IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 6, March 2026
Impact Factor: 8.2

ChatGPT and Artificial Intelligence Tools in Pharmacy: A Review of Opportunities, Challenges, and Evolving Perspectives in Healthcare

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Abstract: *Artificial intelligence (AI) has emerged as a transformative force in the pharmaceutical and healthcare sectors, driving innovations in drug discovery, development, and patient care. Recent advancements in machine learning, deep learning, and natural language processing have accelerated pharmaceutical research by improving data interpretation, predictive modeling, and clinical decision-making. AI technologies are now integral to optimizing drug formulation, quality control, and precision medicine. Among these advancements, ChatGPT, a large language model based on generative AI, has gained prominence in pharmacy education and clinical practice. Studies demonstrate its ability to enhance learning engagement, streamline communication, and support evidence-based therapeutic decisions when guided by pharmacists.*

However, despite its promise, the integration of AI and ChatGPT presents notable challenges, including data privacy concerns, algorithmic bias, and ethical accountability in patient interactions. Ensuring transparency, validation, and human oversight remains essential to prevent misinformation and safeguard patient safety. The evolving landscape of AI-driven tools calls for interprofessional collaboration, policy development, and the upskilling of pharmacists to harness these technologies responsibly.

This review synthesizes recent literature (2023–2025) to examine the dual impact of ChatGPT and AI tools in pharmacy—highlighting their opportunities in education, research, and clinical practice, as well as the challenges that shape their future adoption. By fostering responsible innovation and ethical implementation, AI and generative models like ChatGPT have the potential to redefine pharmaceutical sciences and transform healthcare delivery worldwide...

Keywords: Artificial Intelligence (AI), ChatGPT, Pharmacy Practice, Drug Discovery, Pharmaceutical Education, Generative Language Models

I. INTRODUCTION

• Background and Evolution of Artificial Intelligence in the Pharmaceutical Sciences

The integration of artificial intelligence (AI) into pharmaceutical sciences marks a pivotal advancement in modern healthcare. The foundation of this transformation lies in AI's ability to automate, predict, and optimize complex processes in drug discovery, manufacturing, and quality control. Recent reviews have emphasized how AI-driven systems have revolutionized traditional pharmaceutical workflows by enabling rapid data analysis, precise formulation design, and cost-effective production [1]. This integration has reduced research timelines, improved process reproducibility, and enhanced the accuracy of decision-making in critical stages such as target identification and preclinical screening [1]. Studies analyzing AI-discovered molecules have also revealed a higher success rate in early clinical phases compared to conventionally developed drugs, indicating the growing reliability of machine learning algorithms in therapeutic innovation [2]. These findings illustrate how computational advancements and predictive modeling are reshaping drug development pathways and accelerating the transition from laboratory research to clinical application [2].

Parallel to technological development, the introduction of generative language models such as ChatGPT has expanded the role of AI from laboratory research to patient-centered care. Pharmacists increasingly recognize ChatGPT as a supportive tool in medication counseling, dispensing accuracy, and patient communication [3]. Despite these advantages, professional concerns persist regarding data privacy, ethical compliance, and the interpretability of AIgenerated information [3]. Furthermore, the evolution of AI-mounted technologies in pharmaceutical research demonstrates both strengths—such as automation and precision— and weaknesses, including limited algorithm transparency and dependency on data quality [4]. In clinical settings, AI and ChatGPT-assisted approaches have shown potential in medication therapy management, improving therapeutic outcomes, and minimizing human error in pharmaceutical decision-making [5]. These developments highlight the need for responsible adoption of AI tools through structured regulations, professional training, and interdisciplinary collaboration [4,5].

The progression of AI in pharmaceutical sciences is further evidenced by its impact on academic education, research, and the broader healthcare ecosystem. Intelligent systems learning tools are transforming pharmacy education by fostering technological literacy and analytical problem-solving among students [6,7]. Meanwhile, AI continues to evolve as a key enabler in drug discovery and formulation optimization, offering new insights into molecular mechanisms and target interactions [8,9].

• AI Applications in Drug Discovery, Development, and Delivery

Artificial intelligence (AI) has become an indispensable component of modern pharmaceutical research, influencing nearly every stage of drug discovery and development. Its implementation enables predictive modeling, molecular screening, and optimization of compound structures, leading to improved identification of viable drug candidates [12]. The use of machine learning algorithms allows for data-driven predictions of pharmacokinetic and pharmacodynamic properties, accelerating drug optimization and clinical readiness [12]. Moreover, Intelligent systems analytics enhance formulation design and process automation, bridging the gap between experimental data and practical pharmaceutical application. This technological evolution is transforming how scientists interpret biological complexity and design next-generation therapeutics [13].

Beyond discovery, AI has been instrumental in redefining the early stages of pharmaceutical education and research methodology. Recent studies have shown how generative AI models, including ChatGPT, are influencing pharmacology education and research analysis by assisting in information synthesis and academic writing [14]. Similarly, AI-assisted systems have shown remarkable accuracy in national licensing examinations for medical and pharmacy students, indicating their potential to enhance learning assessment and clinical reasoning skills [15]. As these systems evolve, they offer innovative methods to train future healthcare professionals in evidence-based decision-making and computational interpretation, thereby narrowing the gap between theory and clinical practice [14,15].

