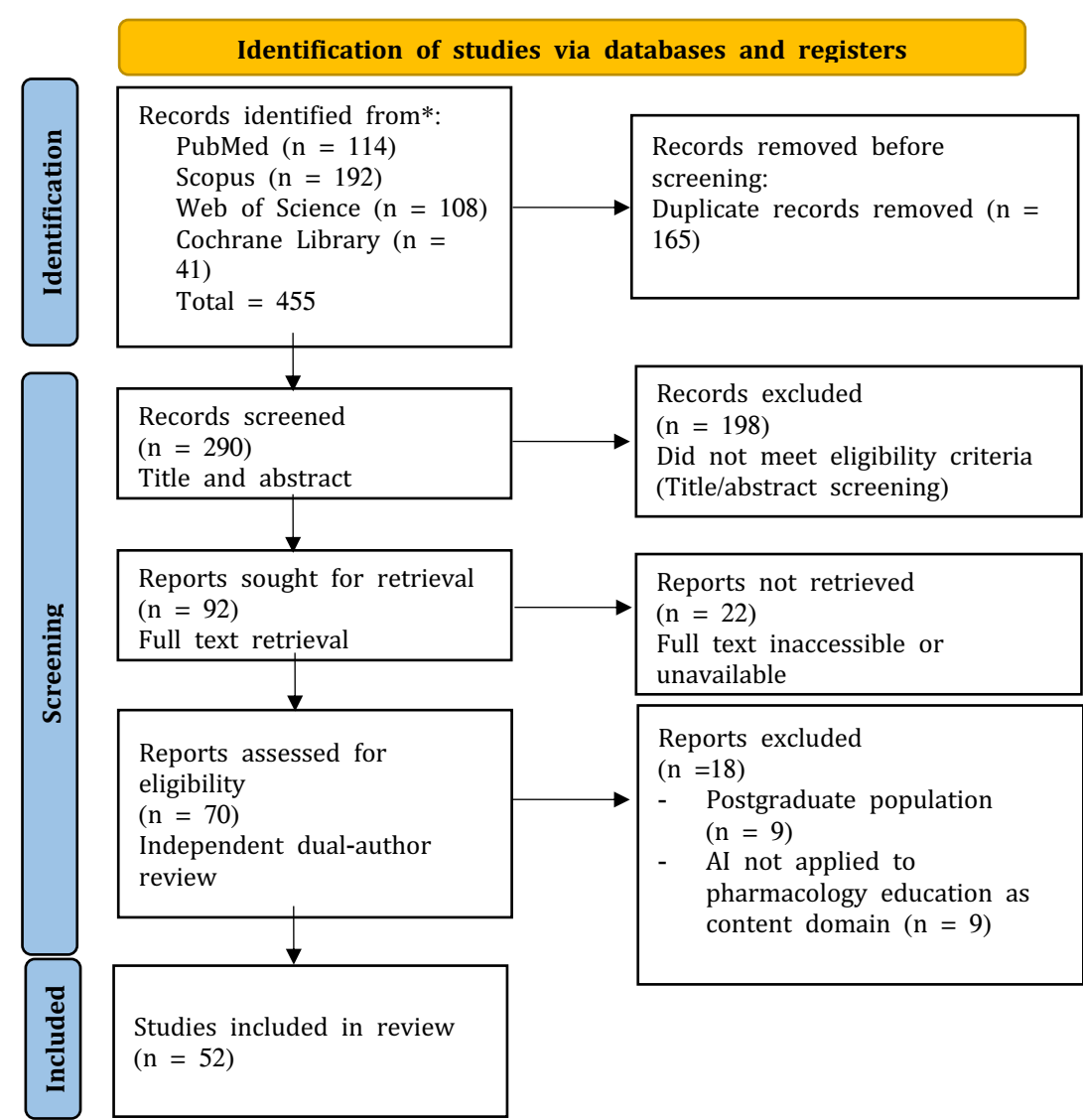
The extracted data from each included study were collected into a table and these include the first author and year, country of study, health profession represented, study design, sample size, AI tool(s) used and pharmacology

domain addressed. No dedicated systematic review or categorisation software was used for this step; EndNote was used only for reference deduplication (see Study Selection). Two reviewers reviewed the data extraction and categorised all included studies manually using this structured table. Any disagreements that arose between the reviewers were resolved through discussion. The extracted data were discussed and resolved before finalisation.

Synthesis of Results

An inductive thematic analysis was performed to identify the role of AI tools in pharmacology education. Both authors independently coded the extracted data. Codes were compared, and discrepancies were resolved through discussion until consensus was reached. Recurring codes were then grouped into themes and subthemes based on patterns, similarities and relationships identified across the included studies.

