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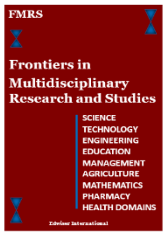

Review Article

Artificial Intelligence in Pharmacy: Transforming Education, Pharmaceutical Research and Patient Care: A Critical Review

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ABSTRACT

Artificial intelligence (AI) has emerged as a major enabling technology in pharmaceutical sciences, healthcare delivery and biomedical research. The increasing availability of large chemical, biological, genomic, clinical and real-world datasets, together with advances in machine learning (ML), deep learning (DL), natural language processing (NLP), computer vision, robotics and generative AI, has created new opportunities throughout the pharmaceutical lifecycle. This review critically examines the evolving role of AI in pharmacy education, pharmaceutical research and drug discovery, clinical pharmacy, patient care, pharmacovigilance and personalized medicine. In pharmacy education, AI-supported adaptive learning, intelligent tutoring systems, virtual laboratories, simulation-based learning and generative AI can facilitate individualized learning and rapid feedback, although concerns regarding academic integrity, overdependence and inadequate AI literacy remain. In pharmaceutical research, AI can support target identification, molecular modelling, virtual screening, quantitative structure–activity relationship modelling, de novo molecular design, drug repurposing, toxicity prediction and clinical-trial optimization. However, recent evidence indicates that computational performance does not automatically translate into clinically meaningful drug-development outcomes, emphasizing the need for rigorous experimental validation and translational evaluation. In clinical pharmacy and patient care, AI-assisted prescription review, drug-interaction detection, medication management, clinical decision support, adherence monitoring and remote patient monitoring may improve efficiency and medication safety. AI also provides opportunities for pharmacovigilance by extracting adverse drug events from clinical narratives and integrating heterogeneous safety data. Responsible implementation therefore requires human oversight, transparent validation, appropriate governance and multidisciplinary collaboration. AI should be viewed as an augmentative technology that strengthens—not replace the scientific, clinical, ethical and humanistic responsibilities of pharmacists. Future pharmacy practice will increasingly require professionals who can critically evaluate AI outputs, understand data-driven systems and integrate computational recommendations with evidence-based pharmaceutical and clinical judgment.

Keywords: *Artificial intelligence; Machine learning; Pharmacy; Pharmaceutical research; Pharmacy education; Personalized medicine.*

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Introduction

Artificial intelligence refers broadly to computational systems capable of performing functions associated with human intelligence, including learning, pattern recognition, reasoning, prediction, language processing and decision support. The development of AI has progressed from rule-based expert systems to statistical machine learning, deep neural networks and, more recently, foundation and generative models.

The relevance of AI to pharmacy arises principally from the data-intensive nature of pharmaceutical sciences. Drug discovery generates chemical and biological datasets; clinical research generates patient-level and trial data; pharmacovigilance produces large collections of safety reports; healthcare systems generate electronic health records and medication information; and pharmacy education increasingly incorporates digital learning resources. Conventional analytical approaches may be insufficient when these datasets are large, heterogeneous and rapidly changing. AI provides computational approaches capable of identifying patterns, generating predictions and automating selected tasks [1].

The project on which this review is based identifies AI as a transformative technology across pharmaceutical education, research, manufacturing, clinical pharmacy and patient care. It particularly emphasizes ML, DL, NLP, computer vision, robotics, big-data analytics, the Internet of Medical Things (IoMT) and expert systems. These applications collectively indicate that AI is no longer restricted to experimental computational research but is increasingly relevant to the complete pharmaceutical ecosystem.

The historical development of AI provides useful context. The term “artificial intelligence” was introduced in 1956 in connection with the Dartmouth research programme. Healthcare applications subsequently developed through expert systems and clinical decision-support approaches, followed by ML and big-data applications and, more recently, DL and generative AI. The project similarly describes a progression from expert systems in the 1970s–1980s to ML and big-data applications in the 2000s, DL in the 2010s and generative AI during the 2020s [2].