In the realm of clinical application, AI has also made a significant impact on patient care, particularly through advanced pharmacy practices. A growing body of evidence has explored the potential of ChatGPT and other conversational AI tools to improve communication, medication management, and adherence [16]. However, the integration of such systems has sparked debate about whether these tools act as disruptive or destructive innovations in pharmacy practice, underscoring the importance of professional regulation and ethical oversight [16]. Similarly, AI frameworks have evolved to assist pharmaceutical scientists in quality assurance, dosage precision, and personalized drug delivery mechanisms [17]. These studies demonstrate that AI not only enhances operational efficiency but also promotes patient-centric treatment designs, improving the safety and efficacy of modern therapeutics [16,17].

AI's expanding role in pharmaceutical management, digital health, and industry optimization illustrates its multifaceted potential. Studies have highlighted its capacity to support pharmacy management systems, streamline workflow automation, and facilitate data-driven decision-making for improved patient outcomes [18]. In parallel, Intelligent systems technologies are being applied in pharmacy operations to assist with clinical data interpretation, regulatory

ISSN: 2581-9429 Volume 6, Issue 6, March 2026 Impact Factor: 8.2

documentation, and inventory control [19]. In drug delivery research, AI has enabled the design of targeted delivery systems, nanocarriers, and smart formulations capable of controlled release and tissue-specific delivery [20].

• Role of ChatGPT and Generative AI in Pharmacy Practice and Education

The introduction of generative artificial intelligence (AI) tools like ChatGPT has initiated a new phase in pharmacy, expanding the traditional role of AI beyond research and manufacturing. Initially, AI's use in pharmaceutical sciences focused on accelerating drug discovery and production efficiency [1]. However, recent innovations have shown its capability to enhance communication and clinical decision-making through natural language processing [3]. ChatGPT, in particular, enables pharmacists to access real-time drug information and support medication counseling, helping minimize dispensing errors and improve patient safety [3].

Despite these benefits, the adoption of ChatGPT and related AI systems in pharmacy practice raises challenges regarding data reliability, ethical boundaries, and privacy [4]. The growing reliance on Intelligent systems technologies highlights the need for standardized frameworks that ensure safe and effective use in healthcare environments [4]. Moreover, AIassisted clinical tools can complement professional expertise by identifying drug interactions and recommending optimized treatment regimens [5].

In pharmacy education, ChatGPT and similar AI models are reshaping how students learn and interact with pharmaceutical knowledge. These tools foster analytical thinking and assist learners in summarizing research literature, developing case analyses, and interpreting pharmacological data [6]. Educational applications of AI have also improved student engagement and confidence in understanding drug information systems [7].

Furthermore, in the broader context of pharmaceutical practice, ChatGPT is emerging as a practical companion for healthcare professionals. It supports pharmacists in patient counseling, dosage verification, and drug information retrieval, thereby strengthening clinical communication and reducing medication-related risks [16]. Similarly, Intelligent systems management systems are being utilized to optimize inventory, forecast drug demand, and improve workflow within pharmacies [18].

• Challenges, Ethical Concerns, and Future Directions

The rapid adoption of ChatGPT and artificial intelligence in pharmacy introduces several operational and technical challenges. While AI models assist in drug data analysis and clinical support, their dependence on large and sometimes biased datasets can compromise accuracy and reliability [12]. Limitations in understanding contextual nuances, particularly in patient-specific data, may lead to misinformation or incomplete recommendations [13]. Therefore, ensuring data integrity and validation remains a significant challenge before these systems can be fully integrated into pharmaceutical practice [13].

Ethical concerns surrounding AI-driven pharmacy systems are equally important. Issues related to data privacy, informed consent, and accountability in AI-assisted decisions have become pressing in healthcare environments [14]. For example, when ChatGPT generates drug-related suggestions, identifying responsibility for errors—whether human or algorithmic—becomes complex [15]. These ethical challenges demand the establishment of clear regulatory frameworks and professional guidelines that govern AI use in patient care and drug development [15].

Role of AI in Pharmacy

The rapid integration of artificial intelligence (AI) in pharmacy marks a revolutionary phase in the healthcare and pharmaceutical industries. Traditionally, pharmacy has relied on empirical methods, human expertise, and linear experimentation for drug development and patient management. However, with the emergence of AI-driven analytics, machine learning algorithms, and natural language processing, the field has witnessed a paradigm shift toward automation, prediction, and precision [2]. AI technologies now contribute across the entire pharmaceutical value chain—from early drug discovery and molecular design to patient counseling and post-marketing surveillance. This transformation is reshaping how drugs are conceived, manufactured, tested, and delivered, ultimately aiming to improve therapeutic efficacy and ensure patient safety [2].

Artificial intelligence has also evolved as a decision-support system for pharmacists and researchers, enabling data-driven insights that enhance the accuracy and efficiency of pharmaceutical operations. In drug research, AI models identify potential drug candidates and predict their interactions with biological targets long before laboratory validation [3]. In formulation science, AI optimizes ingredient ratios, predicts product stability, and minimizes formulation failures. Moreover, in clinical practice, AI supports medication adherence monitoring, adverse drug reaction prediction, and patient counseling through conversational agents such as ChatGPT [3].