Figure 1: PRISMA-ScR flow diagram



RESULT

Characteristics of Included Studies

Among the 52 included studies, three were published before 2023 (17-19), and five were published in 2023 (20-24). The remaining 44

were published in 2024 or later, reflecting the recent emergence of this field following the widespread adoption of generative AI tools. Studies originated from 28 countries across five continents, with six separate additional studies involving multi-country or international collaborations. The United States

of America (USA) (n=11) contributed the most studies. Health professions represented included medicine (n=27), pharmacy (n=14), nursing (n=3), dentistry (n=1), and allied health or mixed professions (n=3). Some studies spanned more than one profession. Study designs were varied, with

predominantly descriptive or evaluative studies (n=26), followed by cross-sectional studies (n=11), systematic or scoping reviews (n=7), quasi-experimental studies (n=4), and qualitative studies (n=4). Full characteristics are presented in **Table 1**.

Table 1: Characteristics of included studies (n=52)

No.	First Author, Year	Country	Health Profession	Study Design	Sample	AI Tool(s)	Pharmacology Domain	Outcome
1	Ab Razak et al. 2023 (22)	Multi-country	Medicine/ Nursing/ Dentistry/ Health Sciences	Narrative review	Varies	ChatGPT, chatbots	Drug memorisation; general pharmacology teaching	Improved engagement, confidence, and clinical decision-making
2	Aksoy & Ozturk 2021 (18)	Turkey	Pharmacy	Quasi-experimental (pre-post)	N = 81	MyDispense (simulation)	Clinical pharmacy, dispensing, and drug interactions	Satisfaction, confidence, and dispensing performance improved
3	Al-Ghazali 2025 (25)	Oman	Pharmacy	Cross-sectional survey	N = 151	General AI (perception)	General pharmacy; drug therapy	Low AI awareness despite high positive perception
4	Al-Worafi et al. 2024 (26)	Yemen	Pharmacy/ Medicine	Expert content analysis	3 expert raters	ChatGPT	Infectious disease pharmacotherapy	ChatGPT content rated 50–92% appropriate and accurate
5	Alhur et al. 2025 (27)	Saudi Arabia	Pharmacy	Cross-sectional survey	N = 501	General AI (perception)	Pharmaceutical practice broadly	Positive AI perceptions; moderate familiarity among students
6	Almasri et al. 2025 (28)	USA	Medicine	Pilot evaluation	10 questions	Google Gemini	Pharmacology (USMLE Step 1 topics)	Gemini scored 89.3% on pharmacology accuracy
7	Alzarea et al. 2025 (29)	Multi-country	Medicine	Comparative observational	160 MCQs	ChatGPT 3.5, Google Bard, Gemini, Perplexity, Microsoft Copilot, Meta AI	Infectious disease pharmacotherapy	ChatGPT 65.6% accuracy on infection MCQs
8	Antonie et al. 2025 (30)	Romania	Medicine	Narrative review	4 primary studies	ChatGPT, Gemini, Claude, AI Chatbot	Antibiotic therapy; antimicrobial stewardship	ChatGPT provided 64% adequate antibiotic therapy suggestions
9	Bell & Birceanu 2025 (31)	Canada	Medicine	Educator innovation	N = 12-25 students per experiment	ChatGPT 3.5, ChatGPT 4.0	Neuromuscular junction physiology and pharmacology	Educator guide only; no formal outcomes measured

10	Berg et al. 2025 (32)	Norway	Medicine	Qualitative (focus groups)	N = 11	GPT-4o (local application)	Core pharmacology (formative assessment)	Mixed student feedback on AI-generated formative feedback
11	Bicknell et al. 2024 (8)	USA	Medicine	Comparative observational	750 MCQs	GPT-3.5, GPT-4, GPT-4o	Pharmacology (USMLE Step 1)	GPT-4o achieved 90.4% USMLE pharmacology accuracy
12	Bland 2025 (33)	USA	Medicine	Mixed methods	N = 40	GPT-4, Claude 3.5, Leonardo.ai, ElevenLabs, CCN	Immune system pharmacology	High engagement and 88% USMLE-style exam performance
13	Brata et al. 2026 (34)	Indonesia	Pharmacy	Cross-sectional (UTAUT2)	N = 201	SMCL-chatbot (Llama 3.1)	Self-medication consultation; minor ailments	90% of students showed positive chatbot use intention
14	Bull & Okaygoun 2024 (35)	UK	Medicine	Quantitative observational	120 assessments	ChatGPT GPT-4	Prescribing safety; adverse drug reactions	ChatGPT passed prescribing safety exam (85.7% score)
15	Charles et al. 2025 (36)	Australia	Pharmacy	Qualitative case study	N = 38	ChatGPT, DALL-E-3, TikTokAI	Vaping/e-cigarette toxicology	AI used mainly for idea generation, not writing
16	Cherif et al. 2024 (37)	Tunisia	Medicine	Cross-sectional comparative	N = 244	ChatGPT 3.5	Pulmonary pharmacology	ChatGPT narrowly passed pulmonary pharmacology exam (51.1%)
17	Chindhalore et al. 2026 (38)	India	Pharmacology professionals	Cross-sectional survey	N = 104	ChatGPT, Copilot, Grammarly	Drug discovery; pharmacovigilance; AI scope	High perceived AI scope; low tool access reported
18	Crowley et al. 2025 (4)	Multi-country	Multiple health professions	Narrative review	NR	AI (discussed broadly)	General pharmacology education; curriculum	Multiple active pedagogies improved pharmacology learning outcomes
19	Driesnack et al. 2024 (39)	Germany	Medicine	Pre-post with follow-up	N = 46	GPT-4-0125-preview	Antibiotic stewardship; antimicrobial therapy	Factual knowledge and antibiotic prescribing confidence improved
20	Salazar 2023 (20)	Philippines	Nursing	Development + usability	N = 41	Chatfuel/NLP chatbot	CNS drugs; nursing pharmacology	Chatbot usability rated 78%; functional quality excellent
21	Gerard et al. 2025 (40)	France	Medicine	Comparative retrospective	N = 210, 302, 249 students	ChatGPT-4o, Gemini, Mistral AI, DeepSeek R1	Clinical pharmacology and therapeutics	LLMs effectively detected ambiguous or

