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Preparing Pharmacists for The Era of AI-driven Pharmacological Sciences: An Opinion Article

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ABSTRACT

Due to its rapid development, artificial intelligence (AI) has gained a lot of popularity in many sectors, including pharmacological sciences. In pharmacological sciences, AI has been applied in various areas, from AI-driven drug discovery and genomic sequencing to the development of personalized medicine. Subsequently, the need for pharmacists with adequate AI-related skills and knowledge increases. However, the current traditional curriculum of pharmacy education does not cover AI courses. To elaborate on the current developments in AI-driven pharmacology and present the discussion of the possibility of whether AI-related courses should be included in the current curriculum. We have gathered 32 references on AI-driven pharmacological applications, pharmacy curricula, and the future trends of pharmacological sciences. The literature is obtained from online databases such as Scopus, PubMed, IEEE, and Google Scholar. Based on the literature reviews, we presented the discussion and scientific-based opinion on the need for AI-related courses in the school of pharmacy. We believe that AI will be the basis of future pharmacological development. Hence, we consider that it is the right time to include AI-related courses in the student's curriculum to prepare future-proof pharmacists.

Introduction

Artificial intelligence (AI) development has grown rapidly in the last decade. Nowadays, AI has found its place in the most novel and advanced research sectors, from engineering, economy, and psychology, to public health and medicine, including pharmacological sciences. There are many studies discussing the utilization of AI in pharmacological sciences. This utilization includes drug discovery [1, 2], drug testing [3], drug repurposing [4], drug toxicity and safety analysis [5], and personalized medicine [6, 7]. Along with the rapid developments in both artificial intelligence and pharmacology sciences, the advancement of AI-based pharmacology research can be accelerated. However, there is one significant issue that arises.

There are many PhDs and specialists in the domains of pharmaceuticals and artificial intelligence, respectively. However, the number of experts in both areas is far from sufficient. This is mainly because the roots of the fields are very different, making it almost impossible to learn both in one formal school. In addition, the rise of AI popularity just started several years ago, making the number of mature AI-specific schools relatively limited, let alone AI-pharmacology schools.

This manuscript presents a scientific-driven opinion and discussion on whether pharmacy schools should consider AI courses in their curriculum. By exploring more than 30 references, we brought evidence of the recent trends of development in pharmacology sciences, all of which are heavily driven by artificial intelligence. These findings and the discussions give insight to the stakeholders on the importance of AI courses in pharmacological sciences.

Finally, the rest of the paper is organized as follows. We presented the research methodology in Section III. Then, the evidence of the recent trends in AI-driven pharmacology sciences is shown in Section IV. Finally, the discussion and the conclusion of this study are described in Section V and Section VI, respectively.

Materials And Methods

In this manuscript, we aim to discuss the importance of AI-related courses in the current pharmacy education curriculum. We summarized the recent trends in AI-driven research in the pharmaceutical sector. In addition, we depicted scientific-based arguments on the importance of AI courses in pharmacological sciences. These arguments were derived from recent high–quality systematic reviews, meta-analyses, and selected literature. In this opinion article, we extensively searched Scopus, PubMed, IEEE, and Google Scholar for articles that described AI-related pharmacology research. The following keywords were used in the search strategy: (AI-driven drug discovery (OR) AI-based genomic sequencing (OR) AI-driven personalized medicine (OR) artificial intelligence) (AND) (pharmaceutical sciences (OR) bioinformatics (OR) pharmacy (OR) pharmacology (OR) pharmacy education). The language of the search was limited to English and Indonesian. There were no limitations on the year of publication or study. As a result, more than 30 published works were gathered. Any research study types were considered in this manuscript. However, unpublished data, submitted manuscripts, and technical notes were excluded.

Results

In short brief, there are at least three major AI applications in future pharmacology research. These three applications can be seen in Figure 1. By utilizing clinical trial efficacy and adverse events information, AI can be used to accelerate clinical trials while maintaining safety (e.g., cancer and biologics trials). Furthermore, we can configure artificial intelligence to build a health prediction model and realize personalized-precision medicine by exploiting the DNA, RNA, protein, and metabolite profiles. As for the third major AI application, it is proven that AI–driven drug discovery and drug efficacy improvement (e.g., antibiotics and cancer therapies) can be achieved by modeling the structures and efficacy of existing small molecules.