• Drug Discovery & Design

Artificial intelligence (AI) has transformed the traditional approach to drug discovery by accelerating the identification of potential therapeutic targets and optimizing molecular design. The integration of machine learning (ML) and deep learning (DL) algorithms into pharmaceutical research allows vast biomedical datasets—such as genomic, proteomic, and chemical libraries—to be processed more efficiently. These technologies enable rapid identification of novel drug candidates and prediction of their pharmacological properties, thereby reducing both time and cost associated with early-stage drug discovery [1].

In the target identification and validation phase, AI systems analyze molecular interactions and biological pathways to recognize potential targets for therapeutic intervention. By utilizing predictive modeling, AI tools can simulate how a compound will interact with a specific receptor or enzyme, which enhances the precision of drug development. This not only helps in identifying effective drug–target pairs but also reduces false leads and experimental failures that are common in traditional screening methods [2].

Moreover, AI-based frameworks have made drug repurposing a more systematic process. Instead of discovering new compounds from scratch, AI models can identify existing drugs that could be repurposed for different therapeutic uses. For instance, predictive algorithms trained on pharmacological and clinical data can reveal secondary mechanisms of action, leading to faster repurposing and clinical approval. These approaches have shown success in identifying new indications for drugs with well-established safety profiles, thereby minimizing the time between discovery and clinical deployment [8].

In de novo drug design, generative AI models—such as variational autoencoders and generative adversarial networks—are now capable of designing entirely new molecular structures with desired pharmacokinetic and pharmacodynamic properties. Such AI-driven molecular generation ensures that proposed compounds meet essential criteria for bioavailability and target specificity, offering a revolutionary advantage over manual or trial-based design strategies [9].

Predictive modeling plays an essential role in molecular screening and optimization. AI tools integrate quantitative structure–activity relationship (QSAR) models, docking simulations, and molecular dynamics data to evaluate the efficacy and toxicity of compounds before synthesis. This predictive insight allows researchers to prioritize molecules with the highest therapeutic potential and minimal off-target effects [10]. Furthermore, the combination of AI with cloud computing and big data analytics has expanded the scale of molecular libraries that can be screened within hours, enhancing productivity and discovery efficiency [11].

Real-world examples illustrate the success of AI in modern drug discovery pipelines. Several AI-assisted programs have identified new drug candidates for oncology, neurodegenerative, and infectious diseases. These systems utilize multimodal data— ranging from imaging to omics—to predict therapeutic response and streamline experimental validation [12].

• Formulation & Manufacturing

The formulation and manufacturing stages represent a critical phase in translating laboratory discoveries into clinically viable drug products. Traditionally, these stages involved extensive manual testing, empirical design, and repetitive trials to achieve stability, bioavailability, and reproducibility. With the advent of artificial intelligence (AI), this paradigm has evolved into a data-driven and precision-oriented process. AI tools enable scientists to predict optimal formulation compositions, control manufacturing variables, and ensure product quality with minimal human intervention [4].

• AI-Driven Formulation Optimization

AI-based formulation design has gained prominence due to its ability to analyze large datasets encompassing excipient properties, particle size, solubility, pH, and stability parameters. By applying machine learning algorithms, researchers can forecast the ideal composition and ratios for both solid and liquid dosage forms. Predictive models evaluate multiple formulations virtually, allowing only the most promising ones to advance for physical testing. This reduces time, materials, and cost while improving overall drug performance [5].

For example, supervised learning models have been developed to predict dissolution rates and stability profiles under various environmental conditions. These systems enable rapid screening of excipient–drug interactions and optimize bioavailability without relying solely on empirical experiments. This approach aligns with the concept of "Quality by Design" (QbD), where formulation design becomes more predictable and scientifically justified rather than trial-and-error based [6].

In nanomedicine and targeted delivery formulations, AI also plays a transformative role in optimizing nanoparticle size, charge, and surface chemistry to achieve desired drug release kinetics. Deep learning algorithms process experimental datasets to identify trends linking formulation parameters with in vivo performance. This helps create smarter drug delivery systems capable of targeting specific tissues while minimizing side effects [8].

Moreover, AI-based predictive modeling enables the identification of excipient compatibility and potential degradation pathways during formulation development. For instance, neural network models have been trained to predict solid-state stability and polymorphic transitions, ensuring the long-term integrity of complex dosage forms [9].

These advancements facilitate the development of robust, patient-centric formulations that enhance therapeutic efficiency and user compliance [8,9].

Process Automation and Quality Control

In pharmaceutical manufacturing, automation supported by AI and the Industrial Internet of Things (IIoT) has redefined the traditional production line. AI systems continuously monitor process variables such as temperature, humidity, pressure, and mixing speed to ensure that all parameters remain within defined limits. Predictive control algorithms automatically adjust conditions to prevent deviations, thus maintaining consistent product quality [10].

