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# Artificial Intelligence and Machine Learning for Pharmacy Students and Pharmaceutical Professionals: a Narrative Review

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**Abstract**

Artificial intelligence (AI) and machine learning (ML) are computer science fields that develop systems capable of learning from data, recognizing patterns and making decisions without explicit programming. They are valuable tools for assisting in student learning, the pharmaceutical industry, drug discovery, clinical trials, etc. Therefore, this review aimed to discuss the application of AI/ML in pharmacy education and pharmaceutical professions. We retrieved articles from online databases such as EMBASE, PubMed, and Google Scholar by using some common terms like "AI/ML," "Pharmacy education/profession," "Pharmaceutical sciences/industry," "Drug design/development," etc. Innovative strategies for teaching and learning are offered by AI/ML, making educational content more accessible. They generate practice questions for self-assessment and exam readiness, aligning with lecture content and case-based approaches in pharmacy. Pharmaceutical professionals can use AI tools in drug discovery and development to propose novel drug-like structures, optimize drug candidates based on efficacy, safety and pharmacokinetics, and predict drug properties using preclinical and clinical data. These tools help to find potential risks early in the development process, allowing for proactive modifications and optimization of drug performance. They can develop a suitable formulation and select an appropriate dosage form for a new drug molecule as well as help determine the nature, quantity and type of pharmaceutical excipient. AI systems can guide manufacturing processes by analyzing preliminary information from batches and converting results into guidelines. They can develop advanced marketing strategies and streamline pharmaceutical supply chains, ensuring efficient manufacturing and inventory management. AI technologies have the ability to revolutionize hospital pharmacy and community pharmacy by providing real-time updates on medications, potential drug interactions, medication errors and adverse reactions and dosage recommendations to ensure patient safety and therapeutic effectiveness. They can significantly boost pharmacy profitability by predicting medication demand, optimizing inventory management, and improving operational efficiency. The most common AI tools used by pharmacy students and pharmaceutical professionals are ChatGPT, Quilobolt, Wolfram, MEDi, AlphaFold, Toxtree, LimTox, ANN, IBM Watson, CASTER, etc.

**Key words:** Artificial intelligence (AI), machine learning (ML), pharmacy education, pharmaceutical professions.

## Introduction

Artificial intelligence (AI) is a big area of computer science that focusses on creating machines or systems capable of performing tasks that typically require human intelligence. It tries to replicate aspects of human intellect, including thinking, problem solving, understanding language and perception in a number of fields (Barhate *et al*., 2024; Xie *et al*., 2025). In contrast, machine learning (ML) is a different branch of AI that encompasses techniques that let computers learn from past data, learn from experiences that are based on inference,

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and become better at making predictions with fresh data (Jarab *et al*., 2023). These improvements have made AI and ML useful in many fields and sectors, including health care for interpreting medical pictures and figuring out what ailments people have (Ranchon *et al*., 2023; Sun *et al*., 2019).

Many businesses are trying to improve their performance to meet the needs and wants of their customers, utilizing various ways (Vora *et al*., 2023). Previously, AI/ML was exclusively used in the engineering field, but in recent years, it has been briefly introduced into the healthcare sector (Agarwal *et al*., 2021). It has also been incorporated more and more into many aspects of pharmacy practice in an effort to streamline operations and save costs. Besides, it makes every pharmacy safer, more accurate, and more efficient. For instance, automated dispensing gives pharmacists more time to interact with a greater number of patients while also improving their health outcomes (Dasta *et al.*, 1992). Additionally, it is used in clinical decision support systems to detect prescription errors, predict bad medication reactions and provide dosage recommendations, improving the management of chronic diseases (Holmes *et al.*, 2004). Robots using AI and ML can make patient consultations more efficient, answer questions from patients, keep track of prescription inventories and give out drugs. AI solutions that combine health data and telemedicine can also find patients who are at risk and help pharmacists provide them the right therapies (Zhang *et al*., 2024).