In the last decades, numerous machine intelligence techniques have been operated in the rational drug development process to speed up the time-consuming and hence expensive traditional studies [8, 9]. According to some reports [10, 11], AI has been used in drug development. DSP-1181 is the first AI-created medication to begin clinical trials. DSP-1181 is a medication for the treatment of obsessive-compulsive disorder (OCD). The introduction of the AI-created medication DSP-1181 into clinical research marked a significant development in the field of drug discovery. As in COVID – 19, AI also has been managed in drug and vaccine discoveries. AI has offered compound property, activity, and reaction prediction [12-14]. Currently, the breakthroughs in this area have shown us unequivocally which AI will demonstrate its immense potential in expediting the discovery of new drugs, the improvement of genetic variants studies, and the application in personalized medicine. Those studies are shown in Table 1.

Table 1. Recent trends in AI-driven pharmacology research

Application	Authors	Study description
AI-driven drug discoveries	Avdagic, et al., (2009) [15]	This study used CB513, a non-redundant dataset, to develop algorithms for secondary protein structure prediction. The model is implemented in MATLAB Neural-Network Toolbox. The prediction accuracy of the 2D structure is 62.72%.
	Zhavoronkov, et al., (2019) [13]	The authors developed a deep generative model called generative tensorial reinforcement learning (GENTRL) to discover potent inhibitors of DDR1, which plays a significant role in fibrosis.
	Popova, Isayev, and	This study implemented ReLeaSE (Reinforcement Learning for Structural Evolution) as a revolutionary computational

	Tropsha, (2018) [16]	approach to develop and create molecules with the desired properties from scratch. It combined two generative and predictive deep neural networks that were trained independently to provide new targeted chemical libraries.
	Yin, et al., (2019) [17]	Compound cytotoxicity as a part of drug discovery was predicted using ensemble learning methods and molecular fingerprints. Various methods of conducting a structure-activity relationship analysis for a cytotoxic endpoint in the AID364 dataset were explored.
	Maciukiewicz, et al., (2018) [18]	This study used a nested 5-fold cross-validation to evaluate the predictive potential of genetic and clinical characteristics and predict duloxetine response in major depression. LASSO regression was used following the conventional genome-wide association method to get the optimal features for machine learning models.
	Wei, et al., (2013) [19]	Risk assessment for IBD (Inflammatory Bowel Disease) was performed using data set from the International IBD Genetics Consortium's Immunochip project. Machine learning is used to build an optimal predictive model.
AI-based genomic study	Wei, et al., (2009) [20]	In this study, the authors constructed a predictive risk model for type 1 diabetes (T1D) using less than 500 variants using T support vector machines (SVM) and L2-regularized (ridge) logistic regression.
	Díez Díaz, et al., (2021) [21]	This study aims to investigate a novel machine-learning approach for identifying groups of SNPs from pathways that can distinguish cases from controls. The method used was called genetic algorithms support vector machines methodology (GASVeM).
	Deneke, Rentzsch, and Renard, (2017) [22]	The authors developed a machine learning-based approach for PaPrBaG (Pathogenicity Prediction for Bacterial Genomes) from NGS data by training on a wide range of species with known pathogenicity phenotypes. By combining diverse genomic information with a rule-based approach, the authors created an extensive list of bacteria that are both harmful and non-pathogenic regarding humans as the host.
	Bhinder, et al., (2021) [23]	The authors explore the utilization of artificial intelligence in personalized medical care and cancer research. These applications include a wide range of subjects, including the molecular characterization of malignancies and their microenvironment, drug discovery and repurposing, and treatment outcomes prediction.
AI-based personalized medicine	Uddin, Wang, Woodbury-Smith (2019) [24]	The authors examine the potential of artificial intelligence to solve the complexity of predicting the risk and prognosis in neurodevelopmental disorders and developing personalized medicine.
	Porumb, et al., (2020) [25]	The authors conducted a pilot study on deep learning for hypoglycemic event detection based on ECG. The study followed healthy volunteers for 14 days straight, using non-invasive wearable sensors, and applied a personalized medicine strategy and AI to automatically diagnose nocturnal hypoglycemia using a few heartbeats of raw ECG output. To solve the intelligibility issue using deep learning techniques, the study also provided a visualization tool that

	allows doctors to see which portion of the ECG signal corresponds to the hypoglycemic incidence in each participant.