Modern AI-enabled control systems utilize real-time feedback loops integrated with sensors and machine vision technologies. These systems detect minor irregularities in tablet compression, coating uniformity, or capsule filling that might escape human observation. Machine learning models, trained on historical production data, predict potential process failures and recommend corrective actions before they occur [11].

This predictive capability not only enhances efficiency but also supports regulatory compliance. Under the framework of the U.S. FDA's Process Analytical Technology (PAT) initiative, AI-driven analytics allow for in-line quality assurance rather than postproduction testing. This ensures continuous verification of critical quality attributes, thereby reducing wastage and recalls [12].

AI-powered anomaly detection is particularly valuable in sterile and biopharmaceutical manufacturing, where maintaining contamination-free environments is critical. Computer vision models can analyze microscopic images of cultures or bioreactor content to detect unwanted microbial growth early, safeguarding product integrity [13].

Smart Manufacturing and Predictive Maintenance

Smart manufacturing marks the convergence of AI, data analytics, and automation into a fully integrated digital ecosystem. Unlike traditional manufacturing lines, smart facilities rely on connected sensors and predictive algorithms

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ISSN: 2581-9429 Volume 6, Issue 6, March 2026 Impact Factor: 8.2

to anticipate equipment maintenance needs and prevent unplanned downtime. These predictive maintenance systems analyze vibration, temperature, and power consumption data to identify early signs of wear or malfunction [15].

In addition, AI-powered digital twins—virtual replicas of physical equipment or production systems—are increasingly used for simulation and optimization. Digital twins replicate real-time manufacturing conditions, enabling engineers to experiment with parameter changes without interrupting production. This technology supports continuous process improvement and cost reduction [16].

AI also enhances energy efficiency in manufacturing plants by optimizing resource utilization. Machine learning algorithms can balance energy consumption across multiple units and predict the best production schedule based on real-time data. This not only minimizes operational costs but also contributes to sustainable pharmaceutical manufacturing practices [17].

Another significant advantage of AI in smart manufacturing lies in predictive supply chain management. Algorithms can anticipate raw material shortages, optimize procurement schedules, and balance inventory levels to avoid disruptions. By integrating AI insights with enterprise resource planning (ERP) systems, manufacturers maintain steady production flow and meet market demand efficiently [18].

Furthermore, AI-driven fault detection systems provide immediate alerts during production anomalies. These systems employ neural networks to recognize patterns associated with potential defects in coating, granulation, or blending. Corrective actions can then be implemented in real time, ensuring that only batches meeting predefined standards proceed to packaging [19].

• Clinical Research: AI-Driven Innovations in Trial Design and Predictive Success Modeling

Artificial intelligence (AI) has redefined the landscape of clinical research, transforming how pharmaceutical trials are designed, conducted, and analyzed. Traditional clinical trials are time-consuming, expensive, and prone to human bias; however, AI enables optimization at every stage — from patient recruitment to endpoint evaluation. By integrating large-scale datasets, including genomic, behavioral, and clinical data, AI tools can identify suitable participants faster and more accurately, leading to reduced trial durations and improved representation [2].

Machine learning (ML) algorithms play a pivotal role in predicting trial outcomes and drug success rates by recognizing subtle trends within clinical and preclinical datasets that would otherwise remain undetected through conventional methods. Predictive analytics allow researchers to model efficacy and toxicity profiles early in the development phase, minimizing costly late-stage failures [11]. Deep learning models can simulate drug interactions and predict pharmacokinetic behavior, ensuring that only the most promising candidates advance to clinical phases [9].

AI also supports adaptive clinical trial designs, enabling real-time modifications of study parameters based on emerging results. This approach increases the efficiency and ethical soundness of trials, as ineffective treatments can be halted early while successful ones receive accelerated evaluation [10]. Additionally, generative AI tools such as ChatGPT are being explored for automating data interpretation, report generation, and literature synthesis, reducing the workload on clinical researchers while maintaining high-quality documentation [5].

Incorporating AI into clinical research further enhances data integrity and regulatory compliance. Automated data-cleaning systems reduce manual errors, while blockchainintegrated AI models offer transparent data management to meet stringent regulatory requirements [4]. Predictive modeling not only forecasts trial feasibility but also supports real-world evidence generation by integrating patient data from electronic health records
and wearable sensors, improving the clinical translation of therapeutic discoveries [12].

• Pharmacovigilance and Data Mining: AI-Enhanced Drug Safety and Regulatory Intelligence

Pharmacovigilance, the science of detecting, assessing, and preventing adverse drug reactions (ADRs), has become a major focus area for the application of artificial intelligence (AI) in modern pharmacy. Traditional methods of safety monitoring largely depend on spontaneous reporting systems and manual data evaluation, which can be timeconsuming and prone to underreporting. AI-driven systems, by contrast, utilize machine learning (ML) and natural language processing (NLP) to identify ADR signals from vast, unstructured data sources such as clinical notes, patient records, and social media discussions [12]. These intelligent algorithms can detect subtle associations between drugs and adverse events that may go unnoticed in conventional pharmacovigilance workflows, significantly improving early detection and intervention [15,16].