					dents from 3 sites N = 69			erroneous exam MCQs
22	Goldman et al. 2024 (41)	USA	Pharmacy	Cross- sectional survey		ChatGPT	Medication management	Knowledge gains noted; critical thinking skills remained weak
23	Granat et al. 2025 (42)	Poland	Medicine	Comparative evaluation	60 ques- tions, 8 chat- bots	ChatGPT 3.5, Copilot, Gemini, Claude 3.5, Perplexity, Character.ai, ChatRTX	Antifungals; hypolipidemic drugs	AI accuracy improved over time but not significantly
24	Gudadapp anavar et al. 2024 (43)	Multi- country	Medicine	Systematic review (71 studies)	71 studies	Machine Learning, Deep Learning, NLP, Convolutio- nal Neural Network, Simplified Molecular Input Line Entry System	Drug discovery; pharmaco- vigilance; pharmacogeno- mics	AI accelerated drug discovery with high diagnostic accuracy
25	Hall et al. 2026 (44)	Austra- lia	Pharmacy	Pilot mixed- methods	N = 9	Microsoft Power Virtual Agents	Clinical pharmacy; Best Possible Medication History (BPMH); medication management	High chatbot engagement, clinical confidence, and satisfaction
26	Huang et al. 2024 (45)	Taiwan	Medicine	Experimental evaluation	600 MCQs	ChatGPT GPT-4	Pharmacology (Taiwanese licensing exam)	ChatGPT averaged 87.8% on Taiwanese licensing exam
27	Kiyak et al. 2024 (46)	Turkey	Medicine	Psychometric study	N = 99	ChatGPT GPT-3.5	Rational pharmaco- therapy; hypertension	AI- generated MCQs showed acceptable psycho- metric quality
28	Krive et al. 2023 (21)	USA	Medicine	Educational innovation	N = 20	AI/intelligent tutoring	Pharmacology and patient safety module	Quiz scores improved from 61% pre to 97% post
29	Kusakabe et al. 2025 (47)	Japan	Pharmacy	Pre-post + qualitative	N = 334	AI translation software	Medication guidance; drug therapy	English motivation increased; over- reliance on translation decreased
30	Lee et al. 2026 (48)	USA	Medicine	Multi-site quasi- experimental	N = 52 (Pre- test) N = 36 (Post- test) from 6 sites	GPT-5, Gemini Nano Banana, ElevenLabs, CCN	Anticoagulant pharmacology	Cinematic AI narrative improved anticoagu- lant exam scores by 8%

