

# IMPORTANCE OF ARTIFICIAL INTELLIGENCE IN THE FIELD OF PHARMACY

## Abstract

Artificial Intelligence is becoming more widely used, notably in the pharmaceutical business. Long and expensive medicine development cycles, as well as consumer and legislator price expectations, dominate the existing pharmaceutical infrastructure. Artificial Intelligence is being employed in the pharmaceutical sector for therapeutic research and development, immunotherapies, pharmaceutical productivity improvement and clinical trials. Artificial Intelligence is also used in drug development. Learn how to compute the QM/MM of an enzyme's active site. Locate some lead-like library chemicals. Only a few companies have agreed to participate in an AI-related study that could be employed in medicine discovery and creation. The goal of this article is to look at recent advancements in Artificial Intelligence in medicine, as well as provide insight into the challenges and risks that health practitioners and institutions face when integrating augmented medicine into medical treatment and future medical leader education, as well as the most common use-cases where AI-powered therapeutic technologies are already being used in medical care.

**Keywords:** Artificial Intelligence, Pharmaceutical Business, Pharmaceutical Infrastructure, Immunotherapies and Health Practitioners.

## Authors

### **Kishori P. Sutar**

Assistant Professor  
Department of Pharmaceutics  
KLE College of Pharmacy, Belagavi  
KLE Academy of Higher Education and  
Research, Belagavi, Karnataka, India.  
kishorisutar@klepharm.edu

### **Utkarsh Shastri**

Department of Pharmaceutics  
KLE College of Pharmacy, Belagavi  
KLE Academy of Higher Education and  
Research, Belagavi, Karnataka, India.  
utkarshshastri8@gmail.com

### **Dr. Prasanna S. Sutar**

Professor  
Department of Pharmacognosy  
Maratha Mandal's College of Pharmacy  
Subhash Nagar, Belagavi, Karnataka, India.  
prs2005@rediffmail.com

### **Nisha S. Shirkoli**

Department of Quality Assurance  
KLE College of Pharmacy, Belagavi  
KLE Academy of Higher Education and  
Research, Belagavi, Karnataka, India.  
nishashirkoli16@gmail.com

### **Arun D. Jadhav**

Department of Pharmaceutics  
KLE College of Pharmacy, Belagavi  
KLE Academy of Higher Education and  
Research, Belagavi, Karnataka, India.  
jadhavarun288@gmail.com

## I. INTRODUCTION

Artificial intelligence (AI) is the computerization of human intelligence (AI). It includes data gathering, usage guidelines, tentative or conclusive results, and self-correction. Many individuals worry that AI will threaten their jobs, although every progress in AI is seen as crucial for society advancement.[1]. Disease diagnosis, monitoring, comprehension, driving autos, trading currencies, and other medicinal chemistry operations could all benefit from Artificial Intelligence. In silico analysis can help with almost any subject that requires the detection of patterns and the discovery of relationships in large datasets [2]. Artificial Intelligence (AI) is widely being used, notably in the pharmaceutical business [3]. Long and expensive medicine development cycles, as well as consumer and legislator price expectations, dominate the existing pharmaceutical infrastructure [2,3]. Artificial Intelligence is being employed in the pharmaceutical sector for therapeutic research and development, immunotherapies, pharmaceutical productivity improvement and clinical trials [1,3]. Artificial Intelligence is also used in drug development [4]. Learn how to compute the QM/MM of an enzyme's active site [5]. Locate some lead-like library chemicals [6]. Only a few companies have agreed to participate in an AI-related study that could be employed in medicine discovery and creation. Euretos is employing massive omics-like datasets to investigate links between biological circuits and diseases [7]. Sparrho's goal is to help the technical community by extracting, curating the most relevant scientific research findings from a growing corpus of literature, employing both AI and human editors. [8]. BioXcel is repurposing traditional medications using artificial intelligence [9] [10]. Creativity is used to identify and answer unmet medical needs. The goal of this article is to look at recent advancements in Artificial Intelligence in medicine, as well as provide insight into the challenges and risks that health practitioners and institutions face when integrating augmented medicine into medical treatment and future medical leader education, as well as the most common use-cases where AI-powered therapeutic technologies are already being used in medical care.

## II. APPROACHES OF ARTIFICIAL INTELLIGENCE

1. Artificial Intelligence (AI).
2. A higher education level.
3. One type of network is Artificial Neural Networks.
4. A well-known example of Artificial Intelligence is machine learning. This method allows computers to reliably adapt and change their functions (e.g., making predictions).
5. AI is being employed in a wide range of disciplines. (Fig 1).