AI models have also enhanced big data analytics in safety monitoring, allowing real-time surveillance of large-scale pharmacovigilance databases maintained by global regulatory bodies such as the FDA and WHO. Through automated data mining and pattern recognition, AI can process millions of records simultaneously to uncover correlations between drug exposure and patient outcomes [19]. This not only strengthens post-marketing safety assessments but also enables continuous risk–benefit evaluation of marketed pharmaceuticals. Predictive analytics can flag potential risks long before they become clinically evident, supporting proactive decision-making by healthcare professionals and manufacturers [17].

The integration of ChatGPT-like generative AI tools into pharmacovigilance further transforms the way safety data are interpreted and communicated. For instance, AI language models can assist regulatory authorities and pharmaceutical companies in drafting adverse event reports, summarizing clinical findings, and explaining safety outcomes in a more accessible manner [3].

AI-enabled regulatory intelligence systems are also emerging as a cornerstone of pharmacovigilance modernization. These systems combine AI analytics with real-world data to assist agencies in monitoring compliance, predicting drug-related safety issues, and formulating rapid policy responses [18]. By automating case triage, prioritizing high-risk signals, and standardizing report quality, AI reduces human workload while improving the accuracy of regulatory evaluations [20]. Furthermore, deep learning techniques are being employed to harmonize global pharmacovigilance datasets, enabling cross-country data sharing and collaborative safety assessments [21].

A key advancement lies in integrating electronic health records (EHRs) and wearable device data into AI-driven safety frameworks. Continuous patient monitoring provides realtime updates on drug efficacy and adverse events, enabling early intervention in high-risk populations [10].

ChatGPT in Pharmacy Practice

The emergence of ChatGPT and other generative AI tools represents a transformative phase in pharmacy practice, bridging the gap between technology and patient-centered healthcare. ChatGPT's natural language processing (NLP) capabilities enable it to analyze vast amounts of medical and pharmaceutical data, offering rapid, context-aware insights to pharmacists in real-world settings. Unlike traditional AI models that require structured data inputs, ChatGPT can understand and generate human-like responses, allowing seamless interaction between healthcare professionals and digital systems. This evolution has redefined the pharmacist's role—from primarily dispensing medications to providing intelligent, evidence-based clinical support [3].

• Medication Counselling and Adherence

Medication counselling is a cornerstone of effective pharmacy practice, ensuring that patients understand how and why to take their medications correctly. ChatGPT can serve as a virtual assistant for pharmacists, helping provide drug information, dosing schedules, side-effect management tips, and adherence reminders in a conversational format [3]. By simplifying complex pharmacological terminology into patient-friendly language, it strengthens communication and enhances medication adherence. Furthermore, when integrated with hospital or retail pharmacy systems, ChatGPT can personalize its guidance based on patient history, allergies, and concurrent therapies—minimizing medication errors and improving outcomes [5].

• Reducing Dispensing Errors and Ensuring Safety

Dispensing errors—ranging from incorrect dosage forms to look-alike/sound-alike (LASA) drug confusions—are among the most critical safety issues in pharmacy. ChatGPT-based systems can act as a real-time verification tool,

cross-checking prescriptions, alerting pharmacists to potential contraindications, and validating drug labels before dispensing [5]. When paired with electronic health records (EHRs), these tools can compare patientspecific data (e.g., renal function, allergies, medication history) with current prescriptions, instantly flagging potential risks [10,14].
Recent developments in AI-driven pharmacy management systems demonstrate how ChatGPT can integrate with barcode scanning and automated dispensing systems to enhance workflow accuracy [18].

• Assisting in Drug Information and Clinical Queries
One of ChatGPT's most valuable contributions lies in clinical decision support and drug information services. Pharmacists frequently encounter complex questions regarding drug mechanisms, interactions, and clinical trial data—queries that often require timeconsuming literature searches. ChatGPT accelerates this process by retrieving, summarizing, and contextualizing current scientific information from validated sources [3].
Generative AI systems can also assist in preparing formulary documents, treatment guidelines, and clinical summaries, reducing the administrative burden on pharmacists and educators [19].

• Patient Communication and Education
Patient education remains a critical factor influencing therapeutic success. ChatGPT offers a new dimension to health communication by generating personalized educational materials, such as FAQs, dosage reminders, or post-treatment care guides in clear, accessible language [7]. It can adapt explanations based on a patient's literacy level or language preference, ensuring inclusivity in healthcare education [6]. In hospital pharmacies, ChatGPT-enabled kiosks or digital portals can help patients understand discharge medication plans, potential side effects, and lifestyle adjustments required for optimal therapy outcomes [3].

• Use in Pharmacy Education and Training
In addition to its clinical utility, ChatGPT is revolutionizing. Students and educators are increasingly adopting generative AI to create quizzes, summarize research articles, and simulate patient cases for experiential learning [6]. Such tools foster analytical reasoning, self-learning, and critical evaluation—skills essential for modern pharmacists. AI-assisted platforms have also been shown to enhance students' confidence in handling drug information systems and interpreting pharmacological data [7].