31	Motaghi Niko et al. 2026 (49)	Iran	Medicine	Cross-sectional observational	195 MCQs	ChatGPT GPT-3.5	Pharmacology (pre-internship licensing exam)	ChatGPT achieved 85.7% accuracy on pharmacology licensing exam
32	Ordak et al. 2025 (50)	Poland	Pharmacy	Comparative evaluation	240 questions + 40 cases	ChatGPT-4o, GPT-3.5, Gemini, DeepSeek	Clinical pharmacology; drug interactions	Variable accuracy; structured prompting improved response quality
33	Orkaby et al. 2025 (51)	Israel	Nursing	Cross-sectional mixed-methods	N = 101 nurses + 91 students	ChatGPT-4, Claude 3.5, OpenAI o1, Meta LLaMA 3	Medication dose calculation; paediatric pharmacology	Six medication dose error-prevention themes identified by nurses
34	Patel et al. 2023 (23)	Multi-country	Medicine/ Pharmacy	Narrative review	NR	ChatGPT, GPT-3/4, GeneGPT	Drug discovery; pharmacovigilance; Adverse drug reaction management	ChatGPT supports drug discovery, pharmacovigilance, and ADR learning
35	Paudel 2025 (52)	USA	Medicine	Retrospective observational	N=175, 175, 299 and 299 across 4 courses	Google NotebookLM	Multiple organ-system pharmacology	AI podcasts had 6–25% engagement vs 50–97% for slides
36	Pratik et al. 2024 (53)	India	Medicine	Review	NR	LLMs ChatGPT	Potential of LLMs in pharmacology education	ChatGPT generated valid MCQs across cognitive domains
37	Roganovic 2024 (54)	Serbia	Dentistry	Quasi-experimental (3-group intervention) (UTAUT)	N = 104	ChatGPT 3.5	Adverse drug effects in dental practice	Improved pharmacology quiz scores; positive technology acceptance attitudes
38	Saad et al. 2024 (55)	USA	Medicine	Expert panel evaluation	10 questions	ChatGPT 3.5	Organ-system pharmacology (NBME)	ChatGPT-3.5 scored 88.1% on NBME-style pharmacology questions
39	Salman et al. 2025 (56)	Saudi Arabia/ USA	Medicine	Experimental comparative	45 MCQs	ChatGPT GPT-4o mini, Copilot, Gemini	Cardiovascular pharmacology	ChatGPT achieved 89% overall cardiovascular MCQ accuracy
40	Sato et al. 2025 (57)	Japan	Pharmacy	Comparative evaluation	345 questions, 18 AI models	ChatGPT, Gemini, Claude, Perplexity (total of 18 models)	Pharmacology (Japanese pharmacist licensing exam)	Top four AI models exceeded pharmacist licensing pass threshold

41	Seneviratne & Mananthunga 2025 (58)	Sri Lanka	Medicine	Methodological validation	30 student responses	GPT-4	Systematic pharmacology (Short Answer Question)	AI scoring strongly correlated with human examiners (r=0.93–0.96)
42	Sridharan & Sequeira 2024 (59)	Bahrain	Medicine	Proof-of-concept descriptive	NR	Claude-Instant, ChatGPT 3.5	Antihypertensive pharmacology	AI successfully generated SLOs and varied assessment item types
43	Sridharan & Sivaramakrishnan 2025 (60)	Multi-country	Medicine	Comparative rubric-based	23 prompts	DeepSeek-V3, ChatGPT 4.0	Gender-affirming hormone therapy pharmacology	LLM-generated educational content assessed via structured rubric framework
44	Stathakou et al. 2020 (17)	Sweden	Health informatics	Qualitative (content analysis)	n=9	Chatbots (general)	Pharmacology (memorisation concepts)	Student-preferred chatbot design features for pharmacology learning identified
45	Thiru et al. 2026 (61)	USA	Medicine	Cross-sectional comparison	150 questions	ChatGPT GPT-4o mini	Pharmacology (preclinical; vs. UpToDate)	ChatGPT matched UpToDate in 73.3% of pharmacology questions
46	Ventola 2019 (19)	Multi-country	Pharmacy	Narrative review	NR	VR systems (Head mounted display, Cave automated virtual environment)	Drug-receptor interactions; pharmacology via 3D	83% felt immersed as clinical pharmacists in VR
47	Wang et al. 2023 (24)	Taiwan	Pharmacy	Comparative evaluation	450 questions	ChatGPT 3.5	Pharmacology (Taiwan pharmacist licensing exam)	ChatGPT passed pharmacology section but failed overall licensing exam
48	Worthley et al. 2025 (62)	USA	Medicine	Quasi-experimental	N = 275	Stable Diffusion, GPT o1, ChatGPT 4o, Kling.ai, CCN	Antiparasitic pharmacology	Students receiving AI content scored 8% higher on exam
49	Xavier et al. 2026 (63)	India	Medicine	Cross-sectional comparison	N = 100	ChatGPT-4o	General, autonomic, cardiovascular, antimicrobial pharmacology	AI-assisted students outperformed internet, e-book, and self-study groups
50	Yang et al. 2024 (64)	USA	Pharmacy	Comparative analysis	219 MCQs, 6 LLMs	ChatGPT 3.5/4, Claude 2, Llama2,	Critical care pharmacotherapy	ChatGPT-4 achieved highest accuracy

						PharmacyGP T		(71.6%) among six LLMs
51	Yap et al. 2024 (65)	Singapo re	Pharmacy	Alpha-test (TAM)	N = 16	ChatGPT 3.5, NightCafe, HeyGen	Patient medication adherence; psychiatric drugs	High medication adherence under- standing; positive TAM behavioural intention
52	Zhang et al. 2024 (66)	China	Not specified	Descriptive conceptual	NR	ChatGPT	General pharmacology curriculum	Proposed curriculum outcomes described concept- tually; not empirically measured

AI = artificial intelligence; CCN = Cinematic Clinical Narrative; LLM = large language model; MCQ = multiple-choice question; NLP = natural language processing; NR = not reported; VR = virtual reality; ADR = adverse drug reaction; BPMH = Best Possible Medication History; SAQ = short-answer question; TAM = Technology Acceptance Model; UTAUT2 = Unified Theory of Acceptance and Use of Technology

Thematic Findings

The thematic analysis yielded four main themes: (a) AI tools documented in pharmacology education; (b) AI performance on pharmacology assessments; (c) instructional and curriculum design applications; and (d) student and educator perceptions of AI. Individual studies may contribute to more than one theme or subtheme because the table maps study features rather than mutually exclusive categories.