**Figure 1:** Artificial Intelligence is being used in a Variety of Fields

### III. ADVANCEMENT OF ARTIFICIAL INTELLIGENCE

#### 1. **Machine Learning:** There are two types of machine learning algorithms [11].

- **Observed Learning:** In supervised learning, the algorithm makes adjustments in order to respond effectively to a set of training cases. As a result, the anticipated output replies are known to be accurate, and feedback statistics are saved in the database for future training. [11]. Regression analysis techniques include random forests, support vector machines and Artificial Neural Networks. [11,12]
- **Unrestricted Learning:** It is based on non-example-dependent feature extraction methods [11]. Other machine learning approaches, such as the probabilistic reasoning method, are also used in pharmaceutical sciences. To explain the logic and reasoning behind the assertions. [13]. This method has the advantages of requiring no expert knowledge of the system, compensating for data noise, and providing easily interpretable projections [14]. This method can also be used to model nonlinear relationships. GA is frequently used as a feature selection method in quantitative QSAR studies involving pharmaceutical research [15,16]. Transfer learning is included in active machine learning. The technique of leveraging a previously trained model to construct a new, anticipated fit for the desired aim is known as transfer learning [17]. The database size of the initial formulation is a critical determinant of transfer learning performance. [18].

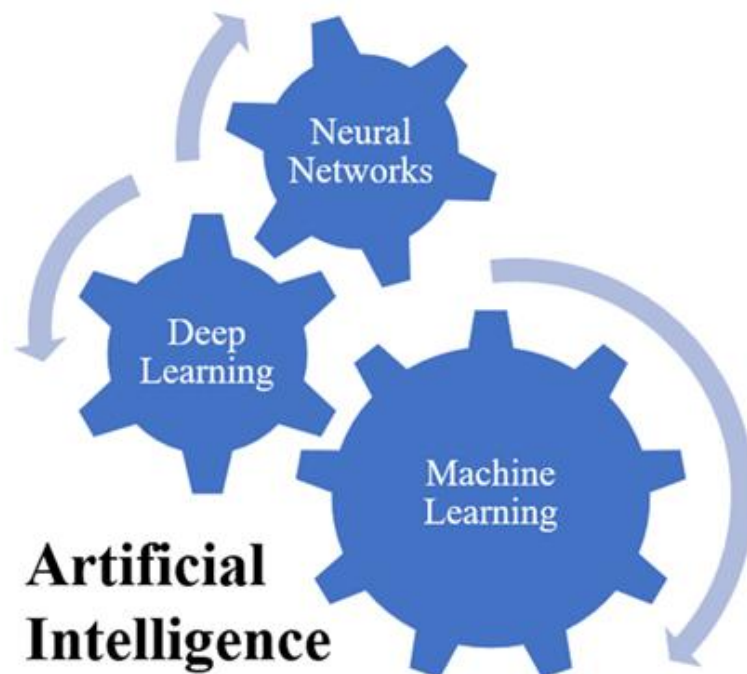
#### 2. **Artificial Neural Network:** Artificial Neural Networks (ANN) can be utilized in a variety of applications. The brain's ability to learn by example is simulated by Artificial Neural Network (ANN). The interconnectedness of these neurons is made up of several synapses connecting one neuron to the next. [19]. In a biological system, a neuron is made up of three parts: a cell membrane with a nucleus that regulates cellular activity,

nerve cells that connect neurons and give signals to the cell, and axons, which look like one long thread carrying data to the next cell. ANNs, like human neurons, are made up by clusters of neurons (PEs) connected by coefficients (weights) [19]. The inputs, hidden, and SoftMax layers are the four fundamental structural systems of a traditional ANN. The system's input is the first layer of an input neuron, which corresponds to the synapses of a true neuron. The layers exist between the source and destination nodes. Each buried layer [20] is densely packed with neurons. To put it another way, they're a network of interconnected advanced computer bits called 'perceptrons,' which resemble biological neurons and respond to electrical impulses similarly to the brain. [21]. ANNs are a sort of network that solves problems by converting discrete inputs into outputs using algorithms, either individually or in groups. [22]. To construct supervised learning that can learn to solve an issue rapidly, repeated intake amounts of antecedent with known responses are used (targets). This is referred to as "learning" or "training." Receiving signals (inputs) from the input layer is the initial step in the learning process. In the hidden layer, these inputs are amplified and summed using network parameters. A transfer function is used to send the results to the output nodes. The activation functions accessible include logistic, tanh, identity, and exponential. [23]. The transfer function is most widely used activation function in medicine. Error back-propagation is an extensively used approach in neural network learning. [24]. In addition to assessing complex data based on elongation and pattern recognition, ANNs are particularly good at simulating nonlinear interactions and collecting extremely precise predictions. [25,26]. The disadvantages of utilizing ANNs include local minimum trapping, noise management, and overfitting/underfitting. The Time Invariant Noise Algorithm (TINA) is used to prevent local minima and control noise. Overfitting can be reduced with this method. Furthermore, stopping the technique at the proper time can help in preventing both overfitting and underfitting [29].