The importance of AI in pharmacy is therefore not simply that it automates existing activities. Its more significant contribution is the possibility of integrating multiple data sources to support prediction, optimization and decision-making across the drug-development and patient-care continuum. At the same time, AI introduces new risks because inaccurate predictions, biased datasets or inappropriate automation can influence scientific conclusions and clinical decisions [3].

Accordingly, the objective of this review is to critically evaluate the current and emerging applications of AI in pharmacy education, pharmaceutical research, drug discovery, clinical pharmacy, patient care and pharmacovigilance, while examining the technological, ethical, regulatory and professional challenges associated with implementation.

AI Technologies Relevant to Pharmacy

AI in pharmacy represents a technological ecosystem rather than a single computational method.

Machine learning

Machine learning enables algorithms to identify relationships within datasets and generate predictions without requiring explicit programming for every individual outcome. In pharmaceutical applications, ML can be applied to drug-response prediction, toxicity assessment, drug–drug interaction prediction, medication adherence, pharmacovigilance and molecular property prediction. The project identifies ML as one of the central technologies supporting modern pharmaceutical research and clinical decision-making.

Supervised learning is particularly useful when labelled outcomes are available, whereas unsupervised learning can identify clusters and previously unrecognized relationships. Reinforcement learning offers another approach in which an algorithm learns strategies through interaction with an environment and feedback [4].

Deep learning

Deep learning uses multilayer neural networks to learn complex representations from large datasets. It has become particularly relevant to image analysis, molecular prediction, protein-related applications and natural-language processing. Its ability to automatically derive features can reduce dependence on manually selected variables.

However, increased model complexity may reduce interpretability. Consequently, high predictive performance should not automatically be interpreted as evidence that a model is clinically reliable.

Natural language processing

NLP allows computational systems to analyse human language. Pharmacy-related applications include processing scientific literature, electronic health records, prescriptions, clinical notes, medication histories and adverse-event reports. NLP can transform unstructured text into structured information suitable for pharmacovigilance and clinical decision support.

Large language models have further expanded these possibilities. They can assist with summarization, information retrieval, educational content generation and documentation. Nevertheless, generated text may contain factual errors, unsupported statements or fabricated references; therefore, human verification remains essential [5].

Computer vision

Computer vision enables automated analysis of images and video. Pharmaceutical applications include tablet and capsule inspection, packaging verification, barcode recognition and manufacturing quality control. It may also support medical image interpretation when integrated with appropriate clinical systems.

Robotics and intelligent automation

Robotics combines computational intelligence with physical automation. In pharmacy, robotic systems can assist with medication dispensing, packaging, storage, inventory control and selected compounding activities. Automation can improve consistency and reduce repetitive workload, but appropriate validation and human supervision are essential.

Big-data analytics and IoMT

Big-data analytics allows pharmaceutical and healthcare organizations to integrate and analyse large heterogeneous datasets. IoMT extends this capability through connected medical devices, wearables and remote-monitoring systems. The project identifies applications including adherence monitoring, chronic disease management, telepharmacy and real-time patient monitoring [6].

Artificial Intelligence in Pharmacy Education

Pharmacy education is undergoing a transition from predominantly conventional classroom-based teaching toward digitally enhanced and personalized educational environments. The project identifies adaptive learning, intelligent tutoring, virtual laboratories, simulation-based learning and AI-assisted assessment as important applications.

Personalized and adaptive learning

AI can analyse student performance and identify knowledge gaps, allowing educational content to be adapted to individual requirements. Students who struggle with pharmacology, medicinal chemistry or therapeutics, for example, could receive additional explanations, practice questions or targeted learning material. This approach potentially changes the educational model from uniform instruction toward individualized learning. However, evidence supporting AI in pharmacy education remains relatively limited. A 2024 scoping review identified only seven studies specifically addressing AI within pharmacy education and highlighted gaps in faculty expertise, generalizability and outcome evaluation.