Opportunities of AI and ChatGPT in Pharmacy
Artificial intelligence (AI) is redefining every stage of the pharmaceutical pipeline by integrating data analytics, automation, and predictive modeling. Its application supports faster drug discovery, improved formulation accuracy, and optimized production efficiency, ultimately contributing to safer and more effective therapies [1]. ChatGPT and similar generative AI models are reshaping pharmacy practice by assisting pharmacists in decisionmaking, medication counseling, and patient communication. These tools promote efficiency and enhance the accuracy of pharmaceutical care through intelligent, data-driven insights [3].
AI technologies are fostering a new era of evidence-based and adaptive pharmacy systems. By combining machine learning with real-time data processing, they enable precise therapeutic development and streamline the transition from research to clinical implementation [21].

• Accelerating Drug Discovery and Development
AI-based platforms enable rapid identification of potential drug targets and prediction of molecular interactions with high accuracy. Machine learning algorithms screen millions of compounds in silico, drastically reducing both time and cost compared to traditional laboratory trials [1]. The integration of AI into preclinical pipelines also aids in optimizing lead molecules for potency, bioavailability, and safety before moving to animal or human testing [2].

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 6, March 2026
Impact Factor: 8.2

ChatGPT-like NLP systems further assist researchers by summarizing scientific literature and generating hypotheses, allowing a more informed and agile discovery process [4].

• Advancing Personalized and Precision Medicine

AI facilitates the shift from "one-size-fits-all" approaches toward individualized therapy. Predictive analytics can process genomic, proteomic, and lifestyle data to tailor drug regimens for each patient [5]. This helps pharmacists select the right medication and dosage, improving therapeutic outcomes and minimizing adverse effects [5].

ChatGPT and similar systems enhance personalized care by providing real-time patient support and monitoring adherence through conversational AI interfaces [6,14]. Combining these capabilities allows healthcare providers to design therapy models that are not only data-driven but also behaviourally adaptive [10,11].

• Predictive Analytics and Drug Safety Enhancement

AI excels in recognizing hidden patterns across massive datasets such as adverse event reports and clinical records [10]. By using deep learning models, early detection of potential drug safety issues becomes more feasible, reducing the risk of post-marketing drug withdrawals [13,19].

When coupled with ChatGPT-like language models, AI tools can summarize pharmacovigilance data, support regulatory decisions, and communicate safety findings to healthcare professionals in an understandable way [18,19].

• Empowering Remote Pharmacy and Telehealth

AI chatbots and virtual assistants have emerged as critical tools for extending pharmacy services to remote or underserved regions [14,16]. Through these systems, pharmacists can conduct medication counseling, monitor therapy adherence, and address patient queries via telepharmacy platforms [3,16].

ChatGPT provides additional value by offering patient education in multiple languages and simplifying complex medical terminology, thereby enhancing accessibility and understanding [15,18]. This democratization of pharmacy knowledge aligns with the global shift toward digital health ecosystems and continuous patient engagement [17,18].

• Enhancing Data-Driven Decision Making

AI enables pharmacists and healthcare systems to integrate data from prescriptions, electronic health records, and wearable devices for smarter decision-making [19,20]. Predictive models can forecast drug demand, optimize inventory, and minimize waste, improving both efficiency and sustainability [18,19].

Furthermore, ChatGPT-style systems can summarize clinical guidelines, support pharmacoeconomic evaluations, and help pharmacists interpret real-time analytics [20,21].

Challenges, Ethical Concerns, and Limitations

While artificial intelligence (AI) and ChatGPT offer transformative potential in pharmacy and healthcare, their practical integration presents a spectrum of technical, ethical, and operational challenges. The growing dependence on digital technologies in healthcare amplifies concerns related to data integrity, patient privacy, model bias, and clinical accountability, demanding a careful balance between innovation and safety [1].

• Data Privacy and Ethical Concerns

One of the foremost challenges in deploying AI within pharmaceutical and clinical environments is ensuring data privacy and ethical use of patient information. AI systems rely on vast quantities of health records, prescription data, and pharmacovigilance reports, which may contain identifiable patient details. Inadequate anonymization or data leakage can violate confidentiality and ethical standards [2]. The digitization of medical records has improved efficiency, but it also exposes sensitive data to cyber threats and unauthorized access. Implementing robust encryption, secure data-sharing protocols, and compliance with international regulations such as GDPR and HIPAA remains essential to maintaining trust [3].

• Hallucination and Misinformation in ChatGPT

Large language models such as ChatGPT have demonstrated remarkable natural language understanding, but they are not immune to hallucination — the generation of inaccurate or unverified information. In pharmaceutical contexts, such misinformation could result in serious clinical or educational consequences, particularly if pharmacists or students rely on AI-generated outputs for drug information or dosing guidance [5]. Even when ChatGPT provides plausible-sounding answers, it may lack scientific verification, potentially spreading false medical claims [6].

• Dependency on Outdated or Biased Datasets

Another major challenge involves dataset bias and temporal obsolescence. Many AI systems are trained on historical biomedical data, which may not accurately represent current clinical standards, demographic diversity, or emerging therapeutic agents [9].