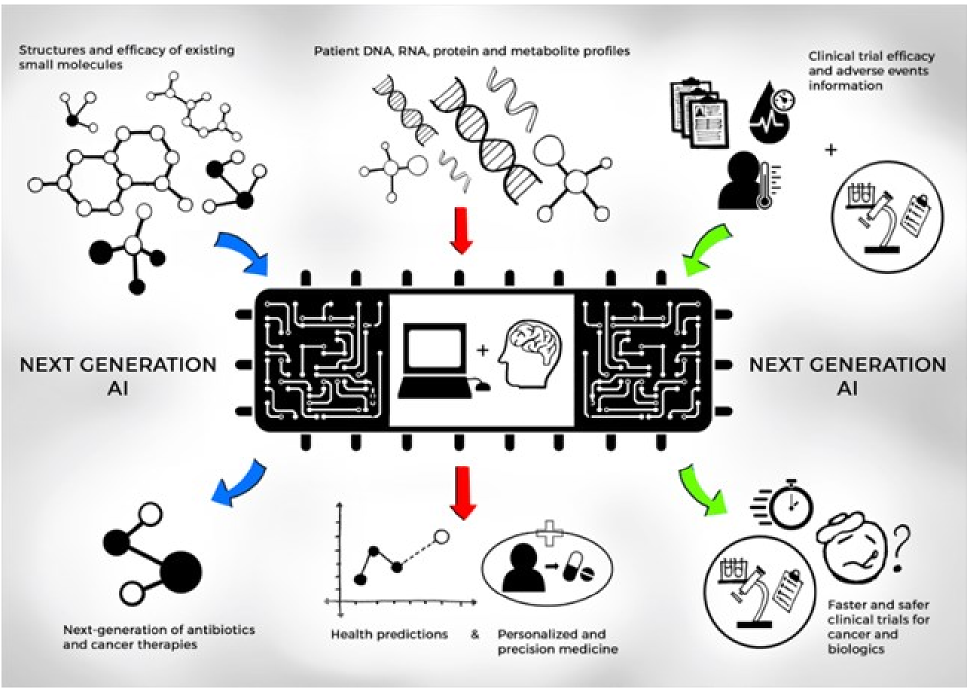

Fig. 1. Future AI-driven pharmacology development [26].

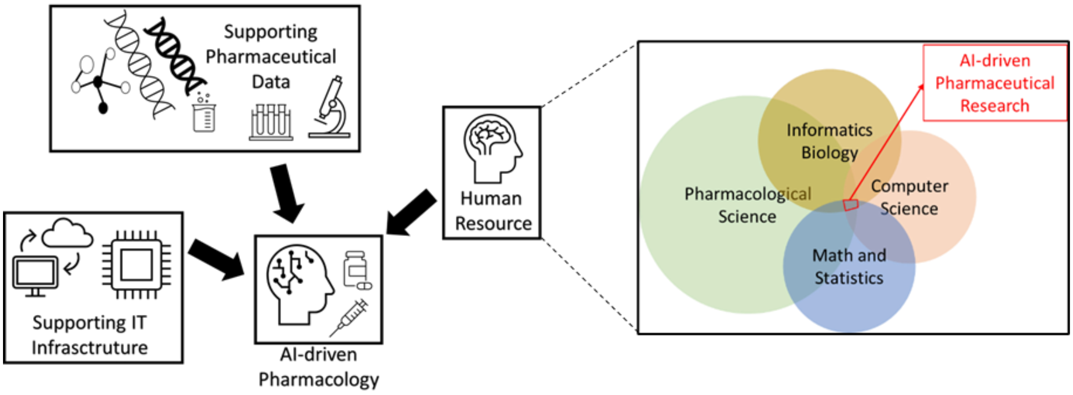

Fig. 2. Factors supporting AI-driven pharmacology development.