Intelligent tutoring systems

Intelligent tutoring systems can provide immediate explanations, questions and feedback. In clinical pharmacy education, AI-driven patient cases can simulate medication histories, laboratory results and therapeutic problems. Students can then formulate pharmaceutical-care plans before interacting with real patients.

Virtual laboratories and simulation

Virtual laboratories may provide safe environments for students to practise selected pharmaceutical procedures before entering physical laboratories. AI-supported virtual patients can similarly facilitate prescription review, counselling and clinical decision-making.

However, virtual environments should complement rather than replace physical laboratory training and direct patient interaction. Excessive substitution of simulated activities could weaken practical and interpersonal competencies.

Generative AI and academic integrity

Generative AI has rapidly changed academic writing, information retrieval and educational support. Students can use such systems to obtain explanations, generate practice questions, summarize material and explore complex concepts. Faculty may use them for educational content development and formative assessment.

At the same time, concerns include plagiarism, undisclosed AI assistance, fabricated references, inaccurate information and reduced independent thinking. A 2024 scoping review specifically examining generative AI in pharmacy education concluded that practical evidence concerning responsible implementation and academic-integrity strategies remains limited [7].

AI literacy should therefore become an educational competency. Students should learn how to formulate appropriate prompts, verify AI outputs, identify hallucinations and distinguish evidence-based information from plausible but unsupported statements.

AI in Pharmaceutical Research and Drug Discovery

Drug discovery is one of the most prominent areas in which AI has been investigated. Traditional drug development involves multiple stages, including target identification, hit discovery, lead optimization, preclinical evaluation, clinical trials and regulatory assessment. AI can potentially assist at several points within this pipeline.

Target identification

AI can integrate genomic, proteomic, transcriptomic, clinical and literature-derived data to identify disease-associated targets and relationships that may be difficult to recognize using conventional analysis [8].

Molecular modelling and structure–activity relationships

Molecular modelling allows researchers to examine molecular properties and interactions with biological targets. ML-based quantitative structure–activity relationship (QSAR) approaches can relate molecular representations to biological or physicochemical properties.

Recent developments have produced the concept of "deep QSAR," combining traditional QSAR concepts with modern deep-learning techniques.

Virtual screening

Virtual screening uses computational approaches to evaluate large chemical libraries and prioritize compounds for experimental testing. AI can improve prioritization by learning from existing chemical and biological data.

The project emphasizes that AI-assisted screening can evaluate very large numbers of compounds and reduce the time and resources required during early discovery.

Nevertheless, computational screening does not guarantee experimental success. Recent critical assessments have emphasized that AI-based hit identification still faces substantial validation and translational challenges [9].

De novo Molecular Design

Generative models can propose new molecular structures according to predefined objectives such as potency, selectivity or physicochemical properties. This creates the possibility of exploring chemical space more efficiently.

However, generated molecules must undergo rigorous assessment of synthetic feasibility, biological activity, pharmacokinetics and toxicity. Computational novelty does not necessarily correspond to therapeutic value.

Drug repurposing

AI can integrate molecular, clinical and literature data to identify potential alternative indications for existing medicines. Because repurposed compounds may have established safety information, successful candidates can potentially move through development more efficiently.

Toxicity and pharmacokinetic prediction

Toxicity is a major cause of attrition in drug development. AI models can predict potential hepatotoxicity, nephrotoxicity, cardiotoxicity and other adverse effects from chemical, biological and historical data. Similar approaches can estimate absorption, distribution, metabolism and excretion-related properties [10].

The project emphasizes toxicity prediction as an opportunity to identify potentially unsafe candidates earlier in development.

Importantly, such predictions should be treated as prioritization tools rather than substitutes for experimental toxicology.

Clinical-trial optimization

AI can assist with patient identification, trial recruitment, stratification, endpoint prediction, monitoring and analysis of real-world information. These applications could reduce operational inefficiencies and improve trial design.