Theme 1: AI Tools Documented in Pharmacology Education

Large language models dominated the evidence base. ChatGPT variants (GPT-3.5, GPT-4, GPT-4o, and related OpenAI models) were the most widely studied tools, appearing in most studies. Google Gemini (formerly Bard) appeared in nine studies, most often as a comparator to ChatGPT rather than as a standalone intervention (28-30,40,42,48,50,56,57). Claude (Anthropic) was referenced in seven studies, primarily in comparative evaluations (30,33,42,51,57,59,64). Two studies reported that DeepSeek was at least as capable as GPT-based models on selected clinical pharmacotherapy tasks (40,50), while Sridharan & Sivaramakrishnan (60) examined its use for teaching material generation. Microsoft Copilot appeared in four studies (29,38,42,56). Previous review studies had shown that generative AI tools are used for retrieval drug information, pharmacovigilance teaching, and antibiotic

stewardship education in health care and health research settings (30,43,67).

Beyond conversational LLMs, several studies documented other AI or AI-adjacent learning technologies including MyDispense, a clinical pharmacy dispensing simulator (18). Chatbots have been developed for medication history-taking (44), self-medication consultation (34), a pedagogical conversational agent for nursing students (20), and pharmacology memorisation (17) as well as an immersive virtual reality approach for 3D drug-receptor visualisation (19). Another cluster of work employed multimodal generative AI to create animated pharmacology education through cinematic clinical narrative approaches, integrating GPT models, image generators, and voice synthesis (33,48,62). Paudel (52) used Google NotebookLM to generate AI-narrated pharmacology podcasts, while Yap et al. (65) combined ChatGPT, image generation, and avatar tools to develop a metaverse art gallery for medication-adherence education in pharmacy students.

Theme 2: AI Performance on Pharmacology Assessments

Across licensing-style examinations in multiple countries, newer frontier LLMs consistently outperformed older models and frequently exceeded the passing thresholds of standardised examinations. GPT-4o achieved 90.4% overall accuracy and 93.2% on the pharmacology subdomain of a 750-item USMLE-style set, compared with a mean

student accuracy of 59.3% (8). ChatGPT-4 reached 87.8% across 10 subjects of the Taiwanese medical licensing examination (45) and four flagship AI models exceeded both the passing cutoff and the mean score of the examinees on the Japanese pharmacist licensing examination (57).

ChatGPT and other LLMs have been used to assess pharmacology across different examination formats and healthcare systems. In a study on pneumology examinations for third-year medical students at the Faculty of Medicine, Tunisia, ChatGPT-3.5 scored 60% on pharmacology questions without contextualization (37). However, it performed better with additional background information, scoring 70%. Similar findings were observed in the pharmacology questions of the Iranian medical pre-internship examination, with a score exceeding the standard passing mark, at 85.7% correct answers (49). A more recent LLM, ChatGPT-4, demonstrated impressive results on the UK Prescribing Safety Assessment (PSA), a standardised test assessing prescribing competence for junior doctors. It achieved an average score ranging from 66.3% to 85.7% across 4 papers (35).

Three studies evaluated the accuracy of several LLMs in pharmacology assessment. Gerard et al. (40) explored the ability of several LLMs (ChatGPT-Omni, Gemini Advanced, Le Chat, and DeepSeek R1) in the Clinical Pharmacology and Therapeutics (CPT). They discovered that the performance of the LLMs was comparable to or exceeded that of the medical students in both knowledge-based and prescribing skills sections. While Salman et al. (56) found that ChatGPT-4 had the highest accuracy in advanced cardiovascular pharmacology MCQs and SAQs, Copilot and Gemini showed significantly lower performance than on easy and intermediate MCQs. On the Polish National Specialisation Examination for Pharmacists, accuracy ranged narrowly between 83% and 86%, across models (ChatGPT-4o, ChatGPT-3.5, Gemini Advanced 2.0 and DeepSeek), with no statistically significant difference (50).

Beyond examination performance, however, studies evaluating LLM outputs against clinical reference standards and expert review further show that correct answers do not always guarantee factual reliability. Across all preclinical subjects tested, pharmacology showed the highest alignment between ChatGPT4o mini and UpToDate, an established

clinical reference database. However, only 59.3% of total responses demonstrated statistically significant similarity to the reference standard (61). Although Gemini produced generally high-quality NBME-style pharmacology questions, one item contained a factual error regarding the mechanism of action of a drug for asthma, highlighting the need for expert verification of AI-generated assessment content (28).