3. **Deep Learning:** DL is both, Deep-Learning and a representational learning approach [30]. Recent breakthroughs in neural networks are included in the state-of-the-art of DL paradigms. The primary difference between ANNs and DLs is that DLs have many more layers (always more than three) and each layer has many more nodes. DL employs a multi-level representation method to learn complex functions. The architecture of Deep Learning often necessitates a large amount of training data, which may limit its application. Deep learning uses CNNs, RNNs, and tightly integrated FFNs (Feed-Forward Networks) as neural network topologies [31]. In a number of pharmaceutical research domains, including as pharmaceutical formulation design [32], drug development [33], and medication retrofitting [34], DL has become vital and of exceptional quality.
  - **Machine Learning Drug Prototyping and Revelation:** Widespread use of HTS (High-Throughput Screening), CC (Combinatorial Chemistry), and computer-aided drug design in pharmaceutical sciences, drug discovery accounts for a significant number of algorithms (CAD). [35]. One of the first ANN applications was in the QSAR research investigations [36,37]. The QSAR criterion connects a substance's physical and chemical properties with its biological and chemical activity. [38,39].

In Quantitative Structure Activity Relationship Structure QSAR research, chemical properties such as molecular weight, partition coefficient (logP), and hydrogen bonding capacity are commonly used. Because empirical QSAR research involves complicated and nonlinear systems, ANNs were one of the most accessible QSAR

modelling methods. As seen by the rapid rise of QSAR research based on ANNs [40], the utility of neural networks in drug development has continued to grow as a result of their power grid and success.



**Figure 2:** Advancements of Artificial Intelligence

- **In Pharmacological Sciences, Machine Learning:** Machine learning is widely being used and has vast pharmaceutical applications, from discovery of new drug to the final stages of product development. There are three main areas of pharmaceutics where ANNs and other machine learning technologies have been actively used. Drug design, Preformulation studies, formulation and development research are the three sorts of investigations.
- **Artificial Intelligence and Drug Development (AI):** Developing novel medications that are effective is a difficult task. The situation is clarified by [41]. For drug target definition and validation, drug design, drug repurposing, R&D efficiency, biological data gathering and analysis, and refining the decision-making process to enrol patients in clinical trials, AI technologies have been used at many stages [42,43]. AI applications that reduce inefficiencies, uncertainty, bias, and human participation could help traditional drug development procedures [44]. AI is also used in drug development to predict drug-like chemical synthetic pathways [45], pharmacological properties [46], protein determinants and functions [47], drug synergy and drug–target interactions [48], and medicine repurposing [49].

New pathways and targets found by omics research include therapeutic targets, customised treatment based on omics indicators, and exposing the links between drugs and disorders [50,51]. DL has a history of recognizing novel drug concepts and appropriately appraising their advantages as well as any potential negative effects [52].

New research could use AI to aid in the identification of new therapy targets, rational prescription design, and pharmaceutical repurposing [55,56]. Previous drug development challenges, such as large dataset analysis and time-consuming compound screening while minimizing standard error, necessitated massive amounts of R&D money and effort, totalling around US\$2.5 billion and spanning more than a decade [53], are now possible to overcome with AI technologies [54].

- **Artificial Intelligence in Pharmaceutical Manufacturing**

- **Tablets with a Controlled Release:** Hussain and his colleagues at the University of Cincinnati were the first to employ neural networks to simulate pharmaceutical formulations. They patterned the in vitro release properties of a number of medicines implanted in matrices made from various hydrophilic polymers in a series of investigations [57,58]. In every situation, neural networks with a single convolutional layer performed well in forecasting drug release. Overall, the findings corroborated statistical analyses [57]. On the other hand, predictions made outside of the limits of the input data performed badly [58]. Even though evolutionary methods were not utilized to update the formulations, the researchers were inspired to look into neural network-based computer-aided formulation design [58].
- **Immediate-Release Tablets:** Two tests were conducted in this location three years ago. Turkoglu collaborated on a study [59] with colleagues from the University of Marmara in Turkey and the University of Cincinnati to forecast hydrochlorothiazide tablet formulations using neural networks and statistics. To increase tablet strength or find the best lubricant, the networks were utilized to create three-dimensional plots of massing time, compression pressure, and crushing strength, as well as drug release, massing time, and compression pressure. Even though patterns were found, no ideal formulations were given. The patterns were created using statistical methods.