However, AI-based patient selection can unintentionally reproduce biases present in historical healthcare data. Therefore, representativeness and external validation are essential [11].

AI in Pharmaceutical Manufacturing and Quality Assurance

AI is increasingly relevant to pharmaceutical manufacturing through process optimization, predictive maintenance, automated inspection and quality monitoring.

Computer vision can identify defects in tablets, capsules and packaging. Predictive models can analyse equipment data to anticipate failures. AI-based process monitoring may identify deviations before they result in significant quality problems.

The project identifies intelligent automation, predictive maintenance, real-time quality monitoring and process optimization as major industrial applications.

The major advantage is a movement from reactive quality control toward predictive and potentially continuous quality monitoring. Nevertheless, AI-based manufacturing systems must remain consistent with established pharmaceutical quality systems, validation requirements, data-integrity principles and regulatory expectations [12].

AI in Clinical Pharmacy and Patient Care

Clinical pharmacy represents an important interface between AI and patient-centred care. AI can analyse medication histories, laboratory results, clinical characteristics and other patient data to identify potential medication-related problems [13].

AI-assisted Prescription Review

AI can screen prescriptions for:

- drug–drug interactions;
- contraindications;
- allergies;
- duplicate therapies;
- dose-related problems;
- therapeutic duplication; and
- selected prescribing errors.

The project describes AI-assisted prescription review as a mechanism for analysing patient information and medications to generate real-time safety alerts.

The principal advantage is speed and consistency. However, excessive alerts can generate alert fatigue and reduce the effectiveness of decision-support systems.

Medication Therapy Management

AI may help pharmacists identify drug-related problems, prioritize patients requiring intervention and support medication reviews. It can integrate medication lists with laboratory and clinical data to identify potentially inappropriate therapies [14].

Drug-interaction Detection

AI can extend conventional rule-based interaction checking by incorporating patient-specific characteristics and large knowledge sources. This could enable more context-sensitive assessment than simple drug-pair matching.

Dose Optimization

Patient-specific dose optimization is particularly relevant where therapeutic response depends on renal function, hepatic function, age, pharmacogenomics or therapeutic drug monitoring. AI may identify relationships among these variables and assist clinicians in selecting appropriate dosing strategies [15].

However, dosing recommendations are clinically high-risk outputs. They should therefore be independently verified before implementation.

Medication Adherence

AI-enabled mobile applications, smart reminders, wearable devices and remote monitoring can identify missed doses and behavioural patterns associated with non-adherence. These approaches could be especially useful in chronic diseases requiring long-term therapy.

Remote Patient Monitoring and Telepharmacy

Connected devices can transmit blood pressure, glucose, heart rate and other health measurements. AI can analyse these data and alert healthcare professionals to potentially significant changes. This may strengthen chronic disease management and expand access to pharmaceutical care in underserved populations [16].

AI in Pharmacovigilance

Pharmacovigilance generates large quantities of structured and unstructured information. Conventional safety monitoring can be resource intensive, particularly when relevant information is distributed across spontaneous reports, electronic health records, scientific literature and other sources.

AI can support:

1. adverse drug-event detection;
2. adverse drug-reaction prediction;
3. safety-signal identification;
4. extraction of drug–drug interactions;
5. processing of spontaneous reports;
6. analysis of clinical narratives;
7. literature surveillance; and
8. integration of heterogeneous safety data.

A systematic review of AI in pharmacovigilance identified applications across adverse-event detection, safety-report processing, drug–drug interaction extraction and prediction of populations at increased toxicity risk.

NLP and deep learning are particularly important for extracting adverse drug events from unstructured clinical text. A 2024 review found that deep-learning approaches showed strong performance in several adverse-event extraction tasks, although model performance varied according to the specific task and dataset [17].

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More recent evidence highlights a critical issue: many AI pharmacovigilance models remain insufficiently externally validated. A systematic review published in 2025 reported higher performance among studies incorporating external validation compared with development-only studies, reinforcing the importance of validation across clinical contexts.