The pharmaceutical sector relies on constant new technology and the acceptance of new ideas to deal with medical crises and solve problems with healthcare across the world (Krikorian *et al.*, 2021). In the pharmaceutical industry, innovation usually results from intensive research and development in a number of areas, including production technology, packaging considerations, and customer-focused marketing strategies (Dastha *et al*., 1992). AI is also used for clinical trials, increasing pharmaceutical production, drug repurposing, and drug research and development. They are helpful and affordable in the drug development process because they can anticipate *in vivo* responses, pharmacokinetic parameters and dosing. The time-consuming process of drug discovery and its cost have been effectively reduced by AI. It has identified the lead molecule and target prediction for drug discovery in a low-time-consuming way (Russell *et al*., 2015). Simulation-based learning is one way to utilize AI in pharmacy education. In this technique, AI-driven virtual patients may give students realistic situations to practice their clinical abilities (Aziz *et al*., 2024).

The International Pharmaceutical Federation published a paper in 2021 on digital health in pharmacy education that discussed about a number of different topics in digital health education (Li *et al.*, 2022). The report indicates that pharmacy students throughout the world are not getting enough training on how to implement and integrate digital health tools. The paper also suggests teaching students and practitioners to be technology tool developers in addition to adding instruction on digital health, including AI, to the curriculum (Bambauer *et al.*, 2017). While more pharmacy education stakeholders are interested in advanced technology topics like AI and ML, it is very important to make education on these technologies more easily accessible to pharmacists so that they can better utilize AI in their ongoing work settings (Cain *et al*., 2023; Shen *et al.*, 2021). Because the use of AI, particularly ML in pharmacy practice might make it easier to manage of medications, maximize the effectiveness of therapeutic outcomes, and enhancing the safety of patients (Ooi *et al*., 2025).

AI will be a vital part of the future pharmacy career, and It could be quite helpful to learn the skills and information which is necessary and become used to the changes that are occurring in the ICT field. Bangladesh is increasingly integrated into the global economy, and the education sector—including pharmacy education—is being encouraged to adopt next-generation technologies, as the pharmacy profession is becoming increasingly reliant on AI and machine learning (Sharma *et al*., 2025). Therefore, we aimed this review in order to analyze the existing

literature on AI's role in pharmacy education and how it is utilized in the field of pharmacy professions. To provide a full picture of the research found in various online databases, including PubMed, Google Scholar, Web of Sciences, etc., on the topic of artificial intelligence (AI) and machine learning (ML) and its applications in the pharmacy field.

## Methods and Materials

*Data searching:* A variety of internet sources, including the Cochrane Library, EMBASE, Web Sciences, PubMed and Google Scholar were used to gather data published before May 2025 regarding the use of AI and ML in pharmacy education and pharmaceutical professionals. Using terms like "AI/ML," "Pharmacy education/profession," "Pharmaceutical sciences/industry," "Drug design/development," and so on, only English-language papers were retrieved. We looked through the selected papers' and reviews' references to find any relevant missing articles.

*Eligibility criteria:* Several preset criteria were taken into consideration when data were extracted from the chosen publications. Some research that didn't satisfy the set criteria were eliminated from the study. The studies considered in this analysis satisfied the following qualifying requirements: (a) articles about AI/ML; (b) articles about the use of AI/ML in the pharmaceutical industry and pharmacy education; (c) articles written in English; and (d) articles from reputable journals. Editorials, comments and publications with insufficient details about the study's objectives were not included in the analysis, nevertheless.

*Data extraction:* We prepared an MS Word document to put in the data that was obtained and got the relevant information. We got rid of any strange things we found while collecting data by following a group discussion among the writers. The author's name, study title, study design, year, goals, study findings, and other basic information were recorded for the included studies. During the data extraction process, we looked at the outcomes of the chosen publications, the eligibility of the comparative research, and the eligibility parameters of the current study.

## Results and Discussion

*AI/ML for pharmacy students:* The advancements in AI/ML have led to the development of complex applications across many areas of life, including education (Çalışkan *et al*., 2022). AI/ML offers innovative approaches to education that tackle a number of problems, including the shortage of teachers and the ease of access to instructional materials. It has been demonstrated that using AI technologies such as sophisticated tutoring programs, virtual facilitators, and learning resources is beneficial (Wakelam *et al*., 2015). In pharmacy school, students are taught a wide range of interconnected subjects that require a strong foundation. Setting up this foundation is very important to facilitate future development. Fortunately, AI can make these complex subjects easier to streamline the learning process. AI technologies make it easy to rephrase traditional lecture contents, book chapters, articles, and theoretical models, and pull out the key ideas. For instance, difficult concepts like the Krebs Cycle can be explained in more digestible terms, aiding comprehension. No matter the subject, such tools serve as versatile learning companions that support continuous education. Digital assistants and platforms like Taskade can create learning aids for understanding pharmaceutical curriculum, including mnemonics, tables, flowcharts, and concept maps, with enhanced capabilities available in pro versions. Enhanced versions of these tools can generate practice questions that align with lecture material and case-based learning strategies, making them useful for self-assessment and exam preparation. Still, caution is needed due to potential guidelines and institutional procedures updates (Aziz *et al*., 2024; Zhang *et al*., 2024; Batson *et al*., 2024; Alexander *et al*., 2025). Additionally, students can benefit from personalized study schedules and improved management of group projects through task delegation and deadline tracking. Educational content