Discussion

There are three key factors that need to be considered in order to accomplish AI-driven pharmacological science (see: Figure 2). These factors are supporting IT infrastructure, supporting pharmaceutical data, and human resources with adequate skills and knowledge. In this article, we focus on the latter aspect, which is human resources.

Commonly, pharmaceutical companies or research centers consists of PhDs and experts in clinical pharmacology, while pharmacology expert with sufficient artificial intelligence background is difficult to find. In fact, the industrial need for AI-pharmacology experts has been growing rapidly in the last decade. In contrast, the availability of AI-pharmacology experts remains limited.

In Figure 2, we can see that the sliced diagram of AI-pharmacology experts is very niche. To become an AI-pharmacology specialist, one should master several branches of science. These branches include informatics, biology, computer science, mathematics and statistics, and pharmacological sciences itself.

At this present, there are a lot of data scientists or computer scientists available in the market. However, without prior knowledge of pharmacological sciences, these computer scientists might face difficulties in developing AI-based pharmaceutical research. On the other hand, most current pharmacological specialists do not have any computer background, making artificial intelligence development seem out of their hands.

To solve this problem, many pharmaceutical companies decided to invest their resources into either two choices: hiring an AI specialist and asking them to collaborate with the existing pharmacological expert or giving the current employees extensive computer and data sciences courses. Neither option is ideal because no matter what their choice, it will take time and huge investments while it does not guarantee an optimal outcome.

This problem might be solved by including AI-related courses such as statistics, data sciences, algorithms, and machine learning in the pharmacy curriculum. However, the current curriculum does not have those courses in its syllabus. For instance, we will show the pharmacy curriculum in Indonesia (see: Table 2).

Table 2. Pharmacy curriculum program in Indonesia

Three-year pharmacy vocational school	**Percentage**
Core curriculum	80%
Local curriculum (additional subjects)	20%
Total minimum credits	120
Four-year pharmacy undergraduate school	**Percentage**
Compulsory curriculum (general)	
Nationalism, religious, citizenship, and national language education	5-10%
Core curriculum	65-75%
Principles of scientific methods and basic science	10-15%
Basic biomedical sciences	15-20%
Pharmaceutical sciences	20-25%
Clinical, social, and community pharmacy	15-20%
Management, administrative and regulation	10-15%
Local curriculum (additional subjects)	
Additional subjects such as: radiopharmaceutical, industrial pharmacy, cosmetics, food analysis, nutraceuticals, forensic, and environmental pollution analysis.	15-30%
Other subjects such as: entrepreneurship, computing, English, accounting	
Total minimum credits	144

One-year professional program	Percentage
Core curriculum	70-80%
Clinical pharmacy: case study, practice, and professional work practice	20-30%
Community pharmacy: case study, practice, and professional work practice	20-30%
Industrial pharmacy: case study, practice, and professional work practice	10-15%
Management, administrative and regulation	10-15%
Local curriculum (additional subjects)	20-30%
Total minimum credits	36

Source: Association of Indonesian Pharmacy Higher Education (2013) [27]; Indonesian Ministry of Health (2016) [28]; Cokro, et al. (2021) [29].

In order to comprehend the pharmacy degree in Indonesia, students must first complete either a three-year vocational school (120 credits) or a four-year undergraduate degree (144 credits) followed by a one-year professional program (at least 36 credits). The Association of Indonesian Pharmacy Higher Education has established academic criteria for undergraduate and professional programs' curriculum and learning objectives based on the Seven Star Pharmacist idea created by the World Health Organization (WHO). Professional pharmacy schools offer additional training and abilities for pharmacy practice; as a result, graduates have more employment options than undergraduates since they are ready for greater responsibility in the field of pharmacy practice. On the other hand, most pharmacy undergraduate programs place a strong emphasis on fundamental competencies in clinical pharmacy and pharmaceutical sciences.