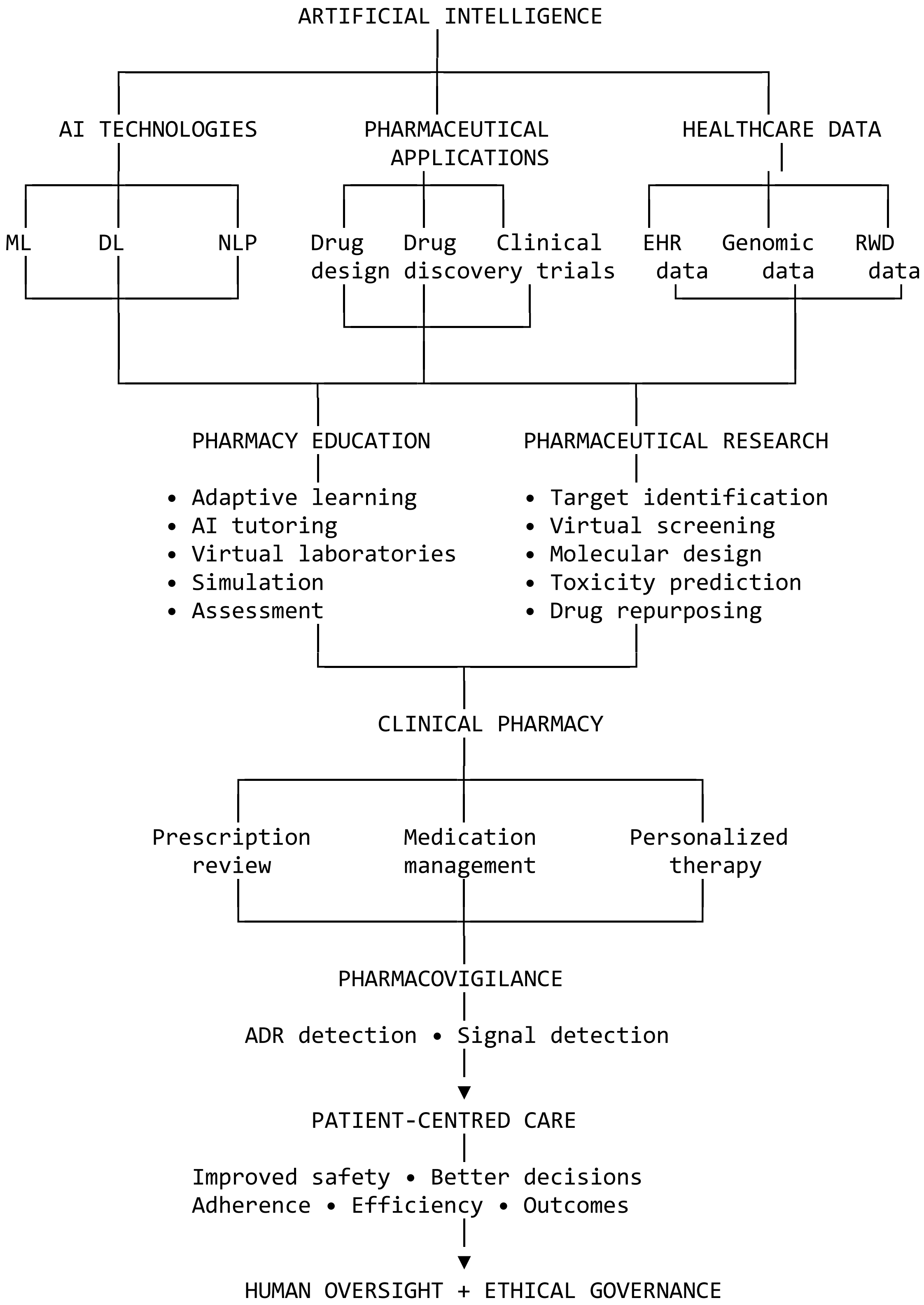

Figure 1: Conceptual framework showing the integration of artificial intelligence across pharmacy education, pharmaceutical research, drug development, clinical pharmacy, pharmacovigilance and patient-centred care.