In a more in-depth research of neural networks in this domain, Kesavan and Peck of Procter & Gamble Pharmaceuticals (Norwich, NY, USA) and Purdue University (West Lafayette, IN, USA) duplicated the manufacture of anhydrous caffeine tablets. Two networks were created from 32 tests, one with five inputs [diluent type, diluent level, binder level, granulation machinery used, and binder addition (wet or dry)] and the other with nine inputs [diluent type, diluent level, binder level, granulation machinery used, and binder addition (wet or dry)]. In forecasting findings, both models were more accurate than hastily generated models with four outputs (tablet strength, friability, thickness, and disintegration time). The AI Ware CAD/Chem application [60] was used to re-analyse the same data.

Comparable neural network models were created and optimized using genetic algorithms. The optimum formulation was shown to be dependent on both the chemical concentrations used in the formulation and the relative importance of the output qualities. Only by sacrificing disintegration time can high tablet strength and low friability be achieved. Lactose was utilized as a diluent in all cases, and the granulating analytical technique of choice was fluidized bed granulating [61].

- **Artificial Intelligence Drug Screening:** Research and development of the drug can take nearly a decade and can cost an average of \$2.8 billion. Despite this, authorities reject nearly nine out of ten medication candidates that fail Phase II clinical trials. [62,63]. Nearest-neighbour filters (RF), ensemble learning machines (SVMs), and Deep Neural Networks (DNNs) are utilized to predict in vivo activity and toxicity in the case of VS. In areas like immuno-oncology and cardiovascular disease, pharmaceutical corporations like Bayer, Roche, and Pfizer have partnered with IT businesses to construct drug development platforms [62].
- **Creating Drug Molecules using Artificial Intelligence:** The target protein's estimated structure in order to accomplish successful therapy, it is necessary to designate the proper target while generating therapeutic molecules [63]. Several proteins have been uncovered as the illness progresses, some of which have been found to be overexpressed in some patients [64]. As a result, while creating a disease-targeting medicinal chemical, it's crucial to forecast the structure of the target protein. AI can help structure-based regenerative medicine by predicting the impact of a drug on the aim as well as its restrictions prior to its synthesis or manufacture by anticipating the 3D protein structure [65]. AI can aid structure-based regenerative medicine by predicting 3D protein structure as the design is in agreement with the chemical environment of the target protein location [66].
- **For Quality Assurance and Control, Artificial Intelligence (AI) is being Applied:** To obtain the necessary output from raw resources, a variety of attributes must be balanced [67]. For product quality control testing and batch-to-batch consistency, manual intervention is essential. While this isn't always the best solution, it does highlight the urgent need for AI adoption [68]. To better comprehend the critical actions and exact criteria that manage a pharmaceutical product's ultimate quality, the FDA suggested a 'Quality by Design' method [69]. Using a combination of AI and human efforts, early discoveries from production batches were reviewed, and feature selection algorithms were constructed. ANN was used to investigate the solubility and dissolving rate of theophylline pellets [70], with an error rate of less than 8%.

AI can also be used to control in-line manufacturing activities to obtain the appropriate product grade. An Artificial Neural Network (ANN) that combines auto evolution, multi-objective, and training algorithm methodologies is used to monitor the freeze-drying process. It can be used to determine thickness of desiccated-cake at a later time point and temperature ( $t + t$ ) for a specific given set of operational parameters, making quality control of the finished version easier [71]. Product reliability can be ensured by combining a complex, intelligent technique with an automated data input platform, like a digital lab notebook[72]. The expert system for total quality management may employ data mining and other knowledge discovery approaches to aid in making challenging judgments and inventing latest technologies for the intelligent management of quality [73].

- **Clinical Trials with AI in the Works:** Clinical trials are used to test a pharmaceutical medication's safety and efficacy in people who have a specific ailment. They necessitate a large financial investment and require 6–7 years to finish. Despite this, just one out of every ten substances tested in these trials gets approved, resulting in

huge loss to the industries[74]. Lack of patient selection, lack of technology expectations, or a damaged infrastructure contribute to these failures. AI could be utilized to help resolve these challenges because digital health data is publicly available [75]. A clinical trial spends one-third of its time seeking volunteers. Enrolling competent patients can help a clinical study succeed, despite the fact that it has an 86 percent failure rate [76]. AI can help in the selection of only a particular sick population for the enrolment by utilising patient-specific genome-exposome profile analysis in Phase II and III clinical trials, allowing for the early identification of promising therapeutic targets in the patients chosen [77]. Using other AI components to uncover therapeutic targets ahead to the start of clinical trials, such as predictive ML and other reasoning approaches, aids in the early prediction of lead medications that will pass clinical trials while considering the patient population [78]. Dropouts from clinical trials account for 30% of study failures, requiring further recruiting and losing both time and money. Proper monitoring and encouraging the patients to adhere to the clinical study procedure on a regular basis, can minimize these errors[79].