can be converted into audio using tools like Speechify and browser extensions, which increases productivity and accommodates different learning preferences. When using external plugins and online resources, critical thinking and independent verification remain essential. Moreover, intelligent applications can assist in generating innovative research ideas by analyzing scientific literature and providing relevant insights. Presenting such content in the classroom can encourage deeper discussion and intellectual engagement. Communication skills—both written and verbal—can also be enhanced through guided drafting of emails, resumes and letters of intent for residency applications. This promotes effective collaboration with faculty and healthcare professionals, preparing students for the interdisciplinary nature of pharmacy practice (Aziz *et al*., 2024; Zhang *et al.*, 2024; Batson *et al.*, 2024; Alexander *et al*., 2025).

*AI & ML in pharmacy professions:* AI tools are gaining popularity in the healthcare industry, employing statistical and mathematical tools to mimic human behavior. They are utilized at different points, including drug discovery and clinical trials by leveraging healthcare data and analytics techniques (Jiang *et al.*, 2017). Among various AI tools, IBM's Watson supercomputer aids oncologists in cancer treatment by analyzing patient clinical data and aptitude, providing optimal treatment options. It efficiently analyzes clinical notes and reports, capturing critical patient information and executing it in English for a comprehensive treatment plan (Khatib *et al.*, 2020). It easily collects, rewrites, and compares patient data with research, providing the best treatment plan based on patient reports (Vyas *et al*., 2018). It also includes a lot of informaton from Memorial Sloan Kettering (MSK) literature, 290 medical publications, over 200 textbooks, and 12 million text pages (Bambauer *et al*., 2017). On the other hand, robotic pharmacy applications aim to improve patient care by identifying and prescribing medications. They aid in cancer treatment preparation, allowing nurses and pharmacists to focus on patient care and teamwork with physicians, enhancing their expertise (Khatib *et al.*, 2020). Robotic technology is an automatic system that electronically receives prescriptions from pharmacists, picks individual drug doses, packs, and dispenses medications, ensuring sterile preparation handling. For example, MEDi is a pain management robot that aims to alleviate pain in children during medical procedures. By building a relationship with the children and providing information about their treatment, the robot can appear to have artificial intelligence, even if it lacks reasoning (McHugh *et al*., 2015). In addition, Aethon TUG robots are autonomous medical vehicles that can carry resources, prescription drugs, meals, specimens, and large items like trash and linen. They can be configured as fixed carts or exchange base platforms, and can transport various trucks or racks. Monitoring is made easy with a touchscreen, and TUGs offer enhanced efficacy, patient safety and employee fulfillment (Aethon *et al*., 2018).

*Drug discovery and development:* AI and ML have significantly impacted drug discovery and development, reducing the time and cost of developing new drugs (Wong *et al*., 2019; Gupta *et al*., 2022; Gupta *et al*., 2021). Deep learning (DL) methodologies and QSAR-based computer models are used to analyze and interpret vast pharmaceutical data (Kalyane *et al*., 2020; Moffat *et al*., 2017; Sellwood *et al*., 2018), while AI and ML techniques have revolutionized drug discovery by determining protein 3D structures. AlphaFold, an AI tool from Google, uses CNN and gradient optimization to analyze genomics, proteomics and clinical data, identifying promising drug targets (Selvaraj *et al.*, 2021; Kim *et al*., 2020; Golriz *et al*., 2021). AI is revolutionizing virtual screening for lead compound identification by analyzing chemical databases and predicting compound-target binding likelihood based on two main approaches such as structure-based and ligand-based methods. SAR (Structure activity relationship) modeling helps to make connections between compound structure and biological activity, optimizing drug candidates with traits that are good like strong potency, selectivity, and good pharmacokinetic characteristics (Sorkun *et al.*, 2020, Savage *et al.*, 2021). AI algorithms can aid in drug

design by proposing novel drug-like structures, optimizing drug candidates based on efficacy, safety and pharmacokinetics, and predicting drug properties using preclinical and clinical data. Techniques like RNN (Recurrent Neural Network), VAE (Variational autoencoder), GAN (Generative Adversarial Networks), and RL (Reinforcement learning) help accelerate drug design timelines and reduce human bias (Yang *et al.*, 2021; Wu *et al.*, 2019).