Theme 3: Instructional Applications and Student Learning Outcomes

AI demonstrated consistent utility for pharmacology assessment-item generation. GPT-generated MCQs achieved mean quality scores of 88.1–90.6% using a 16-criterion NBME rubric (28,55). Kiyak et al. (46) incorporated ChatGPT-generated MCQs into a fourth-year pharmacotherapy examination and found acceptable psychometric properties, although item discrimination was lower than for instructor-authored questions. Another study extended LLM-generated content to multiple cognitive and affective taxonomy levels and to full teaching-material packages including learning objectives, MCQs, clinical scenario-based questions, and OSPEs for pharmacology (53,59). Sridharan and Sivaramakrishnan (60) compared DeepSeek-V3 and ChatGPT 4.0 for generating teaching materials on gender-affirming hormone therapy, finding both models produced educationally usable content when assessed against rubric criteria.

In formative assessment, GPT-4 showed preliminary agreement with expert raters when used for automated short-answer marking (32). Student focus groups valued the immediacy and specificity of AI feedback but raised concerns about leniency bias and repetitive comments (58). At the curriculum level, AI-constructed infectious-disease pharmacotherapy curricula received expert ratings ranging from 50% for needs assessment to 92% for goals and objectives (26). AI was noted as an emerging pedagogical tool in global pharmacology education, requiring educators to remain responsive to evolving trends and challenges in higher education (4,31,66).

The learning outcomes of these instructional applications were generally positive but methodologically limited by small sample sizes, the absence of control groups, and short follow-up periods. A four-week AI elective

module that included AI in pharmacology and patient safety reported post-test quiz scores of 97% and an application assignment score of 89% across the fourth-year cohort (21). Driesnack et al. (39) found that knowledge of antimicrobial stewardship improved from 57.2% to 74.4–83.5% across antibiotic subdomains in a gamified, AI-facilitated course. AI-generated cinematic clinical narratives were associated with higher targeted examination performance among students measured via Situational Interest Survey for Multimedia (48,62). AI assistance produced the largest effect size for improving pharmacology MCQ performance, particularly among students who had already studied the topic (63).

Theme 4: Student Educator Perceptions and Engagement

Among students, awareness and engagement with AI varied considerably by context. In Oman, over 75% of pharmacy students were unaware of specific AI applications in pharmacy, despite reporting general familiarity with AI and a basic understanding of AI technologies (25). While in Saudi Arabia, 75.7% of the pharmacy students reported moderate familiarity with AI, primarily acquiring AI knowledge through online resources rather than university courses (10.4%). In the same study, they found that more than 60% of respondents agreed that AI will be used in the future, even though pharmacists will remain relevant (27). In the US, 82% of pharmacy students applied AI to foundational knowledge of medications (41). Perceptions were not uniformly positive. Pharmacy students in Australia expressed the use of AI as a double-edged sword with positive roles for learning and negative roles for learning assessment that could lead to cheating (36). While, dental students in Serbia were largely reluctant to use ChatGPT, although improved quiz performance in dental pharmacology may have reflected description-induced cognitive bias, rather than a clear learning effect (54). Learner engagement and attitudes were generally favourable. Medical students revealed a high preference and interest in AI-generated CCN with successful learning and retention, as they achieved 88% on examination questions (33). Pharmacy students in Indonesia expressed strong intentions to use the newly developed Self-Medication Consultation Learning (SMCL-chatbot) for future self-directed learning (34). Simulation-based learning such as MyDispense

had improved satisfaction and confidence in pharmacy students in their learning process (18).

Educator perspectives were reported far less often than student perspectives, but the available evidence suggests a similarly mixed picture. When practising pharmacy and pharmacology educators assessed ChatGPT's utility for curriculum development tasks, appropriateness and accuracy ratings ranged from 50% for needs assessment to 92% for setting learning goals and objectives (26). Kusakabe et al. (47) emphasised the importance of pharmacists verifying AI-generated medication guidance in teaching and clinical settings and warned against the uncritical acceptance of AI-generated clinical documents. Educators also identified the main barriers to integrating AI tools into the curriculum include limited access, expertise, and training. Additionally, there is significant concern about resistance to change among faculty and staff, which was higher in academia than in industry pharmacologists (38).

DISCUSSION

This scoping review identified 52 studies across 28 countries, documenting the use of AI in pharmacology education within undergraduate health professions programmes. The elements identified in this review provide empirical evidence that AI is increasingly being explored in this field, with particular emphasis on LLM-based tools, assessment performance, instructional and curriculum design, learning outcomes, perceptions among students and educators, and student engagement. However, the findings also highlight important gaps in faculty readiness, curriculum integration, methodological quality and AI reliability.