- **Artificial Intelligence for Market Positioning:** Many business strategies for firms attempting to build their own distinct brand include a positioning plan. It comprises developing a product's brand in the market to attract customers to buy it [80,81]. This method was used to promote Viagra, a game-changing drug used to treat erectile dysfunction in men as well as other quality-of-life issues [82]. Technology and e-commerce can be used as a platform and businesses may now build natural brand awareness in the public realm. According to the Internet Advertising Bureau, organizations use one of the methods for technology platforms to get a competitive advantage in digital marketing and aid in product placement. Companies are constantly attempting to outrank their competitors websites in order to gain visibility for their brand [83]. To improve market knowledge, statistical analysis methodologies and particle swarm optimization algorithms, for example, can be employed in conjunction with NNs (Developed by Eberhart and Kennedy in 1995). They can help build a product marketing plan that is based on realistic client demand projections [84].

#### IV. CONCLUSION

Artificial Intelligence contributes to a phenomenal growth in the field of pharmacy. AI plays a key role in the drug discovery, Preformulation studies, drug design, formulation of dosage forms and development of business strategies to build a product brand in the market. AI predicts 3D protein structures with proper targets. Deep Neural Networks (DNNs) can predict in vivo activity and toxicity of drug candidates used in cardiovascular disease and immuno-oncology. ANN is widely used in QSAR research investigations which relates the physical and chemical properties of the drug with its biological and chemical activity. AI based selection of patients for clinical trials helps in the proper selection of therapeutic targets with less errors. Implementation of AI technology in numerous fields of pharmacy will decrease the health hazards and also reduce the cost considerably. AI can play a vital role in the better functioning of pharma industries.



## V. ACKNOWLEDGEMENT

Authors express sincere gratitude to the Principal and Department of Pharmaceutics, KLE College of Pharmacy, Belagavi, Karnataka, India.

## VI. CONFLICT OF INTEREST

The authors declare no conflicts of interest.

## REFERENCES

- [1] Mak Kk, Pichika Mr. Artificial Intelligence In Drug Development: Present Status And Prospects. *Drug Discovery Today*. 2019 Mar 1;24(3):773-80.
- [2] Mitchell Jb. Artificial Intelligence In Pharmaceutical Research And Development. *Future Medicinal Chemistry*. 2018 Jul; 10(13):1529-31.
- [3] Review On, Artificial Intelligence In Drug Discovery And Development Debleena Paul, Gaurav Sanap, Snehal Shenoy, Dnyaneshwar Kalyane, Kiran Kalia1 And Rakesh K. Tekade.
- [4] Bergstrom Cas, Larsson P. Computational Prediction Of Drug Solubility In Water-Based Systems: Qualitative And Quantitative Approaches Used In The Current Drug Discovery And Development Setting. *Int. J. Pharm.* 2018 Mar 15; 540(1–2): 185–193.