In silico ADMET (absorption, distribution, metabolism, excretion and toxicity) modeling, machine learning algorithms, and a lot of the same ADMET data to build multitask deep neural networks (DNNs) that can accurately predict and improve medication ADMET (Bao *et al.*, 2021; Yang *et al.*, 2021; Schneider *et al.*, 2020; Chan *et al.*, 2019). Drug toxicity prediction by using web-based applications like Toxtree and LimTox is crucial to prevent adverse effects. AI-based approaches estimate drug-target interactions, bioactivity and sites of drug metabolism (Yang *et al.*, 2019; Mayr *et al.*, 2016; Pu *et al.*, 2019). They are being used in drug repurposing to find new therapeutic applications for existing drugs. To find possible links between drugs and targets, the algorithms utilized in AI tools analyze data from health records, scientific literature and clinical trial databases. They can also optimize clinical trials by predicting treatment outcomes and physicochemical properties (Chavda *et al.*, 2019; Menden *et al.*, 2013).

Furthermore, computational pharmaceutics uses AI and large data to improve drug delivery processes. Machine learning and algorithms is employed by it to look at large data sets and guess how drugs will perform. This accelerates drug development, reduces costs, and increases productivity. It models drug delivery systems at different scales, allowing for a comprehensive understanding of how drugs are delivered in a more complete way. AI tools assist in identifying potential risks early in the development process, allowing for proactive modifications and optimization of drug performance. This approach reduces the need for expensive trial-and-error experiments (Lou *et al.*, 2021; Jiang *et al.*, 2022). In addition, nanorobots are used for coordinated routes, biosensors, and control, with advanced techniques focusing on physicochemical conditions at the target site. AI tools like fuzzy logic influence drug release from implantable nanorobots. Nanotechnology-based nanomedicines offer improved efficacy and bioavailability of drugs, with computational preparation of methotrexate nanosuspension (Fu *et al.*, 2012; Yarkoni *et al.*, 2017).

*Pharmaceutical industry:* In the last five years, the pharmaceutical industry has embraced the benefits of AI and its subfields, such as ML, DL, big data, data science, and advanced analytics. AI has revolutionized the pharmaceutical industry by enabling machines to sense, perceive, analyze and produce data for administrative and clinical healthcare duties. It has also revolutionized drug development, treatment regimen design and drug efficacy analysis. AI is also helping regulatory agencies expedite medication approval processes and accelerate drug discovery (Paul *et al.*, 2021). It has revolutionized the pharmaceutical industry in numerous ways. Some of the key contributions of AI in this domain include the following:

*Advanced pharmaceutical product development:* AI can help formulate the appropriate dosage form for a new drug molecule, minimizing errors and delivering desired effects. The QSPR model minimizes errors like instability and dissolution. AI platforms help to decide the nature, quantity and type of pharmaceutical excipient, monitoring and modifying the process periodically (Jiang *et al.*, 2022). To analyze the powder flow characteristics and dissolution rate profile during tablet manufacturing process, computational fluid dynamics (CFD) and discrete element modelling (DEM) are two examples of the mathematical techniques used in artificial intelligence (AI). It has been very easy and fast to make pharmaceutical items with the aid of all these models (Zhao *et al.*, 2006).

*Pharmaceutical manufacturing:* AI is revolutionizing the pharmaceutical industry by enhancing efficiency, product quality and reducing complexity. Modern methods like CFD and Reynolds Averaged Navier-Stokes solvers help to analyze

machine stress levels and automate processes. AI systems also address complex manufacturing problems, allowing for the efficient production of substances like diphenhydramine hydrochloride and sildenafil. Neurofuzzy logic and equations help to predict fluid addition, machine speed, and granule diameter. Metaclassifiers and tablet classifiers help to manage quality control and reduce manufacturing costs (Saha *et al*., 2023).