Furthermore, dataset bias can arise from overrepresentation of certain populations or diseases in training corpora, reducing generalizability. For example, algorithms trained predominantly on Western datasets may perform poorly when applied to Asian or African populations due to genetic and environmental differences [11].

• Economic Barriers and Implementation Costs

The adoption of AI-driven solutions in pharmaceutical settings is often limited by high infrastructure and maintenance costs. Advanced computational resources, cloud platforms, and AI-powered laboratory equipment require substantial financial investment, often beyond the reach of smaller institutions and community pharmacies [13]. In addition, recurring expenses such as software licensing, cybersecurity systems, and staff training further increase operational costs [14].

The absence of cost-effective and scalable models discourages broad implementation, widening the gap between technologically advanced organizations and resource-limited healthcare facilities [15].

• Lack of Skilled Workforce

Another critical challenge is the shortage of skilled professionals capable of interpreting and managing AI systems. The successful integration of AI into pharmaceutical sciences requires interdisciplinary expertise combining pharmacy, data science, and bioinformatics [17].

Without sufficient technical literacy, pharmacists may misinterpret AI-generated predictions or underutilize available tools. Integrating AI literacy, data ethics, and computational pharmacology into pharmacy education could help bridge this knowledge gap and enhance workforce readiness [19].

• Regulatory and Validation Challenges

The lack of clear regulatory frameworks for AI validation and clinical deployment remains a major obstacle. Unlike conventional pharmaceuticals, AI models evolve continuously through retraining, complicating approval and monitoring processes [20]. Regulatory agencies currently lack standardized methods to assess algorithmic transparency, reproducibility, and accountability [21].

Moreover, questions about legal liability—particularly in cases of AI-related errors or adverse patient outcomes—remain unresolved. Determining whether responsibility lies with developers, users, or institutions is complex. Developing a globally harmonized regulatory strategy that defines the roles, validation standards, and reporting mechanisms for AI tools in healthcare is essential [21].

• Integration and Interoperability Barriers

Beyond regulation, practical integration issues also hinder progress. AI models must operate within existing electronic health record (EHR) systems, laboratory databases, and pharmacy management software. Inconsistent data formats, incomplete documentation, and incompatible platforms limit interoperability and disrupt workflow efficiency [10]. To ensure smooth integration, standardized APIs and interoperable frameworks must be established [20].

Challenge	Description	Potential Solution	Reference
Data privacy	Risk of patient data leakage and ethical misuse.	Secure encryption, anonymization.	[2], [3]
Misinformation	ChatGPT hallucinations or factual errors.	Domain-specific retraining, pharmacist oversight.	[5], [6]
Dataset bias	Outdated or unbalanced data sources.	Regular updates, inclusion of diverse data.	[9], [11]
Cost barriers	High setup and maintenance costs.	Public–private funding models.	[13], [16]
Skills gap	Lack of AI literacy among pharmacists.	Curriculum integration and continuous training.	[17], [19]
Regulatory uncertainty	Absence of AI validation standards.	Global harmonization and accountability frameworks.	[20], [21]

Table 1: Key Challenges in AI and ChatGPT Use in Pharmacy.

Future Perspectives

Artificial intelligence (AI) and generative language models like ChatGPT are expected to transform the future of pharmaceutical sciences, bridging the gap between technology and personalized patient care. The rapid advancements in natural language processing, machine learning, and big data analytics are redefining the way pharmacists, clinicians, and researchers interact with health information [1]. These tools not only support data-driven decision-making but also enable predictive, preventive, and participatory models of healthcare. As pharmacy transitions toward a more digitally integrated ecosystem, AI is anticipated to become an indispensable collaborator rather than a mere computational assistant [2].

A significant area of progress will involve the integration of AI with electronic health records (EHRs). The fusion of EHRs and AI algorithms allows real-time data analysis, identifying subtle correlations that humans might overlook. This integration enables pharmacists to assess patient-specific parameters such as renal function, genetic polymorphisms, allergies, and prior medication histories before prescribing [3]. Through such intelligent systems, medication errors can be minimized, dosage regimens can be optimized, and adverse drug reactions can be predicted early [4]. For instance, AI-based predictive analytics tools are capable of comparing thousands of drug profiles against individual patient characteristics, improving therapeutic precision and safety [5]. When fully implemented, AI-EHR integration will transform clinical pharmacy practice into a more dynamic, patient-centric, and evidence-guided system [18].

Another major development lies in the emergence of domain-specific AI models tailored for pharmaceutical research and practice. While general-purpose systems like ChatGPT demonstrate strong language comprehension, specialized tools—such as DrugGPT, PharmaGPT, or MediAI—are envisioned to handle the technical complexity of pharmacokinetics, pharmacodynamics, and molecular design [8]. These models could simulate drug–receptor interactions, predict formulation stability, and assist in structure– activity relationship (SAR) analyses, accelerating the preclinical discovery process [9]. Such AI models will drastically reduce R&D costs and timelines, enabling

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 6, March 2026
Impact Factor: 8.2

researchers to virtually screen and prioritize drug candidates before entering laboratory or clinical phases [10]. Furthermore, DrugGPT-like systems can serve as intelligent assistants for pharmaceutical scientists, offering data-driven hypotheses and literature insights, ultimately enhancing innovation and reproducibility in drug research [21].