- [5] Ahmadi S, Barrios Herrera L, Chehelamirani M, Hostas J, Jalife S, Salahub Dr. Multiscale Modeling Of Enzymes: Qm-Cluster, Qm/Mm, And Qm/Mm/Md: A Tutorial Review. *Int. J. Quantum Chem.* 2018 Sep 12; 118(9): 255-58.
- [6] Bender A, Glen Rc. Molecular Similarity: A Key Technique In Molecular Informatics. *Organ. Biomol. Chem.* 2004; 2(22): 3204–3218.
- [7] Smith S. Startups Using Artificial Intelligence In Drug Discovery. *Benchsci* 2018. <https://Blog.Benchsci.Com/Startups-Using-Artificial-Intelligence-In-Drug-Discovery>.
- [8] Magistretti B. Sparrho Raises \$3 Million To Democratize Access To Science Research. *Venturebeat* 2017. <https://Venturebeat.Com/2017/07/10/Sparrho-Raises-3-Million-To-Democratize-Access-To-Scientific-Research>
- [9] Nasdaq. Ai-Based Drug Discovery Biotech Bioxcel Therapeutics Sets Terms For \$60 Million Ipo. [Www.Nasdaq.Com/Article/Ai-Based-Drug-Discovery-Biotech-Bioxcel-Therapeutics-Sets-Terms-For-60-Million-Ipo-Cm927198](http://Www.Nasdaq.Com/Article/Ai-Based-Drug-Discovery-Biotech-Bioxcel-Therapeutics-Sets-Terms-For-60-Million-Ipo-Cm927198).
- [10] Mitchell JB. Artificial intelligence in pharmaceutical research and development. *Future Medicinal Chemistry*. 2018 Jul;10(13):1529-31.
- [11] Marsland S *Machine Learning: An Algorithmic Perspective*. 2nd Ed: Crc Press; 2015.
- [12] Lo Y-C, Rensi Se, Torng W, Altman Rb. Machine Learning In Chemoinformatics And Drug Discovery. *Drug Discov Today*. 2018;23(8):1538–46.
- [13] Russell Sj, Norvig P. *Artificial Intelligence: A Modern Approach*. 3rd Ed: Pearson Education Limited; 2016.
- [14] Woolf Pj, Wang Y. A Fuzzy Logic Approach To Analyzing Gene Expression Data. *Physiol Genomics*. 2000; 3(1): 9–15.
- [15] Serra A, Önlü S, Festa P, Fortino V, Greco D. Manga: A Novel Multi-Niche Multi-Objective Genetic Algorithm For Qsar Modelling. *Bioinformatics*. 2020; 36(1): 145–53.
- [16] De P, Bhattacharyya D, Roy K. Exploration Of Nitroimidazoles As Radiosensitizers: Application Of Multilayered Feature Selection Approach In Qsar Modeling. *Struct Chem*. 2020:1–13.
- [17] Li X, Fourches D. Inductive Transfer Learning For Molecular Activity Prediction: Next-Gen Qsar Models With Molpmofit. *J Cheminformatics*. 2020; 12:1–15.
- [18] Ye Z, Yang Y, Li X, Cao D, Ouyang D. An Integrated Transfer Learning And Multitask Learning Approach For Pharmacokinetic Parameter Prediction. *Mol Pharm*. 2018; 16(2): 533–41.
- [19] Agatonovic-Kustrin S, Beresford R. Basic Concepts Of Artificial Neural Network (Ann) Modeling And Its Application In Pharmaceutical Research. *J Pharm Biomed Anal*. 2000; 22(5): 717–27.
- [20] Shin-Ike K. A Two Phase Method For Determining The Number Of Neurons In The Hidden Layer Of A 3-Layer Neural Network. *Proc Sice Ann Conf*. 2010; 20(10): 238–42
- [21] Beneke, F. And Mackenrodt, M-O. Artificial Intelligence And Collusion. *Iic International Review Of Intellectual Property And Competition Law* 2019; 50: 109–134.