*Quality control (QC) and quality assurance (QA):* Maintaining product equilibrium and quality control is crucial in manufacturing. The FDA has amended the Current Good Manufacturing Practices (cGMP) with the 'Quality by Design' methodology to better understand critical operations and product quality. Artificial neutral networks (ANN) can predict errors in dissolution rate profiles, ensuring consistency. AI systems can guide manufacturing processes, analyzing preliminary information from batches and converting results into guidelines. Freeze-drying processes based on ANN work to maintain quality and consistency. Computerized platforms like Electronic Lab Notebooks ensure product quality. Data mining and smart methods in Total Quality Management improve decision-making and create advanced technologies for advanced quality products (Aksu *et al*., 2013; Spark *et al*., 2021).

*Pharmaceutical marketing:* AI can be a helpful tool in pharmaceutical marketing because the pharmaceutical sector is a sales-driven one. Pharmaceutical businesses can use AI to investigate and develop innovative marketing techniques that guarantee significant sales and brand recognition. Al can help with customer journey mapping, which helps businesses determine which marketing strategy brought in visitors (lead conversion) and convinced those people to buy from them. This makes it possible for pharmaceutical companies to focus more on marketing tactics that generate the most conversions and boost sales. To ascertain which marketing initiatives continued to yield the highest profits, Al Tools can also examine past campaigns and compare the outcomes. The pharmaceutical sector needs expertise to integrate AI, but collaborations with academic institutions, AI-driven medical discovery firms, and R&D teams can improve productivity (Khatal *et al*., 2025).

*Supply chain:* AI plays a great impact on the improvement of supply chain of pharma companies. Good supply chain management is important to make sure that medications are available properly. AI is used to optimize pharmaceutical supply chains to make production, inventory management, and the distribution department to perform quickly and correctly. AI models may look at historical data, market patterns, and other factors to make predictions about demand and optimize inventory management. This lowers the chance of running out of drugs, overstocking, or understocking. They also make quality control procedures better, which helps operations run more smoothly and cost-effectively (Bhatt *et al*., 2024).

*Clinical trial design:* Poor patient selection, insufficient infrastructure, and out-of-date technology are common causes of clinical trial failure, which may last anywhere from 6 to 7 years and a substantial amount of financial investment. AI can help to minimize these issues by utilizing digital medical data (Arivanantham *et al*., 2023). This occupies one-third of the time in a clinical study. During the performance of clinical studies, there is a chance that only a percentage of registered patients could be based on specific to the analyzing the patient's genome-exposome profile. AI may assist in selecting which affected community to recruit for clinical studies in phases II and III. The chosen patients' potential therapeutic targets may even be predicted early by the intended afflicted group, as failure cases make up roughly 86% of all trials. Preliminary predictions of the key compounds that will survive clinical trials are also aided by preclinical molecule discovery and earlier lead compound prediction before the start of clinical trials, taking into account the selected group of patients and other predetermined features of artificial intelligence (Arivanantham *et al*., 2023; Mak *et al*., 2023). Because of dropout cases of the patients,

thirty percent of clinical trials fail in the completion process, wasting time and this is avoided by regularly keeping monitoring on the patients and helping them follow the approved clinical study process. During a Phase II study, AI cure developed portable applications that monitored the regular prescription drug use of schizophrenic patients. This raised patient compliance by 25%. It was indispensable for the successful conduct of a clinical trial (Shruti *et al*., 2025).

*Retail pharmacy store;* When it comes to retail pharmacies, AI has the potential to revolutionize the industry by improving efficiency, customer experience, and personalized healthcare services. It can optimize inventory management via the use of this technology by predicting demand patterns and ensuring that the right amount of pharmaceuticals is in stock. Additionally, it is able to provide personalized medication regimens according to the individual's health conditions, genetics, and lifestyle factors. Chatbots and virtual assistants powered by AI can provide 24/7 customer support, while facial recognition technology can enhance the process of prescription pick-ups. AI can also improve medication adherence by reminding patients to take their medications on time. AI can also provide predictive analytics for health trends, enhance security measures, and provide business insights. Robotic Process Automation (RPA) can automate routine tasks, while AI systems can assist pharmacists in making informed decisions. However, ethical and privacy concerns must be considered (Raza *et al*., 2022).