The conceptual model is consistent with the project, which presents AI as a technology spanning education, pharmaceutical research, clinical pharmacy, pharmacovigilance and patient care rather than as an isolated computational intervention [18].

Therefore, AI should be considered an augmentation of pharmacovigilance expertise rather than an autonomous safety authority.

AI and Personalized/Precision Medicine

Conventional pharmacotherapy often applies population-level recommendations, whereas precision medicine attempts to account for individual biological and clinical variation.

AI can integrate:

- genomic information;
- demographic characteristics;
- laboratory results;
- medication history;
- clinical phenotype;
- lifestyle information; and
- real-world healthcare data.

ML models can then identify patterns associated with treatment response or adverse outcomes.

For pharmacists, this creates an expanded role involving interpretation of AI-assisted treatment recommendations, evaluation of pharmacotherapeutic appropriateness and communication of individualized treatment information to patients.

However, precision medicine depends heavily on the quality and representativeness of the underlying datasets. If specific populations are underrepresented, predictions may be less reliable for those groups.

Benefits and Limitations of AI in Pharmacy

Table 1: Major applications, potential benefits and principal limitations of AI in pharmacy.

Domain	Representative AI applications	Potential benefits	Major limitations/risks
Pharmacy education	Adaptive learning, tutoring, virtual patients, generative AI	Personalized learning, rapid feedback, improved accessibility	Academic dishonesty, hallucinations, overdependence, unequal access
Drug discovery	Virtual screening, QSAR, molecular design, target identification	Faster prioritization, reduced experimental burden, exploration of chemical space	Dataset bias, false positives, limited translational evidence
Drug repurposing	Molecular and clinical-data analysis	Identification of alternative indications	Association does not prove therapeutic efficacy
Toxicology	Toxicity prediction	Earlier identification of potentially unsafe candidates	False predictions require experimental validation
Clinical trials	Recruitment, stratification, monitoring, prediction	Operational efficiency and potentially improved trial design	Selection bias, privacy and generalizability concerns
Manufacturing	Predictive maintenance, computer vision, process monitoring	Improved efficiency and quality monitoring	Validation, data integrity and regulatory requirements
Clinical pharmacy	Prescription screening, interaction detection, dose support	Medication safety and workflow efficiency	Alert fatigue, incorrect recommendations
Medication adherence	Smart reminders, wearables, behavioural prediction	Better monitoring and adherence support	Privacy, device dependence, false alerts
Pharmacovigilance	ADR extraction, signal detection, literature surveillance	Rapid processing of large safety datasets	Bias, poor external validation, interpretability
Personalized medicine	Genomic and clinical prediction	Individualized therapy selection	Population bias, complex data governance
Telepharmacy	Remote monitoring and AI-assisted counselling	Improved access to care	Digital divide, cybersecurity, reduced human contact

The advantages and disadvantages summarized above correspond closely with the project, which identifies faster data analysis, reduced research time, improved prediction, personalized care and automation as major advantages, while emphasizing data quality, privacy, transparency, cybersecurity, technical expertise and regulatory challenges [19].

Ethical, Legal and Regulatory Considerations

The expansion of AI in pharmacy cannot be separated from ethical governance.

Data privacy and confidentiality

Pharmaceutical and healthcare AI frequently uses sensitive information. Patient records, genomic information, prescription histories and pharmacovigilance reports must be protected against unauthorized access.

Algorithmic bias

AI systems learn from existing datasets. If historical data reflect inequalities or underrepresentation, AI may reproduce these patterns. Bias can therefore arise during data collection, model development or deployment.

Explainability

A clinically important AI recommendation should ideally be interpretable enough for a pharmacist or clinician to understand why a particular output was generated. This is particularly important for high-risk decisions.