AI's role will also expand in pharmacy education and professional training. Traditional pharmacy curricula often rely on static textbooks and limited practical exposure, but AIpowered systems can offer dynamic, adaptive, and personalized learning environments [6]. ChatGPT and similar models can serve as virtual tutors, generating case-based scenarios, simulating patient interactions, and offering real-time feedback to students [7]. This digital pedagogy aligns with the global movement toward competency-based and problem-solving education. Additionally, AI-driven platforms can facilitate international collaboration through shared databases, virtual labs, and simulation-based assessments, helping harmonize pharmacy education standards across regions [15]. The integration of AI into pharmacy training will thus prepare the next generation of pharmacists to operate effectively within an increasingly digital healthcare environment [18].

From a clinical standpoint, AI is redefining the role of pharmacists. The shift from manual dispensing to AI supervision and interpretation is already underway in advanced healthcare systems. Pharmacists will act as "AI overseers," validating algorithmic recommendations and contextualizing them according to patient-specific and ethical considerations [16]. This evolution signifies a paradigm shift—AI will complement human judgment rather than replace it. Pharmacists' responsibilities will expand toward critical evaluation of data outputs, ensuring accuracy, safety, and appropriateness in therapy management [17]. Therefore, developing AI literacy and data interpretation skills among pharmacists will be a key educational and policy priority in the coming decade [19].

In addition, global collaboration and policy alignment will be essential to ensure AI adoption remains safe, ethical, and equitable. The creation of international frameworks that govern algorithmic validation, data sharing, and interoperability can promote consistent standards across nations [20]. Collaborative research networks and open-access AI repositories can democratize innovation, enabling even low-resource regions to benefit from AI-driven pharmaceutical advancements [13]. As interoperability improves, AI systems will be able to exchange information seamlessly with EHRs, laboratory databases, and hospital networks, creating a unified ecosystem for intelligent healthcare delivery [14].

However, realizing these future demands that the pharmaceutical sector address ethical and regulatory challenges in parallel. Issues of data privacy, algorithmic transparency, and model accountability must be carefully managed to maintain patient trust and safety [11]. The development of consent-driven frameworks and strong cybersecurity measures will form the ethical backbone of sustainable AI integration in pharmacy [12]. Regulatory bodies must also establish standardized guidelines to evaluate AI performance, reproducibility, and fairness before widespread clinical deployment [19].

Ultimately, the future of AI in pharmacy will depend on balanced synergy—where technology amplifies human expertise rather than substitutes it. With strategic investments in AI research, interdisciplinary education, and ethical governance, pharmacy can transition from a reactive to a predictive discipline. The integration of AI across drug discovery, clinical care, education, and policy holds the promise of a more efficient, safe, and personalized healthcare future [17]. By embracing innovation responsibly, pharmacists will not only adapt to technological change but also lead it, shaping a new era of intelligent, compassionate, and data-informed healthcare [21].

Emerging Trend	Description	Expected Impact	References
AI–EHR Integration	Linking patient data with AI for clinical decision support	Reduces medication errors, personalizes therapy	[3], [5]
DrugGPT / PharmaGPT	Domain-specific generative AI for R&D	Accelerates discovery and optimizes development	[8], [9], [21]
AI in Pharmacy Education	Adaptive, interactive learning tools	Improves training and global collaboration	[6], [7], [15]

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Pharmacist as AI Supervisor	Oversight of algorithmic decisions	Ensures ethical, contextaware AI use	[16], [17], [19]
Global AI Collaboration	Shared frameworks and open data ecosystems	Promotes standardization and innovation	[13], [20]

Table 2: Key Future Trends of AI Integration in Pharmacy Practice.

II. CONCLUSION

Artificial intelligence (AI) and conversational models like ChatGPT have emerged as transformative tools that are redefining modern pharmacy practice. From drug discovery and formulation to patient counseling and pharmacovigilance, these technologies offer unprecedented speed, precision, and efficiency in handling complex pharmaceutical data. However, while the opportunities are vast, their integration must be approached with thoughtful consideration. AI systems, though powerful, remain dependent on the quality of their training data and the ethical standards guiding their use [1].

In pharmacy practice, AI and ChatGPT should be viewed as augmentative tools rather than replacements for human expertise. Pharmacists play an indispensable role in verifying AIgenerated recommendations, interpreting context-specific information, and ensuring patient safety [4]. The future of pharmacy will depend not only on the sophistication of algorithms but also on the collaboration between humans and machines in decision-making.

To sustain this progress, ongoing research and ethical oversight are essential. Regulatory bodies, educators, and healthcare organizations must work collectively to develop standards that ensure transparency, data privacy, and accountability in AI applications [13,17]. Furthermore, training programs that promote digital literacy among pharmacists will be crucial to bridge the gap between traditional practice and technology-driven innovation [21].

Ultimately, the true potential of AI in pharmacy lies in its ability to empower pharmacists, enhance patient outcomes, and foster a more evidence-based, data-driven healthcare ecosystem—one that combines the analytical precision of machines with the empathy and judgment of human professionals.

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