In comparison, India offers pharmacy programs at the diploma, undergraduate, and master's degree levels. A six-year Doctor of Pharmacy (Pharm.D.) curriculum that includes a one-year internship program with a stronger emphasis on clinical and community professions was added in recent years [30]. Meanwhile, in 2008, the Pharmacy Council of Thailand required the students to complete a six-year Pharm.D. program with a minimum of 140 credit hours of professional to get a Pharm.D title. Students must complete courses in their fifth year and clerkships in their sixth year. A Pharm.D. student in Thailand must devote 51.5% of their study time to theory, 46.7% to practice, and 1.8 percent to research throughout the six-year course [31]. Vietnam likewise offers a comparable pharmacy education curriculum to other nations [32].

Considering the dense syllabus in the current pharmacy education curriculum, the addition of courses related to artificial intelligence at the vocational and undergraduate levels needs to be reconsidered. Referring to Table 2, courses associated with AI-driven pharmacy can be added to additional subjects and 'other subjects' at vocational schools, undergraduate schools, and professional pharmacy programs. Furthermore, at some universities, 'other subjects' is filled with various elective courses, including computing. However, the computing class provided is usually in the form of a basic Microsoft office class or a basic analysis class using statistical software such as SPSS and R language. In addition to being inserted in additional subjects, AI-related courses can be included as an elective program where the students will be able to choose to study AI intensively for several months, whether inside or outside the university.

Certainly, basic AI classes as additional subjects and elective programs will not be sufficient to satisfy the minimum requirements to develop an AI, let alone AI-driven pharmacological sciences. However, introducing AI at the vocational or undergraduate level might be a good foundation for the pharmacist to understand the basic principle of AI and its potential in pharmacological sciences. Pharmacists who are interested in this subject can deepen their knowledge in graduate school. This is because not all pharmacy school students have a high interest in the development of artificial intelligence in pharmacology sciences.

Afterward, the authors would like to present a discussion on whether a specific graduate school of AI-driven pharmacological sciences should be founded. In terms of AI itself, there is plenty of universities that teach AI curriculum to their students. Generally, in Indonesia, AI is the branch or concentration of electrical and computer engineering major under the faculty of engineering or computer science. In addition, many universities in Indonesia have opened graduate schools in AI majors in the last few years. However, until now, none of those universities have opened a major nor a study concentration of AI in Pharmacology.

School of Pharmacy has a similar situation. While most major universities have a graduate school of pharmacy, none of them have a major or concentration branch of AI in Pharmacology.

Considering the current trends of AI application in pharmacological sciences and the fact that we lack skilled pharmacists with adequate AI backgrounds, it is important for the stakeholders to start to take action. For starters, a graduate school of AI and a graduate school of pharmacy can collaborate to form a concentration branch of AI-driven pharmacological development, in which the curriculum consists of basic AI development courses such as mathematics, statistics, algorithms and data structures, big data management, and machine learning. In addition to the advanced pharmacological sciences courses such as drug discovery, genomic analysis, personalized medicine, and many more.

Conclusion

In the last decade, pharmaceutical research has shifted its paradigm towards AI-based research. One of the groundbreaking milestones is the invention of DSP-1181. This invention is arguably the first AI-driven drug discovery. Following this invention are many AI-based types of research, not only drug discovery but also genomic sequencing and personalized medicine development.

In this manuscript, we elaboratively discussed AI utilization in the recent trends of pharmaceutical research. We also briefly present the importance of AI-related courses to be included in the current pharmacy curriculum. Accounting for the density of the current syllabus, the basic knowledge courses introducing AI in pharmacology can be included as optional subjects or even an elective program in vocational, undergraduate, or even professional school. Moreover, a foundation for graduate school of AI-driven pharmacology also needs to be considered. As a prefix, both graduate schools of AI and pharmacy can collaborate to form a concentration branch of AI-driven pharmacological development.

Conflict of Interest

The authors declare that there is no conflict of interest.

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