AI Tools Documented in Pharmacology Education

Interestingly, the literature is relatively recent, with 85% of the included studies published in 2024 or later. The dominance of ChatGPT is most evident in early-stage, single-site evaluations, showing the field is being rapidly adopted and documented almost in real time rather than through extensive longitudinal studies. Most research focused on assessing the performance of the LLMs and benchmarked accuracy in examinations or clinical assessments instead of integrating

tools within the instructional frameworks (28,29). Comparative evaluations of ChatGPT, Gemini, Claude, and Perplexity have generated a growing accuracy dataset; however, interpretability remains limited due to variations in language, prompts and input tasks (57).

Non-LLM tools such as dispensing simulators, chatbots, virtual reality and multimodal platforms are discussed in some studies (33,34,62,68). The tools were created to address specific educational problems, such as medication history-taking, adherence counselling, and visualisation of the immune system or antiparasitic pharmacology. In contrast, LLMs studied general-purpose knowledge retrieval. While LLM research focused on the performance of the tools, the non-LLM studies examined the content or skills that the tools should teach.

AI Performance in Pharmacology Education

Across licensing examinations in multiple countries, LLMs consistently exceeded the passing scores and the average student scores on pharmacology which range from the high 80s to low 90s (8,45,49,57). However, their performance on clinical pharmacology items varied even when researched in the same study (40,50,56). Thus, high examination scores should not be taken as proof of pharmacological competence due to model-specific limitations in clinical pharmacology content and tasks, despite strong examination results. These findings suggest that LLMs may serve as useful tools for examination preparation or self-study. However, good test performance does not guarantee reliable pharmacological reasoning across different assessments, clinical contexts, or health-system guidelines.

Almasri et al. (28) reported hallucination-related errors in AI-generated pharmacology questions such as incorrect descriptions of drug mechanisms of action. Similar issues were observed in inconsistent accuracy of drug-interaction information (50), unstable pharmacotherapy recommendations with repeated testing (29), and the continuous need for human verification of AI-generated pharmacology content against evidence-based sources (61). Unverified LLM errors may introduce misinformation into learning materials, potentially affecting patient safety. Therefore, LLMs may assist in factual knowledge and examination preparation, but

they should not replace supervised learning in pharmacology, reasoning or clinical decision-making.

Instructional Applications of AI in Pharmacology

AI-based instructional tools in pharmacology education remain closer to proof-of-concept. Most studies were descriptive, small, and without control groups. AI-constructed pharmacotherapy curricula performed best for appropriateness and accuracy, but they were less effective in formulating learning objectives and conducting needs assessment (26). Meanwhile, AI-generated MCQs demonstrated acceptable psychometric properties, effectively differentiating between high and low-performing students, though option functionality was inconsistent (46). AI may be useful for generating educational content frameworks but aligning these frameworks with the specific educational context still requires human review and curriculum expertise.

The most advanced application was AI-generated formative feedback, appreciated by students for its immediacy but criticised for being too lenient and repetitive. (32). AI-generated multimodal clinical narratives were associated with better learning strategies and higher scores in situational interest scores compared to traditional case-based instruction (48,62). These instructional applications remain promising, but the reported performance and engagement gains cannot be attributed to the AI intervention alone. Novelty effects, participants' pre-existing knowledge and increased time spent engaging with the material are plausible alternative explanations for these findings. These confounding variables were rarely addressed in the included studies, as only one quasi-experimental study explicitly acknowledged a potential novelty effect as a limitation of its own design (62). Full integration into the curriculum requires expert oversight to ensure that the educational quality and clinical relevance are evaluated independently of these confounding effects.

Student Perceptions of AI in Pharmacology Education

Across the included studies, students generally perceived AI positively but relied mainly on informal exposure rather than formal institutional training. Data from Saudi Arabia,

Oman, India, Japan, and the United States revealed a consistent gap between the interest of the students in AI and their ability to use it critically in pharmacy or pharmacology education (25,27,38,41,47). This indicates that AI adoption is currently being driven more by student self-directed use than by formal curricular design, highlighting the need for guided AI literacy, verification skills, and integration within the discipline. Students with AI knowledge appeared to be mostly self-directed and lack of proper guidance. Instead of following a structured curriculum, AI use was often shaped by informal online learning and applied mainly focusing on basic tasks such as idea generation, retrieval, and basic knowledge support (27,36).

Educator Perceptions of AI in Pharmacology Education

The comparatively small evidence base on educator perspectives is itself a notable finding: curriculum decisions about integrating AI into pharmacology teaching appear to be informed far more by learner attitudes than by the readiness or concerns of the educators responsible for delivering that curriculum. Where educator views were captured, the pattern was one of measured endorsement rather than enthusiasm. Appraisal ratings were consistently higher for structured, well-defined tasks such as setting learning objectives than for open-ended tasks such as needs assessment (26), suggesting educators trust AI more with routine instructional tasks than with judgment-dependent ones. This caution aligns with Kusakabe et al.'s (47) point that educators are expected to verify AI-generated content before it reaches learners, a quality-control role that itself demands AI-literacy training few programmes currently provide. The barriers educators reported limited access, expertise, and training, alongside resistance to change (38), point to a faculty-readiness gap rather than a technology gap, echoing patterns seen elsewhere in health professions education where institutional adoption stalls not on tool capability but on staff development. This suggests that scaling AI use in pharmacology curricula will depend less on further tool validation and more on deliberate investment in educator training and support.