*Hospital pharmacy:* Clinical pharmacy practice is being revolutionized by AI technologies, which are combining the responsibilities of pharmacists with clinicians, enhancing collaboration in hospital settings. Platforms that are powered by AI provide real-time updates on medications, drug interactions, and dosage recommendations, ensuring patient safety and therapeutic effectiveness. For instance, IBM Watson for Oncology is an AI tool that assists oncologists in identifying effective cancer treatments by analyzing patient medical history, literature, and clinical trial data (Raza *et al*., 2022; Huang *et al*., 2019; Zhou *et al*., 2018). This assists physicians in managing cancer patients more effectively. The identification of medication errors and adverse responses, the provision of insights into potential systemic issues, and the prediction of adverse occurrences in hospitals to enhance patient safety are all ways in which AI contributes to quality improvement. In particular, Google announced a significant advancement in cardiovascular disease (CVD) research in 2018. Using machine learning techniques, their team created an AI model that can assess a person's risk of heart disease based on retinal test results. Take the Chemical Substructure Representation (CASTER) as an additional illustration. This AI tool makes use of deep knowledge to provide a nationwide representation of drugs. By doing so, it enhances the safety and effectiveness of pharmaceutical treatments by facilitating improved prediction of drug interactions and adverse effects (Raza *et al*., 2022; Huang *et al*., 2019; Zhou *et al*., 2018).

The predictive analytics capabilities of AI can enhance patient care by forecasting health trajectories using plans for treatment and previous histories of health. Some algorithms, such as Google DeepMind, have shown the capacity to reliably predict hospital readmission rates for patients with heart failure, giving pharmacists a more accurate tool for tailoring treatment plans. AI's quick examination of research results and patient information that is made possible by AI allows pharmacists like PathAI to offer therapy suggestions that are supported by evidence, which enhances collaborative healthcare processes. AI algorithms play a key role in monitoring of therapeutic drug as well as analyzing of patient data to assess medication efficacy and safety. Platforms such as Dosis Personalized Dosing provide recommendations for ideal doses based on individual responses, enhancing patient outcomes and increasing the level of job satisfaction experienced by pharmacist (Raza *et al*., 2022; Huang *et al*., 2019; Zhou *et al*., 2018).

*Community Pharmacy:* AI is set to make a revolution community using pharmacy as a practice by improving supply chain management and automating reordering processes. It can analyze data to predict demand for medications, minimizing stockouts and overstock. Additionally, AI can help to evaluate suppliers using characteristics such as product quality, delivery speed, pricing, and dependability. AI also provides recommendations for the ideal supplier for each product, ensuring that the inventory is of high quality and that it is cost-effective. AI can enhance Automated Dispensing Systems (ADSs) by enhancing accuracy, precision, and optimization of the system. To improve operational efficiency and provide individualized patient care, it can sort and label prescriptions, predict when maintenance is needed, and adjust dispensing based on patients' demands. AI can also integrate using electronic health records and techniques for inventory control for enhanced safety. Through the analysis of large-scale health data sets, it contributes to the monitoring of public health by detecting trends in disease outbreaks and drug usage patterns. It can alert pharmacists to potential outbreaks and help tackle the difficulties of health equity via the analysis of data like zip codes and demographics (Al Meslamani *et al*., 2023; Naeem *et al*., 2023). Besides, AI may assist to identify regions with health disparities, provide individualized advice to patients and inform strategic healthcare initiatives tools can significantly boost pharmacy profitability by predicting medication demand, optimizing inventory management, and improving operational efficiency. It is possible for pharmacy staffs to focus on providing higher-value services by automating duties such as the inventory management and the dispensing of medicines, enhancing service quality and potentially opening new revenue streams. AI tools can also increase patient engagement, reduce dispensing errors, and facilitate data-driven decision-making. Efficient staffing through AI not only improves patient satisfaction but also has a direct connection to profitability, as satisfied customers lead to repeat business and referrals from word-of-mouth. This ultimately enhances the pharmacy's overall financial health (Al Meslamani *et al*., 2023; Naeem *et al*., 2023).