Accountability

When AI contributes to a medication or clinical decision, responsibility must remain clearly defined. AI cannot independently accept professional, legal or ethical responsibility.

Regulatory oversight

Regulatory approaches are evolving. The U.S. FDA's 2025 draft guidance proposes a risk-based credibility-assessment framework for AI models used to generate information supporting regulatory decisions concerning drug safety, effectiveness or quality [20].

In January 2026, FDA and EMA-associated work further emphasized ten guiding principles for good AI practice in drug development, including human-centric design, risk-based approaches, clear context of use, multidisciplinary expertise, data governance, model-development practices, performance assessment and lifecycle management.

Ethical governance

The WHO emphasizes that AI in health should be designed and deployed with ethics and human rights at the centre. Its guidance highlights issues including autonomy, safety, transparency, accountability, equity and responsible governance [21].

These principles are highly relevant to pharmacy because pharmacists frequently operate at the intersection of technology, medication safety and patient autonomy.

Challenges to AI Implementation In Pharmacy

Several barriers must be addressed before AI can achieve broad and reliable implementation.

Data quality

AI performance is strongly dependent on the quality of training and validation data. Missing, inconsistent or incorrectly labelled information can generate unreliable predictions.

Interoperability

AI systems need to communicate with electronic health records, laboratory systems, pharmacy-management systems and other healthcare platforms. Poor interoperability limits practical usefulness.

Cybersecurity

The increasing connectivity of healthcare systems creates additional attack surfaces. AI infrastructure must therefore incorporate strong security controls.

Infrastructure and cost

Advanced AI systems may require substantial computational resources, secure data environments and specialized software. Institutions with limited infrastructure may face difficulties adopting these technologies.

Human expertise

AI implementation requires professionals who understand both pharmaceutical sciences and computational methods. The project identifies lack of AI expertise as an important implementation barrier.

Overdependence on AI

AI can support decision-making but cannot replace clinical reasoning. Overdependence may result in automation bias, where users accept machine-generated recommendations without sufficient scrutiny [22].

Digital inequality

AI-based healthcare may disproportionately benefit populations with access to digital devices and reliable connectivity. The digital divide must therefore be addressed to prevent AI from increasing existing healthcare inequalities [23].

Changing Role of the Pharmacist

AI is unlikely to eliminate the need for pharmacists; rather, it is likely to change the nature of pharmaceutical work.

Routine activities such as data entry, prescription screening, inventory forecasting and selected information-retrieval tasks may become increasingly automated. This creates opportunities for pharmacists to devote more time to medication optimization, patient counselling, clinical decision-making and interdisciplinary collaboration.

Future pharmacists will require competencies in:

- AI literacy;
- interpretation of algorithmic outputs;
- data quality assessment;
- evidence appraisal;
- digital ethics;
- cybersecurity awareness;
- clinical decision-making;
- communication; and
- human-centred care.

Recent research involving pharmacy students similarly reports interest in AI/ML education while identifying concerns including AI-generated errors, alert fatigue and potential effects on person-centred care [24].

Thus, the pharmacist of the AI era should not be viewed as a passive recipient of algorithmic recommendations. Instead, the pharmacist should act as an informed human-in-the-loop professional who evaluates, contextualizes and communicates AI-assisted information.

Future Perspectives

The future of AI in pharmacy is likely to be characterized by increasing integration rather than isolated applications.

Explainable AI

Future systems should provide understandable explanations for predictions, especially when outputs **affect medication safety or therapeutic decisions.**

Multimodal AI

Integration of text, images, laboratory data, genomic information and longitudinal clinical records may provide more comprehensive decision-support capabilities.

Generative AI

Generative models may increasingly support literature synproject, educational content, research ideation, documentation and patient communication. However, their outputs require verification because fluent language does not guarantee factual accuracy.