Evidence Gaps and Implementation Challenges

The first gap related to the methodological quality of the studies, mostly single-institution, cross-sectional, and focused on AI tool performance. Only one study directly evaluated student learning outcomes in pharmacology and patient safety (21). Many studies had limitations such as small sample sizes, absence of control groups, and short follow-up periods (32,36,39). This gap between rapid AI adoption and the quality of evidence poses potential risks to educational standards and patient safety. Therefore, AI-generated MCQs, feedback, curriculum support, and multimodal materials should undergo structured pilot studies with clear learning outcomes, control conditions, and safety checks.

The second gap is geographic and contextual. The US contributed most, reflecting a narrow distribution across health-system contexts. AI performance varies across examination formats, clinical guideline frameworks and prescribing conventions. Iran and Tunisia reported lower performance below expected benchmarks, while Japan was strong (37,49,57). AI tools in pharmacology education should need local validation before adoption. Tools developed or tested elsewhere should not be assumed to perform equivalently across different settings.

The third gap is faculty readiness, representing structural barriers beyond training alone. Low faculty computational literacy and limited institutional funding are major barriers to AI integration in medical pharmacology curricula (21,38). These constraints cannot be solved with brief workshops. Therefore, faculty development should be treated as a precondition for AI integration, supported by protected institutional time, training in computational skills, academic staffing, infrastructure, and sustained pedagogical development.

The final gap is regulatory. AI is largely missing from pharmacology accreditation frameworks and curriculum standards (4,38). Although some individual educators may incorporate AI into teaching, systemic integration requires clear standards of AI literacy for pharmacology graduates. This may include integration with pharmacological reasoning, prescribing safety, and medication-error prevention, not as a separate digital skill. Professional regulatory and accreditation bodies should formalise this standard for scalability and safe implementation.

CONCLUSION

This scoping review mapped the AI tools, their reported performance on pharmacology assessments, their instructional approaches, and the perceptions and engagement of both students and educators in curriculum integration practices in pharmacology education. The evidence base is dominated by LLM evaluations and early-stage instructional pilots. The instructional applications of AI, including question generation, formative feedback, curriculum design, and multimodal content creation, show promise but remain largely at proof-of-concept stage. Student attitudes are consistently positive, whereas formal institutional integration remains rare. The most persistent gaps are the methodological immaturity of the evidence base, limited geographic and contextual diversity, insufficient faculty readiness, and the absence of pharmacology-specific AI content from accreditation frameworks.

LIMITATIONS AND RECOMMENDATIONS

Several limitations exist. Restricting searches to English-language publications likely underrepresents evidence from non-English-speaking countries, especially in Asia, Latin America, and Africa, where AI in education is growing rapidly. Including studies where pharmacology was secondary broadened the evidence but increased variability in content depth. The evidence base mainly consists of early-stage, single-institution, and cross-sectional work. No formal quality appraisal was done, so the evidence is heterogeneous and methodologically variable. Grey literature and conference proceedings were not systematically searched, possibly missing early implementation reports from institutions not yet published in indexed journals. Data charting and categorisation were performed independently by both authors, with disagreements resolved through discussion rather than a formal inter-rater reliability statistic. Rapid AI model versioning and variability in prompting approaches across studies further limit comparability of reported performance findings. Additionally, 22 of the 92 full texts sought could not be retrieved and were excluded, which may have introduced availability bias.

Future research should prioritise controlled longitudinal studies measuring pharmacological competence outcomes, not only attitudes, satisfaction, or AI accuracy

scores. Pharmacology-specific AI tools should be validated across languages, health-system contexts, and low-resource educational settings. Regulatory and accreditation bodies should consider incorporating AI literacy, verification of AI-generated drug information, and safe-use standards into pharmacology programme requirements, as these are likely to be stronger levers for systemic integration than reliance on individual faculty initiative alone.

CONFLICT OF INTEREST

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AUTHOR CONTRIBUTIONS

WMSWS: Conceptualisation and design of the review; protocol development; database search; study screening; data extraction and charting; analysis and interpretation; writing of the original draft; manuscript revision; corresponding author.

NEHAR: Second independent reviewer for study selection and data extraction, with disagreements resolved through discussion; verification of extracted data; critical review and editing of the manuscript.

DECLARATION OF GENERATIVE AI USE

During the preparation of this manuscript, the authors employed Claude (Anthropic), ChatGPT and Scite AI for language improvement and citation verification across multiple sections of the review, including the introduction, results, discussion, and conclusion. The Scite AI tool was used to retrieve and verify full-text excerpts and citation statements from included studies. Following the use of these generative AI and AI-assisted technologies, the authors meticulously reviewed and edited the content as required, assuming full responsibility for the publication's content.

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