- [22] Steels, L. And Brooks, R. *The Artificial Life Route To Artificial Intelligence: Building Embodied, Situated Agents*, Routledge 2018.
- [23] Statistica®. Help Documentations. Tibco Software Inc. 2018 Jul 17.
- [24] Rumelhart De, Hinton Ge, Williams Rj. *Learning Representations By Back-Propagating Errors*. Cogn Mod.
- [25] Sutariya V, Groshev A, Sadana P, Bhatia D, Pathak Y. *Artificial Neural Network In Drug Delivery And Pharmaceutical Research*. Open Bioinform J. 2013; 7: 49–62.
- [26] Krogh A. *What Are Artificial Neural Networks?* Nat Biotechnol. 2008; 26(2): 195–7.
- [27] Burton Rm Jr, Mpitsos Gj. *Event-Dependent Control Of Noise Enhances Learning In Neural Networks*. Neural Netw. 1992; 5(4): 627–37.
- [28] Nazir J, Barlow Dj, Lawrence Mj, Richardson Cj, Shrubbs I. *Artificial Neural Network Prediction Of Aerosol Deposition In Human Lungs*. Pharm Res. 2002; 19(8): 1130–6.
- [29] Marsland S *Machine Learning: An Algorithmic Perspective*. 2nd Ed: Crc Press; 2015.
- [30] Lecun Y, Bengio Y, Hinton G. *Deep Learning*. Nature. 2015; 521(7553): 436–44.
- [31] Chen H, Engkvist O, Wang Y, Olivecrona M, Blaschke T. *The Rise Of Deep Learning In Drug Discovery*. Drug Discov Today. 2018; 23(6): 1241–50.
- [32] Yang Y, Ye Z, Su Y, Zhao Q, Li X, Ouyang D. *Deep Learning For In Vitro Prediction Of Pharmaceutical Formulations*. Acta Pharm Sin B. 2019; 9(1): 177–85.
- [33] Ma J, Sheridan Rp, Liaw A, Dahl Ge, Svetnik V. *Deep Neural Nets As A Method For Quantitative Structure–Activity Relationships*. J Chem Inf Model. 2015; 55(2): 263–74.
- [34] Aliper A, Plis S, Artemov A, Ulloa A, Mamoshina P, Zhavoronkov A. *Deep Learning Applications For Predicting Pharmacological Properties Of Drugs And Drug Repurposing Using Transcriptomic Data*. Mol Pharm. 2016; 13(7): 2524–30.
- [35] Chan Hs, Shan H, Dahoun T, Vogel H, Yuan S. *Advancing Drug Discovery Via Artificial Intelligence*. Trends Pharmacol Sci. 2019; 40:801.
- [36] Aoyama T, Suzuki Y, Ichikawa H. *Neural Networks Applied To Structure-Activity Relationships*. J Med Chem. 1990; 33(3): 905–8.
- [37] Aoyama T, Ichikawa H. *Basic Operating Characteristics Of Neural Networks When Applied To Structure-Activity Studies*. Chem Pharm Bull. 1991; 39(2): 358–66.
- [38] Liu G, Yang X, Zhong H. *Molecular Design Of Flotation Collectors: A Recent Progress*. Adv Colloid Interf Sci. 2017; 246:181–95.
- [39] Hansch C, Maloney Pp, Fujita T, Muir Rm. *Correlation Of Biological Activity Of Phenoxyacetic Acids With Hammett Substituent Constants And Partition Coefficients*. Nature. 1962; 194(4824): 178–80.
- [40] Niculescu Sp. *Artificial Neural Networks And Genetic Algorithms In Qsar*. J Mol Struct Theochem. 2003; 622(1–2): 71–83.
- [41] Segler Mh, Kogej T, Tyrchan C, Waller Mp. *Generating Focused Molecule Libraries For Drug Discovery With Recurrent Neural Networks*. Acs Central Science. 2018 Jan 24;4(1):120-31.
- [42] Huang Z, Juarez Jm, Li X. *Data Mining For Biomedicine And Healthcare*. Journal Of Healthcare Engineering. 2017 Jan 1;2017.
- [43] Mamoshina P, Vieira A, Putin E, Zhavoronkov A. *Applications Of Deep Learning In Biomedicine*. Molecular Pharmaceutics. 2016 May 2;13(5):1445-54.
- [44] Seddon G, Lounnas V, Mcguire R, Van Den Bergh T, Bywater Rp, Oliveira L, Vriend G. *Drug Design For Ever, From Hype To Hope*. Journal Of Computer-Aided Molecular Design. 2012 Jan;26:137-50.
- [45] Merk D, Friedrich L, Grisoni F, Schneider G. *De Novo Design Of Bioactive Small Molecules By Artificial Intelligence*. Molecular Informatics. 2018 Jan;37(1-2):1700153.
- [46] Klopman G, Chakravarti Sk, Zhu H, Ivanov Jm, Saiakhov Rd. *Esp: A Method To Predict Toxicity And Pharmacological Properties Of Chemicals Using Multiple Mcase Databases*. Journal Of Chemical Information And Computer Sciences. 2004 Mar 22;44(2):704-15.
- [47] Menden Mp, Iorio F, Garnett M, Mcdermott U, Benes Ch, Ballester Pj, Saez-Rodriguez J. *Machine Learning Prediction Of Cancer Cell Sensitivity To Drugs Based On Genomic And Chemical Properties*. Plos One. 2013 Apr 30;8(4):E61318.
- [48] Nascimento Ac, Prudêncio Rb, Costa Ig. *A Multiple Kernel Learning Algorithm For Drug-Target Interaction Prediction*. BMC Bioinformatics. 2016 Dec;17:1-6.
- [49] Schneider G. *Automating Drug Discovery*. Nature Reviews Drug Discovery. 2018 Feb;17(2):97-113.
- [50] Matthews H, Hanison J, Nirmalan N. *“Omics”-Informed Drug And Biomarker Discovery: Opportunities, Challenges And Future Perspectives*. Proteomes. 2016 Sep 12;4(3):28.
- [51] Hamet, P. And Tremblay, J. *Artificial Intelligence In Medicine*. Metabolism 2017; 69: 36–40.