*Future perspectives and innovations:* More and more people want AI and ML to be a part of pharmacy practice. AI and ML offer significant opportunities to transform pharmacy education, enhancing learning experiences and preparing students for future practice. For example, one interesting scholarship opportunity is to look at how to employ AI-powered resources for the pharmaceutical education and training sector, including admissions and evaluation tools, course materials, and professional development opportunities. AI can be integrated into curricula to improve teaching, research, and practice, in the end, making things better for patient care and outcomes. Opportunities for integrating AI into pharmacy education will arise as its use grows and its use becomes more standardized (Aziz *et al*., 2024).

The integration of AI and machine learning ML into the pharmaceutical industry is quite exciting since it might lead to new innovations and advancements (Rafiq *et al*., 2023). In last several years, the pharmaceutical industry has embraced AI and ML as game-changing technology, allowing for optimization of clinical trials and new drug discoveries. Deep learning algorithms have gotten a lot of interest lately because they have the ability to decipher complex biological data and expedite the process of identifying medication candidates. Notably, companies like In-silico Medicine have used deep learning models to speed up drug discovery pipelines, and they have had good results in a wide range of therapeutic areas. As AI and ML continue to come together, they are predicted to lead to further breakthroughs. Improvements in predictive modelling, virtual screening, and target identification are likely to change the way pharmaceutical research is done (Andrews *et al*., 2023; Danishuddin *et al*., 2023).

*Limitations and future research directions:* Using AI in pharmacy education isn't without its challenges. Faculty time and experience are required, technologies have limited generalizability, outcome

data is lacking, and there are many legal and ethical concerns (Zhang *et al*., 2024). Students may not use AI technologies in their academic pursuits if they have limited knowledge about them or aren't familiar to them. Because of technological or resource issues, students may not have access to suitable AI tools or encounter obstacles in their usage. Furthermore, resistance to adopting new technologies, when they perceive AI as complex or unfamiliar. If mentors and institutions do not support AI technologies, this problem might be worsened (Risana et al., 2024). But more AI and ML education is required for both students and practicing pharmacists. The advancement of AI/ML implementation in the pharmacy area can only be achieved by close cooperation between institutions, AI/ML companies, and pharmacists themselves (Aziz *et al*., 2024).

Undeniably using AI in drug discovery and development has revolutionized the pharmaceutical industry in a big way. But this new technological advancement does have certain problems. One big challenge is that it may be hard to get good data for training AI models. AI algorithms can only be successful in drug development if they have access to comprehensive and reliable datasets. This might be a problem in areas where data sharing and standardization practices may vary. Additionally, the capacity to understand and explain AI-generated insights is still a significant concern, particularly in the highly regulated pharmaceutical fields. To get around these limitations, further research in this area should focus on creating strong data-sharing frameworks, improving AI algorithms more open, and making it easier for pharmaceutical companies, research institutions, and regulatory authorities to work together. Moreover, looking at the potential ethical effects of using AI to discover and develop new drugs is important to make sure that these technologies are used in advancing healthcare solutions (Sampene et al., 2024).

## Conclusion

The current literature suggests that AI and ML are beginning to infiltrate pharmacy practice. Artificial intelligence (AI) in pharmacy has shown significant potential in improving pharmacy education, pharmaceutical industry, hospitals and community pharmacy. In pharmacy education, ChatGPT, Taskade, Speechify and other AI tools enhance learning by simplifying various complex concepts, organizing study materials and improving communication. These technologies are constantly promoting personalized and efficient learning. However, they required critical judgment to reaffirm precision and alignment with academic standards. To fully harness the benefits of AI in pharmacy education, curriculum development should integrate digital literacy and AI tool proficiency as essential skills. Institutions must provide faculty training on responsible AI use and establish clear policies and ethical guidelines to manage AI-assisted learning. Furthermore, academic course content should be routinely updated to align with the evolving capabilities of AI and to ensure students are equipped for real-world healthcare settings. Beyond education, the use of AI in pharmaceutical industries has already brought about advancements in drug development, patient monitoring and personalized treatment. AI is revolutionizing drug delivery methods, allowing targeted, personalized and adaptable medicines. As AI continues to evolve, the future of pharmacy practice will be shaped by innovations, interdisciplinary research, and advancements in AI technology aimed at improving patient outcomes and revolutionizing healthcare services. However, collaborations between various stakeholders, continuous learning and ethical considerations are essential for the successful integration of AI in pharmacy practice.

## Conflict of interest

The authors declare no conflict of interest.

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