AI-supported precision pharmacy

The integration of pharmacogenomics, therapeutic drug monitoring, clinical phenotyping and AI could enable increasingly individualized pharmacotherapy.

AI-assisted drug discovery

AI will probably remain important in molecular generation, virtual screening and biological prediction, but future research should focus less on model novelty alone and more on whether AI improves experimental and clinical decisions. A 2026 critical perspective in Nature Reviews Drug Discovery emphasizes that clinically meaningful impact remains limited and calls for stronger attention to translational relevance and real-world decision-making.

AI literacy in pharmacy curricula

AI should be incorporated into pharmacy curricula through structured learning rather than informal exposure alone. Educational programmes should cover fundamental AI concepts, appropriate use of generative tools, data interpretation, ethics, validation and professional accountability.

Discussion

The evidence reviewed indicates that AI is developing into an important enabling technology throughout pharmacy. The project similarly concludes that AI has progressed from early rule-based systems toward ML, DL, NLP and generative applications spanning education, research, clinical pharmacy and patient care [25].

The strongest near-term value of AI may not necessarily be complete automation. Instead, AI is likely to be most useful where it augments human expertise by processing information at a scale and speed that would be difficult for individual professionals [26].

In pharmaceutical research, AI can reduce the search space and prioritize experiments. In education, it can provide individualized learning support. In clinical pharmacy, it can identify potentially relevant medication-related problems. In pharmacovigilance, it can accelerate information extraction and signal detection [27].

Nevertheless, the central limitation is the distinction between computational prediction and real-world clinical utility. A model may perform well on an internal dataset but fail when exposed to different populations, healthcare environments or data distributions. This problem is particularly relevant to drug discovery and clinical AI. Consequently, external validation, prospective evaluation and lifecycle monitoring should become standard components of responsible implementation [28].

The same principle applies to generative AI. Its ability to produce fluent explanations can be educationally valuable, but fluency should never be confused with reliability. Pharmacists and pharmacy students must therefore develop critical appraisal skills capable of identifying unsupported or incorrect outputs [29].

The evidence concerning pharmacy education is also still developing. The relatively small number of studies identified in earlier scoping work indicates that enthusiasm for AI has grown faster than the evidence base demonstrating its educational effectiveness. More recent studies suggest increasing willingness among students and educators to integrate AI, but also highlight the need for structured curricula, faculty development and clear policies [30].

Therefore, the future of AI in pharmacy should be governed by a principle of augmentation rather than replacement. AI should perform computationally intensive tasks while pharmacists retain responsibility for interpretation, ethical reasoning, communication and patient-centred decision-making.

Conclusion

Artificial intelligence is reshaping pharmacy by connecting computational intelligence with pharmaceutical science, education and patient care. ML, DL, NLP, computer vision, robotics, big-data analytics and generative AI provide diverse opportunities for personalized learning, drug discovery, molecular optimization, toxicity prediction, clinical-trial support, manufacturing, prescription review, medication management and pharmacovigilance.

The evidence suggests that AI can improve efficiency and expand the analytical capabilities of pharmacists and pharmaceutical researchers. However, its value depends on data quality, appropriate validation, transparency, interoperability and professional oversight. The rapidly evolving regulatory environment further emphasizes risk-based evaluation, clear context of use, multidisciplinary expertise and lifecycle management.

AI should therefore not be regarded as an autonomous substitute for pharmacists, researchers or educators. Its greatest potential lies in human–AI collaboration. Pharmacists equipped with AI literacy and strong clinical, scientific and ethical competencies will be better positioned to interpret complex information, improve medication safety and deliver individualized pharmaceutical care.

The future of pharmacy will consequently depend not on choosing between human expertise and artificial intelligence, but on developing reliable systems in which computational intelligence and professional judgment operate together. Responsible implementation, evidence-based validation and human-centred governance will determine whether the promise of AI translates into measurable improvements in pharmaceutical research, education and patient outcomes.

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Conflict of Interest

None declared.

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