- [52] Hughes Jp, Rees S, Kalindjian Sb, Philpott Kl. Principles Of Early Drug Discovery. *British Journal Of Pharmacology*. 2011 Mar;162(6):1239-49.
- [53] Mohs Rc, Greig Nh. Drug Discovery And Development: Role Of Basic Biological Research. *Alzheimer's & Dementia: Translational Research & Clinical Interventions*. 2017 Nov 1;3(4):651-7.
- [54] Katsila T, Spyroulias Ga, Patrinos Gp, Matsoukas Mt. Computational Approaches In Target Identification And Drug Discovery. *Computational And Structural Biotechnology Journal*. 2016 Jan 1;14:177-84.
- [55] Emig D, Ivliev A, Pustovalova O, Lancashire L, Bureeva S, Nikolsky Y, Bessarabova M. Drug Target Prediction And Repositioning Using An Integrated Network-Based Approach. *Plos One*. 2013 Apr 4;8(4):E60618.
- [56] Duch W, Swaminathan K, Meller J. Artificial Intelligence Approaches For Rational Drug Design And Discovery. *Current Pharmaceutical Design*. 2007 May 1;13(14):1497-508.
- [57] Hussain, A.S., Yu, X. And Johnson, R.D. *Pharm. Res.* 1991; 8: 1248–1252.
- [58] Hussain, A.S., Shivanand, P. And Johnson, R.D. *Drug Dev. Ind. Pharm.* 1994; 20: 1739–1752.
- [59] Turkoglu, M., Ozarslan, R. And Sakr, A. *Eur. J. Pharm. Biopharm.* 1995; 41: 315–322
- [60] Kesavan, J.G. And Peck, G.E. *Proc. 14th Pharm. Technol. Conf.* 4–6 April, Barcelona, Spain, 1995; 2: 413–431.
- [61] Colbourn, E.A. And Rowe, R.C. *Pharm. Technol. Eur.* 1996; 8(9): 46–55.
- [62] Álvarez-Machancoses Ó, Fernández-Martínez J.L. Using Artificial Intelligence Methods To Speed Up Drug Discovery. *Expert Opin. Drug Discovery*. 2019; 14:769–777.
- [63] Fleming N. How Artificial Intelligence Is Changing Drug Discovery. *Nature*..
- [64] Dana D. Deep Learning In Drug Discovery And Medicine; Scratching The Surface. *Molecules*. 2018; 23:2384.
- [65] Wan F., Zeng J. Deep Learning With Feature Embedding For Compound–Protein Interaction Prediction. *Biorxiv*. 2016;2016
- [66] Alquraishi M. End-To-End Differentiable Learning Of Protein Structure. *Cell Syst*. 2019; 8:292–301.
- [67] Gams M. Integrating Artificial And Human Intelligence Into Tablet Production Process. *Aaps Pharmscitech*. 2014; 15:1447–1453.
- [68] Rantanen J., Khinast J. The Future Of Pharmaceutical Manufacturing Sciences. *J. Pharm. Sci.* 2015; 104:3612–3638.
- [69] <sup>169</sup> Critical Quality Attributes Of Ramipril Tablets Manufactured By Wet Granulation. *Pharm. Dev. Technol.*
- [70] Goh W.Y. Application Of A Recurrent Neural Network To Prediction Of Drug Dissolution Profiles. *Neural Comput. Appl.* 2002; 10:311–317.
- [71] Drăgoi E.N. On The Use Of Artificial Neural Networks To Monitor A Pharmaceutical Freeze-Drying Process. *Drying Technol.* 2013; 31:72–81.
- [72] Reklaitis R. *Pharmahub Towards Intelligent Decision Support For Pharmaceutical Product Development*. 2008.
- [73] Wang X. *International Conference On Computational Intelligence And Software Engineering. Ieee*; 2009. Intelligent Quality Management Using Knowledge Discovery In Databases 2009; 1–4.
- [74] Hay M. Clinical Success Rates For Investigational Drugs. *Nat. Biotechnol.* 2014; 32:40–51.
- [75] Harrer S. Artificial Intelligence For Clinical Trial Design. *Trends Pharmacol. Sci.* 2019; 40:577–591.
- [76] Likelihood Of Success: A Review. *Contemp. Clin. Trials Commun.* 2018; 11:156–164.
- [77] Mak K.-K., Pichika M.R. Artificial Intelligence In Drug Development: Present Status And Future Prospects. *Drug Discovery Today*. 2019; 24:773–780.
- [78] Harrer S. Artificial Intelligence For Clinical Trial Design. *Trends Pharmacol. Sci.* 2019; 40:577–591.
- [79] Fogel D.B. Factors Associated With Clinical Trials That Fail And Opportunities For Improving The Likelihood Of Success: A Review. *Contemp. Clin. Trials Commun.* 2018; 11:156–164.
- [80] Kalafatis S.P. Positioning Strategies In Business Markets. *J. Bus. Ind. Marketing*. 2000; 15:416–437.
- [81] Jalkala A.M., Keränen J. Brand Positioning Strategies For Industrial Firms Providing Customer Solutions. *J. Bus. Ind. Marketing*. 2014; 29:253–264.
- [82] Ding M. *Springer; Innovation And Marketing In The Pharmaceutical Industry* 2016.
- [83] Dou W. Brand Positioning Strategy Using Search Engine Marketing. *Mis Quarterly*. 2010:261–279.
- [84] Chiu C.-Y. An Intelligent Market Segmentation System Using K-Means And Particle Swarm Optimization. *Expert Syst. Appl.* 2009; 36:4558–4565.